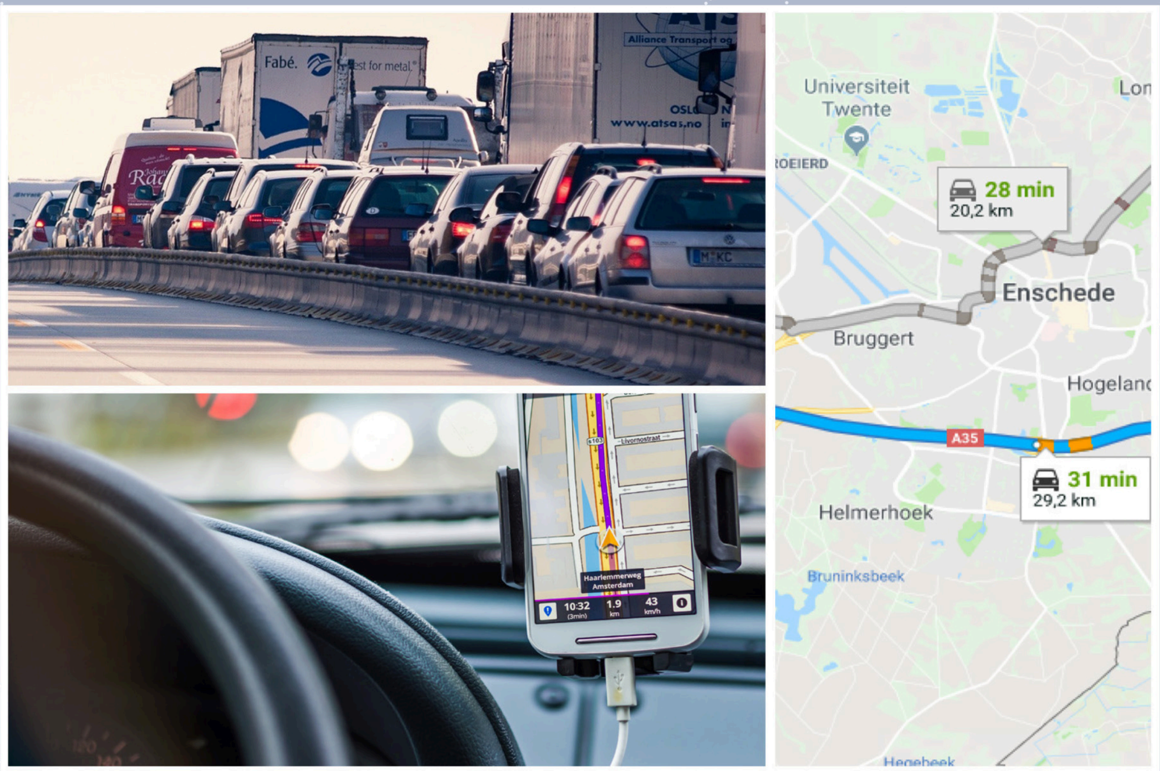
TRAIL THESIS SERIES

Mariska van Essen



The Potential of Social Routing Advice

THE POTENTIAL OF SOCIAL ROUTING ADVICE

Mariska Alice van Essen

Graduation Committee:

Prof. dr. G.P.M.R. Dewulf	University of Twente, chairman
Prof. dr. ir. E.C. van Berkum	University of Twente, promotor
Prof. dr. ir. C.G. Chorus	Delft University of Technology, promotor
Dr. T. Thomas	University of Twente, co-promotor
Prof. dr. E. Avineri	Afeka Tel-Aviv Academic College of Engineering
Prof. dr. E. Cherchi	Newcastle University
Dr. ir. M.R.K. Mes	University of Twente
Prof. dr. ing. K.T. Geurs	University of Twente

TRAIL Thesis Series No. T2018/7, the Netherlands TRAIL Research School
TRAIL Research School
P.O. Box 5017
2600 GA Delft
The Netherlands
E-mail: info@rsTRAIL.nl

DSI Ph.D. Thesis Series No. 18-008
Digital Society Institute
P.O. Box 217
7500 AE Enschede
The Netherlands

ISBN: 978-90-5584-237-7
ISSN: 2589-7721

This dissertation is the result of a PhD research carried out from 2014 to 2018 at the University of Twente, Faculty of Engineering Technology, Centre for Transport Studies. This research has been funded by the TRAIL Graduate School Programme, which is financed by the Netherlands Organisation for Scientific Research (NWO).

TRAIL *Research School for Transport, Infrastructure and Logistics*

UNIVERSITY OF TWENTE. | DIGITAL SOCIETY INSTITUTE

Cover illustration: 1) Ralf Vetterle (SD-Pictures), obtained under the free Creative Commons Zero License, 2) Dariusz Sankowski, obtained under the free Creative Commons Zero License, 3) Google Maps, 2018.

Printed in the Netherlands

THE POTENTIAL OF SOCIAL ROUTING ADVICE

PROEFSCHRIFT

ter verkrijging van
de graad van doctor aan de Universiteit Twente,
op gezag van de Rector Magnificus,
prof. dr. T.T.M. Palstra,
volgens besluit van het College voor Promoties,
in het openbaar te verdedigen
op vrijdag 5 oktober 2018 om 12:45 uur

door

Mariska Alice van Essen

geboren op 30 augustus 1990
te Apeldoorn

This dissertation is approved by:
Prof. dr. ir. E.C. van Berkum [promotor]
Prof. dr. ir. C.G. Chorus [promotor]
Dr. T. Thomas [co-promotor]

Preface

I am proud and delighted to present this thesis which brings a wonderful, valuable but also challenging period in my life to an end. It was Jaap Vreeswijk who inspired me to explore the topics of route choice and travel information during my master Civil Engineering and Management at the University of Twente. I did some small projects on these topics and finally decided to do my master's thesis on these topics as well. So, I went to the Virginia Tech Transportation Institute (VTTI) in Blacksburg, Virginia, USA, to conduct a field experiment on route choice behaviour in response to travel information. During that time, it was Eric van Berkum who informed me about the PhD funding opportunity at the TRAIL Research School. He thought that my initial findings were quite interesting and would make a good starting point for some larger PhD-project. We applied, got the funding, and that is how I started the PhD-life.

During my PhD, I gained experience in (concise) writing, publishing and (social) networking, and developed skills in conducting surveys, field experiments and data-analyses. Moreover, I was able to present my ongoing work at several national and international conferences. These conference visits did not only provide me with new insights, an extended network and revived motivation, it also provided me valuable life experience as they brought me to the best places in the world; International Conference of Travel Behavior Research (IATBR) 2015 and 2018 - Windsor (United Kingdom) / Santa Barbara (United States), Annual Meeting of the Transportation Research Board (TRB) 2016 and 2018 - Washington D.C. (United States), International Choice Modelling Conference (ICMC) 2017 - Cape Town (South Africa), Symposium of the European Association for Research in Transportation (hEART) 2017 - Haifa (Israel), and several cities in The Netherlands (of course) for TRAIL Congresses, courses and workshops.

Soon I joined the TRAIL PhD-council and even became their chair. As such, I quickly found my way in the TRAIL community and broadened my network extensively. I highly enjoyed contributing to the activities of TRAIL, helping in organizing the TRAIL Congress 2016, giving presentations to new TRAIL members about the PhD-life and even about how I wrote

and published my very first literature review. Thank you, Bert van Wee, Vincent Marchau, Conchita van der Stelt and Esther van Baarle for this opportunity and for the nice collaboration. Also, thank you to all fellow council members who represented the different universities that are united within TRAIL.

Now, I would like to take this opportunity to thank all those who have contributed to my research. First of all, I would like to thank my promotors Prof. Dr. Eric van Berkum (University of Twente) and Prof. Dr. Caspar Chorus (Delft University of Technology). They helped crystallize this research from the beginning and their time and expertise provided me with valuable insights at all stages of the project. Eric, your eye for detail often drove me crazy and we did not always agree on used definitions and labels. Looking back, these seemingly small details contributed substantially to my understanding of the topic and took my work to a higher level. Caspar, your quick responses are very much appreciated and your endless revisions and corrections of my texts have improved my writing skills significantly. Our meetings were highly motivational and you always encouraged me to look into whatever idea I had.

Besides my promotors, I am very thankful to my daily supervisor Dr. Tom Thomas (University of Twente). Our discussions during the research process were very valuable to me. Your ability to create more questions during a conversation than we initially started with, kept me critical at my own work and made me realize the complexity of the topic. Moreover, your enthusiasm and dedication are highly appreciated. Also, many thanks to all colleagues of the CTS group at the University of Twente. You were of great support and helped in many ways. I especially like to thank Oskar and Amelia. Oskar, thank you for your mathematical support and contributions to the network simulations on which you spend many hours. Without your help, I would have been completely lost. And Amelia, our discussions on influencing travel behaviour, experimental set-ups and discrete choice models helped me in reflecting on my own work. Also, Andani, Bo, Sander and all other colleagues, thank you for the nice conversations and fun times during and outside working hours.

This work would also not have been possible without the cooperation of Mobidot, who offered their smartphone application for data collection. Special thanks go to Johan Koolwaaij for his technical support and patience in explaining me the technical aspects of working with the application. Moreover, I am grateful to Prof. Hesham Rakha for sharing his route choice datasets with me.

Finally, I would like to thank the ones who made the most important contribution. Opa, Oma, Papa, Mama, Lianne, thanks for being my biggest fans. Your sincere interest and endless belief in me strengthened my self-confidence and made me achieve things beyond my own expectations. Also, many thanks go out to all my friends for nice conversations, jokes, laughs, gossips, drinks, board games etc. (especially to Denise and Iris for the many tea breaks at my office, and Serena for the online motivation). I would like to give special thanks to my best friend and life partner. Cor, I am very grateful for your love, support and patience in the past years. I admire your positive attitude and ability to put my ‘problems’ into perspective. You celebrated every small victory with me and told me every day how proud of me you are. Thanks for sharing your life with me. I always enjoyed going home to you after a long day of hard work.

Mariska Alice van Essen
October 2018

Content

1. Motivation, scope and methodology

1.1. Introduction

Traffic congestion is one of the main problems of today's society. After all, time spent stuck in traffic is simply wasted. For example, a commuter in the UK spent on average 31 hours in traffic congestion during 2017 (INRIX, 2018). Public space to enhance the existing road network is scarce and costly. Hence, it comes as no surprise that the topic of traffic management is high on the governmental agenda of nearly every city, region and country. Over the past years, the application of information-based demand measures is increasingly expected to be successful in reducing congestion and improving road network efficiency.

It is well-known that there exists a conflict between the individual interest of the traveller and the collective interest of the traffic authority; the traveller aims at minimizing his own travel time, while the traffic authority aims at minimizing overall travel time. Yet, conventional (personalized) travel information aims at the individuals' benefit. This thesis deals with the problem of improving efficiency of the existing road network by stimulating social choice behaviour using travel information and social routing advice. The primary intended audience of this thesis is scientists within the field of traffic and behaviour as well as policy planners and traffic managers. Nonetheless, this thesis might also be of interest to professionals who work at commercial travel information services and software companies. The purpose of this thesis is: 1) to provide a conceptual framework on the role of travel information, bounded rationality and social choice behaviour in travellers' route choice behaviour and network state; 2) to provide empirical evidence to support the application of an information-based demand measure using social routing advice; 3) to demonstrate the effects of a social routing service on individual route choice behaviour and network state.

1.2. Problem statement

Let me introduce the research problem by the following example as told by Hayes (2005):

"Suppose you have two routes home from the office. Main Street is never congested, but it has many stoplights, and so the trip always takes an hour. The freeway has a higher speed limit and will get you home in 30 minutes if traffic is light; however, if more than half the commuters in town crowd onto the freeway, traffic freezes up, and that route too takes an hour. Which way should you go?

Assuming that travel time is the only factor at issue, you have nothing to lose by taking the freeway. If you get lucky, you save half an hour; if not, you're no worse off than you would have been on Main Street. The trouble is, everyone else in town reasons the same way, with the result that everyone endures a full hour of bumpertobumper on the freeway, while Main Street is deserted. Looking at the situation from a more global point of view, there is clearly a better solution. If the stream of traffic were divided halfandhalf between the two roads, no one would have a longer trip, and half the drivers would get home 30 minutes sooner. The average travel time would fall from an hour to 45 minutes."

Hayes (2005).

Long ago, Wardrop (1952) introduced two principles of network equilibria that are in line with the two situations pictured in the aforementioned story; the User Equilibrium and the System Optimum. In a user equilibrium "the journey times in all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route" (Wardrop, 1952, p. 345), whereas in a system optimum the sum of generalized travel costs within the network is minimized. The example by Hayes illustrates that selfish choice behaviour generally results in the less efficient user equilibrium, while social choice behaviour could enable a system optimum. Hence, in order to improve road network efficiency and to arrive at a system optimum, at least some travellers need to act non-selfish and choose route alternatives possibly at their own expense; i.e. they might need to take a detour. But how to motivate those travellers to take this detour?

Conventional steering approaches, such as road pricing or personalized incentives (e.g. discounts or rewards), have shown to be successful in changing behaviour (e.g. Anas & Lindsey, 2011; Ettema, Knockaert, & Verhoef, 2010), although their social desirability is questioned (e.g. Te Brömmelstroet, 2014; Verhoef, Nijkamp, & Rietveld, 1997). However, with advances in information & communication technology (ICT) the application of real-time traffic management using personalized information strategies becomes more promising. First of all, more traffic related data has become available through the introduction of inductive loop detectors, Bluetooth equipment and camera's (Antoniou, Balakrishna, & Koutsopoulos, 2011). More recently, so-called floating car data and floating phone data were introduced, which are collected by recording localization, speed, direction of travel and/or time information from individual vehicles or individuals (Messelodi et al., 2009). These new technologies combined with current data-fusion techniques and sophisticated prediction models, make it possible to provide a high-quality description of current and future traffic states in a road network (e.g. Bachmann, Roorda, Abdulhai, & Moshiri, 2013). Moreover, the provision of travel information has shifted from a collective (i.e. public) distribution through radio or variable message signs (VMS) to a personalised (i.e. individual) distribution through recently introduced nomadic devices, such as in-car navigation systems and smartphones. Although collective travel information is often associated with adverse effects, such as oversaturation (i.e. driver is unable to process the large amount of available information), overreaction (i.e. too many drivers respond), concentration (i.e. less variation in routes among travellers) or strategic choice behaviour (i.e. travellers base their choice on their expectations of the behaviour of others) (Ben-Akiva, de Palma, & Kaysi, 1991; Parvaneh, Arentze, & Timmermans, 2011), personalised state-of-the-art travel information is believed to overcome these adverse effects (e.g. Adler & Blue, 1998; Bottom et al., 1999; Parvaneh et al., 2011).

Besides technological advances, existing knowledge on choice behaviour is another important aspect. Neoclassical choice theories largely build upon two behavioural assumptions, i.e. individuals are rational in how they choose and selfish in what they choose. This concept is widely criticized by behavioural economists who build upon psychology, social sciences and economics in order to explain deviations from this rational selfish choice behaviour. Main line of criticism is that individuals have cognitive limitations, make errors, have biases or emotions influencing their decision-making (e.g. Simon, 1955; Tversky & Kahneman, 1991; Zajonc, 1980), i.e. they are boundedly rational. In line with this, several studies found that travellers choose a short travel time alternative, although not necessarily the shortest travel time alternative (e.g. Ciscal-Terry, Dell'Amico, Hadjidimitriou, & Lori, 2016; Vreeswijk, Rakha, Van Berkum, & Van Arem, 2015; Zhu & Levinson, 2010). These findings indicate that individuals do not necessarily want to use the route alternatives that benefit them the most, are not able to correctly identify these or are not particularly interested in this.

Moreover, many studies found evidence that individuals do not exclusively behave in selfish ways, but that they do care about others' welfare as well (e.g. Georgescu-Roegen, 1954; Ostrom & Walker, 2003; Poteete, Janssen, & Ostrom, 2010; Sen, 1977). Although studies within various fields continued this line of research, researchers within the field of transportation started to consider this behavioural component only more recently, and mostly related to sustainable transportation (e.g. Nilsson & Küller, 2000; Van Vugt, Van Lange, & Meertens, 1996). A traffic-related example of this behaviour is that car drivers often give right of way to others at intersections, merges, or lane changes, accepting a (very) short delay to avoid delay for others (although often imposed by regulations). Evidence of this behaviour related to route choices does not exist yet. However, these findings and examples on non-selfish non-rational choice behaviour lead to increased expectations that travellers might comply with travel information and routing advice that directs them towards a particular route alternative, not for their own sake, but to benefit the road network as a whole.

Overall, there exist high hopes on the potential of state-of-the-art personalised travel information to direct travellers towards system-optimal routes and thereby improve road network efficiency. As such, travel information and routing advice should not only be regarded as a service to road users, but as a 'soft' measure to influence choice behaviour as well (Waygood & Avineri, 2010). However, firm evidence on network performance that empirically supports these renewed positive expectations regarding the potential of cutting-edge travel information and routing advice does not exist. After all, human response towards travel information and advice is not completely understood yet, especially when this advice might not directly benefit travellers themselves.

1.3. Research objective and scope

The main objective of this research is *'to empirically determine the potential to use current state-of-the-art, personalized travel information and social routing advice to make more efficient use of the existing road network'*.

In approaching system optimal network conditions, this thesis only considers route choice optimization by car drivers. Stimulating favourable departure time changes or motivating car drivers to switch to other modes of transportation would have a positive effect on road network efficiency as well. However, this would make the problem unnecessarily complex to start with. Moreover, it is likely that during relevant moments in which efficient use of the road network is especially desired, such as peak hours or when certain events take place, most travellers are captives and have to make their trip by car during that time of day. Note that this thesis deals with travellers who actually make route choices. In the (near) future, travellers might no longer be involved in the process of choosing routes as autonomous vehicles – currently a hot research topic – might take over this task. Hence, my research findings and implications should be expanded to that end. However, for now, vehicle routing is outside the scope of this thesis.

Several perspectives could be used regarding network efficiency or optimality; the most common being the travel time perspective, although the sustainability perspective (e.g. Ahn & Rakha, 2013), the safety perspective (e.g. Sahnoon, Shawky, & Al-Ghafli, 2018) and the liveability perspective (e.g. Baets et al., 2014) receive increasingly attention within literature as well. These perspectives all relate to congestion or externalities that arise from congestion; i.e. air pollution, accidents and cut-through traffic. Such externalities directly affect both travellers and inhabitants within a specific area. Hence, those externalities play an important societal role, especially on a local scale. Nonetheless, in general, travellers do not take into account any of these externalities when choosing their routes. This thesis mainly focuses on network efficiency from the commonly used travel time perspective. Nonetheless, optimization goals from the sustainability perspective and safety perspective are shortly addressed as well and impacts on liveability receive attention.

This thesis deals with both the individual perspective and the network perspective when assessing the potential effects of travel information and social routing advice. This contrasts with earlier studies which adopted only one of these perspectives, either by ignoring the effects at the network level (e.g. Chorus, Molin, & van Wee, 2006a, 2006b; Lyons, Avineri, Farag, & Harman, 2007; Shiftan, Bekhor, & Albert, 2011; Tanaka, Uno, Shiomi, & Ahn, 2014), or making very simplified assumptions on individuals' choice behaviour (e.g. Ben-Akiva et al., 1991; Emmerink, Axhausen, Nijkamp, & Rietveld, 1995; Yang, 1998). I argue that, in order to examine the potential of travel information and social routing advice to improve network efficiency, it is of importance to first identify travellers' response to system-optimal travel information (i.e. the individual level) and use the obtained results as input to assess the impacts on road network performance (i.e. the network level). After all, traffic flows are generated by individual drivers.

Finally, this thesis puts forward a strong focus on social route choice behaviour. Social choice behaviour is expected to play an important role in establishing efficient road network use as illustrated by the route choice example provided in Section 1.2. That is, the research problem entails a social dilemma: individuals profit if they act in their own interest, but if all individuals behave out of self-interest, the whole group or society ends up being worse off.

Hence, individuals need to cooperate. There exists extensive literature stating that individuals do not exclusively behave in selfish ways, but that they do care about others and that their choices are affected by motives, such as fairness, reciprocity, commitment, morality and social responsibility (e.g. Fehr & Schmidt, 1999; Ostrom & Walker, 2003; Sen, 1977). However, not much attention has been addressed towards individuals' social choice behaviour in specifically route choice decision-making.

Resulting from the main research objective and scope, the following main research questions can be derived:

1) *What role do (conventional) travel information, bounded rationality and non-selfish behaviour play in the route choice behaviour of travellers and network efficiency?*
2) *To what extent do travellers comply with social routing advice and what are their main motivations for (non-)compliance?*
3) *To what extent could a system optimum be achieved by the application of information-based demand measures using social routing and what are the implications for individual travellers?*

1.4. Research methodology

Figure 1 provides an overview of the research structure of this thesis. The research structure consists of three parts; background research, research on route choice on the individual level and research on impacts on the network level. Each part will be explained in detail below.

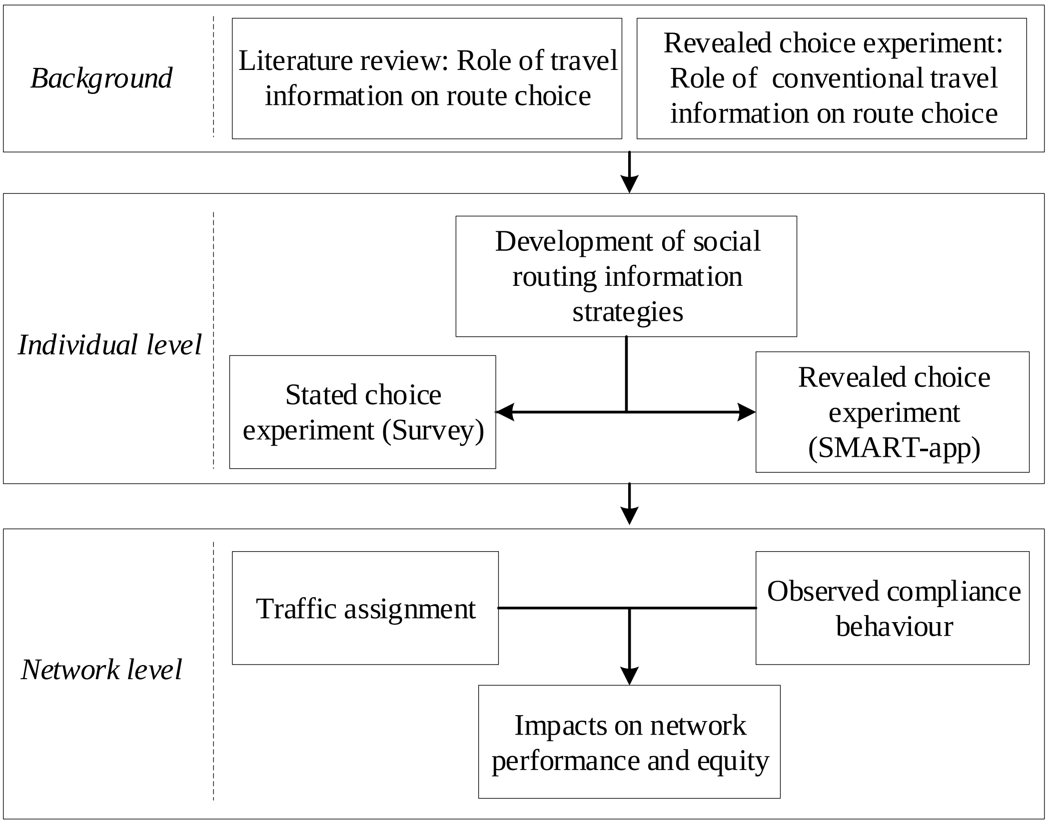


Figure 1. Research structure consisting of three parts; the background, the individual level and the network level.

1.4.1. Research on theoretical and empirical background

In order to obtain sufficient background knowledge on the topic, a literature review on the role of travel information, bounded rationality and non-selfish choice behaviour on route choice behaviour is conducted from both the individual and network perspectives. In addition to the literature review, travellers' route choice behaviour in response to conventional travel time information as well as in absence of travel information is examined empirically by a revealed choice experiment in order to gain insights into day-to-day route choice behaviour and the current role of travel information in the decision-making process. These insights provide valuable knowledge for interpretation and comparison of results in response to social routing advice. After completion of this part of the research, a comprehensive overview of relevant aspects is obtained and research gaps for the continuation of the research are identified.

1.4.2. Research on the individual level

Several social information strategies are developed to influence individuals' route choice behaviour without restricting their freedom of choice; each with the objective to improve network efficiency. These strategies range from low information content (i.e. almost no contextual information) to high information content (i.e. detailed information on context as well as consequences of certain choice behaviour). Moreover, in line with the literature review, some strategies capitalize on existing bounded rationality, whereas others focus on influencing or reinforcing the attitude towards the behavioural change. Each strategy combines several principles that are potentially successful in changing (travel) behaviour according to literature. This is done in such a manner that the strategies are quite distinct from each other while remaining both realistic and practical.

In order to assess the impact of each information strategy, several valid methods exist; i.e. stated choice experiments, laboratory experiments or field experiments. Stated choice experiments and laboratory experiments are flexible and low-cost, attribute values can be easily controlled and behavioural responses can be easily observed (Kroes & Sheldon, 1988; Verhoef & Franses, 2003). However, a major drawback of stated choice experiments is a potential discrepancy between stated behaviour and actual behaviour (Kroes & Sheldon, 1988). Reasons might be that respondents try to control policies by strategic responding (e.g. Fujii & Gärling, 2003; Lu, Fowkes, & Wardman, 2006), provide socially desirable answers (e.g. Fujii & Gärling, 2003; Train, 2009) or just do not know what they would do if the hypothetical situation occurred in reality (e.g. Train, 2009). Therefore, it is debated how well findings from such studies can be extrapolated to the real world. Field experiments tend to have higher external validity, although they often suffer from smaller sample sizes – resulting in low statistical power – and attribute values which cannot be properly controlled for, potentially even prohibiting statistical inference due to e.g. serial correlation. In order to exploit the strengths and mitigate the weaknesses of each approach, and to facilitate comparison, both a stated choice experiment and revealed choice experiment are conducted; and their results are compared.

In the revealed choice experiment, participants receive tailor-made information messages through a smartphone application, called 'SMART Mobility' (SMART in Twente, 2016). This application automatically collects trip-data, i.e. origin, destination, departure time, arrival time, route and mode (-chain) for each trip. Therewith, this application provides the ability to use a real-life environment in order to obtain data based on revealed choice behaviour over a longer period of time. In addition, the application can be used for experience-based sampling, asking a subject about its behaviour in a certain situation directly after that particular situation has revealed itself. Experience-based sampling is a powerful method for understanding a range of psychological phenomena, such as mood, behaviour, thoughts or feelings, as they occur in the daily lives of individuals (Hektner, Schmidt, & Csikszentmihalyi, 2007). However, this method is not yet often used in travel behaviour research. Nonetheless, the potential of this method with respect to choice behaviour in response to travel information is clearly visible. Experience-based sampling is used as a survey tool to assess motivations of (non-)compliance with the received social routing advice.

After completion of this part of the research, insights into and understanding of the (stated) behavioural response of travellers to social routing information strategies have been obtained and recommendations for the design of an effective social routing service can be made.

1.4.3. Research on the network level

Observed compliance behaviour obtained from the individual choice experiments is translated to the network level in order to identify the impacts of the application of an information-based demand measure based on social routing advice on road network performance and equity.

A transport planning model of part of the region of Twente is used. The choice for this network has several reasons. First of all, the Twente road network is a realistic large-scale network that contains congestion, while it is not saturated yet; this leaves room for efficiency improvements. Moreover, the road network coincides with the study area of the revealed choice experiment, the authors are familiar with the network which makes it easier to interpret results and the network was simply available. A static (multiclass) traffic assignment is applied using the Disaggregate Simplicial Decomposition method as introduced by Larsson and Patriksson (1992). This algorithm is more efficient than commonly used optimization algorithms, especially for large-scale applications like this. Moreover, the algorithm takes a route-based rather than a link-based approach. As such, it provides an overview of used route alternatives and their flows in equilibrium state without additional time-consuming calculation efforts.

Several methods exist in order to implement social choice behaviour in traffic assignment models (e.g. Stackelberg routing (e.g. Roughgarden, 2006), agent-based models (e.g. Klein, Levy, & Ben-Elia, 2018) or just a reconfiguration of the cost-function (e.g. Çolak, Lima, & González, 2016)). The latter is the most common and straight-forward method that is suitable for large-scale applications like this, hence, this line of research is followed. Two user classes are introduced; the first class consists of selfish trips (i.e. individual travel cost are minimized), while the second class consists of social trips (i.e. marginal travel costs are minimized). Trips are allocated over these classes using several distributions, so-called social trip shares. I argue what shares of social trips would be realistic to expect when a social routing service is applied based on observed compliance behaviour – from the individual choice experiments – and assess their implications.

After completion of this part of the research, insights into the (possible) impacts of a social routing service are obtained and the research objective can be fulfilled.

1.5. Research relevance

The research that will be presented in the next chapters has several contributions to the existing literature and society.

1.5.1. Scientific relevance

The difference between the user equilibrium and the system optimum has been studied for a long time. Over the past decade, the application of travel information and social routing advice in order to approach the system optimum is gaining more and more attention. This thesis contributes to the literature on this topic as follows.

First of all, many researchers have studied the effects of (social) travel information on either individual compliance or network performance (e.g. Ben-Akiva et al., 1991; Chatterjee & McDonald, 2004; Chen & Jovanis, 2003; Dia & Panwai, 2007). This thesis combines both the individual perspective and the network perspective. Moreover, the bulk of studies concerning the effect of information on travel behaviour is based on stated choice or laboratory experiments (e.g. Abdel-aty, Kitamura, & Jovanis, 1997; Mahmassani & Liu, 1999). I have the unique opportunity to collect data in a real-life environment using a smartphone application. Hence, choices in a day-to-day context where the consequences of these choices are actually experienced by the decision-maker are obtained. This is especially relevant when considering social route choice behaviour since the consequences might not directly be beneficial to the decision-maker. However, studies on social routing – of which currently only a few exist (e.g. Jahn, Möhring, Schulz, & Stier-Moses, 2005; Van den Bosch, Van Arem, Mahmod, & Misener, 2011; Çolak et al., 2016) – mainly build upon theoretical assumptions rather than empirical findings. In order to advance the strong need for empirical evidence, this thesis contributes to the literature by conducting empirical experiments. Furthermore, recent studies (e.g. Ben-Elia & Avineri, 2015) call for a stronger focus on social choice behaviour in establishing cooperative and efficient road network use. This thesis answers to this call by assessing the role of travel information, bounded rationality and non-selfish choice behaviour on route choice. As such, it complements previous reviews that mostly focused on bounded rationality only (e.g. Szeto, Wang, & Han, 2015). Finally, this thesis develops a theoretical framework on the potential of travel information and social routing advice to achieve a more efficient road network state. Based on this framework, several designs for social information provision strategies are provided. Overall, this thesis provides evidence on compliance behaviour of individual travellers in response to social routing advice and shows the effects of this behaviour on network performance and equity.

1.5.2. Societal relevance

Rapid urbanisation and the increasing demand for mobility burdens the existing road network. Congestion imposes high costs on society; i.e. it affects liveability, the environment and economic prosperity, among others. These issues emphasise the need for better utilisation of the existing road network for both the citizen and the government. To that end, several governmental programmes are launched in which the deployment of travel information receives special attention:

- The *ITS Action Plan and Directive* of the European Commission (2017b) states that Intelligent Transport Systems (ITS) can significantly contribute to a cleaner, safer and more efficient transport system through the deployment of innovative (cooperative) transport technologies. The aim is to address compatibility, interoperability and continuity of ITS solutions. In this, travel information is one of their main priorities.
- The *Horizon 2020* programme by the European Commission (2017a) focusses in their work programme for the section of ‘Smart, Green and Integrated Transport’ on better mobility, less congestion, more safety and security by the deployment of digitally based information services and modern information and communication technology (ICT) applications.

- The *'Beter geinformeerd op weg'* (Better informed travellers) programme by the Dutch Ministry of Infrastructure and Environment (2013) is a collaboration of public and private parties which focusses on the organizational process in order to establish a consistent mix of travel information through smartphones, navigation devices and collective road-side information systems.
- In the Dutch *'Beter Benutten'* (Optimising Use) programme (Platform Beter Benutten, 2014), Government, regions and businesses work together to improve accessibility using a variety of measures to make better use of the existing road network and provide more choice options and services to the traveller.

Central to each of the abovementioned programmes is the provision of travel information in order to improve road network efficiency and to reduce congestion. However, as properly pinpointed by Vreeswijk (2015), their focus seems to be on technological, organisational and operational challenges; traveller behaviour and responses to received travel information do not receive much attention. A better understanding of these aspects might be crucial to the success of these programmes. As such, findings in this thesis motivate whether these programmes will be effective and will actually improve current traffic conditions. This emphasizes the societal relevance of the research.

1.6. Thesis outline

This is the final section of Chapter 1, the introduction. The research is introduced by putting forward the topic and defining the research problem and its relevance from a scientific and societal point of view. In addition, the reader is now familiar with the research objective, research questions and research methodology. The remainder of this thesis follows the research structure as presented in Section 1.4; i.e. the first chapters provide theoretical and empirical background, while subsequent chapters present research on the individual level and network level, respectively. Finally, this thesis presents key conclusions, discusses results and implications and provides recommendations for future research.

Chapter 2 provides an in-depth literature review in order to create a theoretical framework for the remainder of the study. This review focusses on both the individual level and network level. It introduces general neoclassical theories on choice behaviour and discusses them in light of rationality and selfishness. These general theories are subsequently applied within the field of transportation. Finally, the review brings in the effects of travel information.

Chapter 3 provides empirical insights into the effect of conventional travel information (i.e. aiming at travellers' personal benefit) on day-to-day route choice behaviour in a real-world context. It answers whether travellers used received travel information and whether this affected their route switching and maximizing behaviour. Moreover, it distinguishes several behavioural patterns or profiles for individual day-to-day route choice and provides insights in which factors explain individuals' adoption of a certain behavioural profile. Finally, it provides insights into individuals' shift between behavioural profiles across different origin-destination (OD) pairs and the role of travel information in this shift.

Chapter 4 presents travellers' compliance with social routing advice based on SP and RP experiments. It introduces the social routing information strategies that are developed and provides insights into compliance rates. Analysis of motivations sheds light on reasons for (non-)compliance. Additionally, stated intentions and actual compliance behaviour are compared and explanatory factors for compliance behaviour are obtained. In this, special attention is paid to participants' decision style and their attitude towards social choices.

Chapter 5 presents the impacts of social routing advice on road network performance and equity. First, traffic assignment is conducted using a variety of social trip shares and findings on road network performance and equity are presented. In a subsequent discussion, social trip shares that might realistically be expected when applying a social routing service are determined based on the observed compliance behaviour from Chapter 4. Impacts resulting from these social trip shares are elaborated upon and conclusions are drawn. As such, this chapter directly links individual choice behaviour with network effects.

Chapter 6 answers the research questions by providing a comprehensive overview of the role of travel information in the route choice behaviour of travellers. Moreover, travellers' compliance behaviour and their main motivations are discussed and network impacts are summarized. Based on this overview of the results, the potential of information-based demand measures in order to improve road network efficiency is assessed. In addition, this chapter discusses the usability of the results and their implications for transport policy and traffic management. Finally, it provides recommendations for future research.

2. Literature review

This chapter is an extended and adapted version of the following publication: Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. G. (2016). From user equilibrium to system optimum: A literature review on the role of travel information, bounded rationality and non-selfish behaviour at the network and individual levels. *Transport Reviews: A Transnational Transdisciplinary Journal*, 36(4), 527-548. Available at Taylor and Francis Online via https://doi.org/10.1080/01441647.2015.1125399

2.1. Abstract

Travel information continues to receive significant attention in the field of travel behaviour research, as it is expected to help reduce congestion by directing the network state from a user equilibrium towards a more efficient system optimum. This literature review contributes to the existing literature in at least two ways. First, it considers both the individual perspective and the network perspective when assessing the potential effects of travel information, in contrast to earlier studies. Secondly, it highlights the role of bounded rationality as well as that of social choice behaviour in route choice and in response to information, complementing earlier reviews that mostly focused on bounded rationality only. It is concluded that information strategies should be tailor-made to an individual's level of rationality as well as his or her social value orientation in order to approach system optimal conditions on the network level. Moreover, considerations on the application of system-beneficial travel information, suggestions on information provision strategies and future research directions are provided for assessing the potential of travel information in improving network efficiency of existing road networks.

2.2. Introduction

Travel information continues to receive significant attention within the field of travel behaviour research, which is mostly driven by the expectations that the provision of travel information may help reduce congestion by directing the network state from the well-known user equilibrium towards a more efficient system optimum. This chapter provides an in-depth literature review on route choice behaviour mechanisms and the potential and limitations of travel information in establishing a system optimum, resulting in suggestions on potential successful information provision strategies and a discussion on related implementation issues. It contributes to the literature in general, and to previously published literature reviews in particular, in at least two ways. First, it considers both the individual perspective and the network perspective when assessing the potential effects of travel information. This contrasts with earlier studies which adopted only one of these perspectives, either by ignoring the effects on the network level (e.g. Chorus et al., 2006a, 2006b; Lyons et al., 2007; Shiftan et al., 2011; Tanaka et al., 2014), or making very simplified assumptions on individuals' choice behaviour (e.g. Ben-Akiva et al., 1991; Emmerink et al., 1995; Yang, 1998). Secondly, it focusses on the role of bounded rationality as well as that of social behaviour in route choice and in response to information. Herewith, this review complements previous reviews that mostly focused on bounded rationality only (e.g. Szeto et al., 2015). Note that recent studies, such as that of Ben-Elia and Avineri (2015), called for a stronger focus on studying social choice behaviours as they may play an important role in establishing cooperative and efficient network use; this review answers to that call.

From the abovementioned, it is hypothesized that the conceptual model as presented in Figure 2 applies, i.e. in order to understand the potential of specific travel information in terms of directing the transport system towards a system optimum at the network level, one needs to understand how bounded rationality and social choice behaviour interact at the individual level. After all, bounded rationality and social choice behaviour may influence an individual's response to travel information and should, therefore, be incorporated in the information strategy that is used to change individual choice behaviour in order to improve network efficiency. Thereby, these might be both essential in improving current travel demand management strategies.

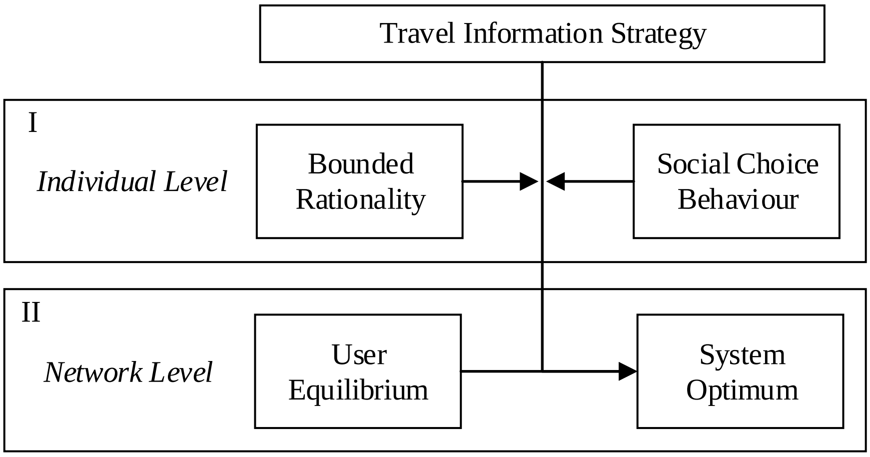


Figure 2. Conceptual framework on the potential of travel information to improve road network efficiency.

The conceptual framework provides the scope of this review and is followed throughout the chapter. First, Section 2.3 introduces general theories on choice behaviour focusing on individual choice behaviour as well as interacting choice behaviour. These general theories are subsequently applied within the field of transportation in Section 2.4, specifically regarding route choice behaviour and network equilibria. As such, these sections each focus on the blocks from the conceptual framework. This is followed by the introduction of travel information (Section 2.5), especially on how this influences individuals' choice behaviour and affects the network state. Therewith, Section 2.5 focusses on the arrows from the conceptual framework. Finally, Section 2.6 discusses the application of travel information as a travel demand management measure with respect to both individual behaviour and network efficiency, and provides suggestions on potential successful strategies.

2.3. General theories on choice behaviour

Classical economic theories developed in the 18th and 19th century provided a conceptual framework of human choice behaviour based on hypotheses and philosophies in order to understand the economic developments of that time. During the 20th century, the perspective on economics shifted from the somewhat theoretical approach towards a more mathematical approach. Neoclassical theories largely build upon two behavioural assumptions, i.e. individuals are rational in how they choose and selfish in what they choose (e.g. Kestemont, 2011).

2.3.1. Perspective on individual choice theory

Neoclassical theory introduced the concept of the 'Homo Economicus', which characterizes humans as being selfish, rational maximizers of personal utility (e.g. Schneider, 2010). It assumes that individuals are rational decision-makers who oversee all available choice alternatives and have perfect knowledge about the implications of each potential choice. As a result, it is expected that an individual is able to identify the optimal alternative, even when conditions change, and will actually choose this optimal alternative. This concept is widely criticized by behavioural economists who build upon psychology, social sciences and economics in order to explain deviations from this rational selfish choice behaviour. Many of these economists have even won Nobel Prizes in Economics for their critical work (e.g. Herbert Simon, Daniel Kahneman and Elinor Ostrom), emphasizing the strength and legitimacy of their critiques. Now, the main line of criticism will be elaborated.

Critique on the assumption of rationality

Simon (1955) was one of the first to criticize the assumption of rationality within the concept of the 'Homo Economicus'. He thought that this assumption is not consistent with reality because individuals are limited by their available knowledge, computational capacities and the finite amount of time to make a decision (Simon, 1955, 1956). This notion is referred to as bounded rationality. In line with these cognitive limitations, Kahneman and Tversky identified several cognitive errors and biases. First of all, they state that individuals are loss-aversive and therefore tend to weigh losses associated with a certain alternative heavier than gains of similar magnitude (Tversky & Kahneman, 1991). Secondly, they found that individuals rely their estimates or perceptions on information or initial values that might not even be related to the choice problem, referred to as the anchoring effect (Tversky & Kahneman, 1974). Additionally, they noted that individuals overweight small probabilities, that is, the probabilities of rare events are perceived to be higher than they actually are (Kahneman & Tversky, 1979).

Well-known examples that violate the rationality assumption in situations under risk are the Allais paradox and the Ellsberg paradox. The Allais paradox (Allais, 1953) shows that two choice situations that are similar except that for one situation the probabilities in each choice option are equally reduced with respect to those in the other situation, could result in completely opposite choice behaviour. That is, individuals prefer options with the highest utility in low-probability cases, while they will choose the most certain option in high-probability cases, even if this results in a lower utility. This effect contributes to risk-aversive choice behaviour towards choices containing sure gains and risk-seeking behaviour towards choices containing sure losses (Kahneman & Tversky, 1979). The Ellsberg paradox (Ellsberg, 1961) shows that individuals are aversive to ambiguity and uncertainty and therefore prefer the alternative for which the probabilities of success are known for sure over an alternative with unknown probabilities.

Other studies suggest that feelings and emotions influence our decision-making. Zajonc (1980) was one of the first to promote emotions in decision-making. He stated that individuals often make decisions based on what they 'like' and justify these choices by rational considerations. Moreover, when some chosen option ends up being worse than expected or worse than the rejected options, individuals will feel negative emotions, such as regret or disappointment (e.g. Zeelenberg, Van Dijk, Manstead, & Van der Pligt, 2000). Individuals tend to avoid these negative emotions, and instead strive for positive emotions. Consequently, prospects of fun and excitement associated with choice alternatives might result in risk-seeking choice behaviour (Slovic, Finucane, Peters, & MacGregor, 2007).

It is believed that due to these cognitive limitations, errors, biases and emotions, individuals are often not capable to identify their own interests correctly and choose alternatives that conflict with their rational objectives.

Critique on the assumption of selfishness

In the early 1950s, Georgescu-Roegen (1954) already criticized the assumption of selfishness within the concept of the 'Homo Economicus', by arguing that an individual's experienced utility not only depends on individual factors, but include social factors as well. More rudimentary, Fehr and Fishbacher (2003) and Godbout (2000) state that actions and choices are mainly driven by the notions of gift and reciprocity. That is, a gift creates a sense of obligation to respond in kind. In other words, if I do something for you, you do something for me. Therewith, this principle is partly motivated by self-interest, although the welfare of others is important as well. Ostrom (e.g. Ostrom & Walker, 2003; Poteete et al., 2010) observed motivations for reciprocity and collaboration related to a large range of public goods and commons within different societies. Furthermore, Sen (1977) believes that individuals make choices based on sympathy or commitment. In this, sympathy refers to "the case in which concern for others directly affects one's own welfare" (Sen, 1977, p. 326), while commitment refers to the case in which actions are performed out of some kind of duty. As opposed to sympathy, which is partly motivated by self-interest, an individual would still make a choice out of commitment even if this does not maximize his personal utility. Additionally, it is believed that individuals might dislike outcomes that are perceived unfair (i.e. they are inequity aversive) and sacrifice their own payoff in order to obtain more fair outcomes (Fehr & Schmidt, 1999). Moreover, several researchers (e.g. Liebrand & McClintock, 1988) motivate that the extent to which individuals acts selfishly or selflessly can be captured by their social value orientation (i.e. individualistic, competitive, cooperative or altruistic). Experimental evidence conflicting the notion of exclusive self-interest within the concept of the 'Homo Economicus' is provided by Henrich et al. (2005), among others.

They found that individuals care about fairness and reciprocity, are willing to sacrifice their own gains in order to change the outcomes of others and sometimes reward those who act socially and punish those who do not (e.g. by rejection, exclusion, or gossip), even if these actions come at a cost.

These critiques imply that certain individuals are not purely selfish, but under certain circumstances take other people's welfare into consideration when making their decisions. Moreover, these studies are only a small part of extensive literature stating that individuals do not exclusively behave in selfish ways, but that they care about others to some extent and that their choice behaviour can be affected by motives, such as fairness, commitment, morality and social responsibility. These notions should therefore not be ignored when examining individual's choice behaviour.

2.3.2. Perspective on interacting choice theory

Choice theory on the interacting network level is mainly studied by two theories; i.e. social choice theory and game theory. Social choice theory studies the collective decision processes and procedures by aggregating individuals' preferences, interests or welfares into a collective decision or social welfare (List, 2013). In this, the main theme is how a group of individuals can choose an optimal outcome from their available set of alternatives. Arrow (1963) considered several social welfare functions based on ordinal preferences and concluded that there is no rational way to aggregate individual preferences into a scheme of social priorities or collective preferences (i.e. Arrow's Impossibility Theorem). Others (e.g. Sen, 1982) proposed to use additional information, such as interpersonally comparable welfare measurements. Game theory (Von Neumann & Morgenstern, 1944) studies interacting choices in which each individual considers the possible strategies used by other individuals in order to determine his own strategy. These games often assume rational decision-makers, although several researchers have argued to incorporate bounded rationality, for instance through constrained maximization, evolution or inductive reasoning (e.g. Matsushima, 1997; Rubinstein, 1998).

Games within game theory often contain social dilemmas consisting of conflicts between self-interests and collective interests that highly challenge the functioning of a group or society. That is, individuals benefit if they act in their own interest, except if all individuals behave out of self-interest; in that case, the whole society might end up being worse off. A discipline that deals with this notion is non-cooperative game theory, in which individuals act independently (e.g. the prisoner's dilemma). Nash (1951) has shown that the optimal solution to non-cooperative games is an equilibrium point in which "each player's strategy maximizes his payoff if the strategies of the others are held fixed. Thus each player's strategy is optimal against those of the others" (Nash, 1951, p. 287). On the other hand, if individuals would be able to cooperate by negotiating and making agreements about their choices, this could lead to better and more efficient outcomes than when acting independently and in their own interests (i.e. collective success instead of individual gain) as shown by cooperative games (e.g. the common goods dilemma and the tragedy of the commons). Solutions to cooperative games are provided by, among others, the Core and the Shapley Value (Serrano, 2009). The core (Gillies, 1959) is a collection of possible stable pay-offs that no coalition of players can improve or hinder, while the Shapley value (Shapley, 1953) provides the payoff that each player reasonably can expect, resulting from their contribution to the overall cooperation.

A system's efficiency depends clearly on the outcomes resulting from each individual's choice behaviour. The degradation of a system's efficiency due to selfish non-cooperative behaviour is called the 'Price of Anarchy' (Koutsoupias & Papadimitriou, 1999). Thereby, this is often regarded as a measure of social welfare.

2.4. Route choice behaviour and network equilibria

Section 2.3 has introduced general theories on choice behaviour and criticism on the assumptions of these theories. In this section, this knowledge is extended to the field of transportation, more specifically, route choice behaviour (i.e. individual level) and related network equilibria (i.e. network level). Route choice behaviour concerns the selection of routes between origins and destinations in a road network. In selecting their route, travellers are often assumed to behave according to the concept of the 'Homo Economicus', that is, rationally choosing a route alternative in their own interest. Section 2.4.1 elaborates on this traditional, yet criticized, concept with respect to route choice behaviour and introduces alternative concepts that provide a more realistic representation of actual choice behaviour as they build upon raised criticisms on rationality and selfish behaviour. When many travellers want to use the same low-cost roads at the same time, this may lead to severe congestion at certain locations in the road network and slow down overall traffic movement. Thus, travellers who are trying to minimize their own travel cost, may (unintentionally) produce high travel cost for all road users. This can be characterized as a 'Tragedy of the Commons' in which the public road network represents the common good. Section 2.4.2 elaborates on this interacting route choice behaviour and introduces several concepts of network equilibria that relate to social choice behaviour and rationality.

2.4.1. Perspective on individual route choice behaviour

The main perspective on how travellers choose their route is the theory of utility maximization (Ben-Akiva & Lerman, 1985), which builds upon the concept of 'Homo Economicus' by characterizing individuals as selfish, omniscient, rational maximizers of personal utility. The idea is that each route in the network performs differently on certain attributes that contribute to route choice (e.g. travel time, distance, reliability, etc. (e.g. Chen, Chang, & Tzeng, 2001)). Some of these attributes might be considered more important than others depending on individual preferences. Each route alternative in the choice set receives a certain utility based on the sum of the different attribute values and their weights. A traveller chooses the route that provides him with the highest utility. This approach assumes that the decision-maker knows the travel conditions (i.e. riskless). Nonetheless, travellers might make random errors in assessing these travel conditions. Therefore, random utility theory (Ben-Akiva & Lerman, 1985) adds a stochastic error term to the utility function providing an individual's perceived utility. However, due to day-to-day dynamics and incidents, travel conditions might be uncertain (i.e. risky). A natural extension to the utility theory, taking this risk into account is the expected utility theory (Von Neumann & Morgenstern, 1944). This theory assumes that the different possible outcomes resulting from the uncertain travel conditions follow a certain probability distribution that is known to the decision-maker. The expected utility of the different alternatives is then calculated by the weighted average of the utilities associated with these different outcomes.

Over the years, several other perspectives on decision rules are proposed which may provide a more realistic representation of actual choice behaviour as they build upon criticisms on rational choice behaviour accounting for systematic biases such as loss aversion, risk aversion and regret aversion. These are, for instance, based on the idea that individuals evaluate alternatives in terms of gains and losses relative to certain reference points, such as the prospect theory (Kahneman & Tversky, 1979), or in riskless contexts, the referencedependency theory (Tversky & Kahneman, 1991). Others are based on the notion of emotions in decision-making assuming that choices are determined by the desire to minimize regret rather than to maximize utility, such as regret theory (Loomes & Sugden, 1982), or in riskless contexts the random regret minimization theory (Chorus, 2010). Applications of these principles within a travel choice context can be found in Hess, Rose, and Hensher (2008), De Borger and Fosgerau (2008), Van de Kaa (2008) and Bekhor, Chorus, and Toledo (2012). Note that these decision rules still assume a maximizing strategy.

Johnson and Payne (1985) introduced the effort/accuracy framework which states that an individual bases his decision strategy on a trade-off of both the perceived effort and perceived accuracy of the different decision rules. Maximizing decision rules such as the utility theory, prospect theory and regret theory are only used when an individual needs highly accurate choice outcomes, because exploring and testing travel options consumes time, effort and attention, which are scarce resources. In order to simplify their decision strategy and minimize cognitive efforts, individuals tend to use other decision rules in which the individual rather seeks for a satisfactory solution instead of seeking for the optimal solution using thresholds or aspiration levels. Examples are elimination-by-aspects (Tversky, 1972), lexicographic choice (e.g. Saelensminde, 2006) and the satisficing principle (Simon, 1955). These decision rules are part of a growing body of literature on attribute processing strategies and choice set processing strategies (Bovy, 2009; Van de Kaa, 2010) and efforts are made to build in risk and uncertainty as well (e.g. Li & Hensher, 2013). Applications of these principles within a route choice context can be found in Hess, Stathopoulos, and Daly (2012), Hess, Rose, and Polak (2010) and Takao and Asakura (2005). Furthermore, if travel choices become highly repetitive, travellers start to make their route choices in a habitual manner (e.g. Garling & Axhausen, 2003; Van der Mede & Van Berkum, 1993). That is, automated cognitive processes take control and travellers will repeatedly use the route alternative that provided them with the most positive experience in the past, without even thinking about it (e.g. Verplanken, Aarts, & Van Knippenberg, 1997). Since none of the available route alternatives needs to be assessed, habitual decision-making does not need any cognitive effort at all (Chorus et al., 2006b). Note that the effort/accuracy framework assumes rational optimization of the trade-off, although it can be argued that cognitive limitations force individuals to use certain heuristics (Gigerenzer, 2015).

An overview of existing rules and strategies can be found in Chorus (2014), Leong and Hensher (2012) and Van de Kaa (2010). The use of a certain rule or strategy influences a traveller's route choice. Moreover, each individual might use a different rule or strategy in the same choice situation. This might lead to different decisions as well as identical decisions among individuals. Moreover, even the same individual might make different choices in the same choice situation from time to time. As a result, some travellers switch back and forth between routes, while others consistently take one route alternative for their regularly made trips (Tawfik, Rakha, & Miller, 2010). Within these route choices patterns, decision rules cannot be distinguished from each other. However, what can be identified is route switching and inertia, which represents the tendency of users to continue choosing their current path, increasing the utility of that path (Srinivasan & Mahmassani, 2000). Inertia takes place within certain inertia thresholds (i.e. indifference band). That is, "drivers will only alter their choice when a change in the transportation system or their trip characteristics, for example travel time, is larger than some individual situation-specific threshold" (Vreeswijk, Thomas, van Berkum, & van Arem, 2014, p. 11).

An individual's social route choice behaviour, or more generally social travel choice behaviour, has not received much attention in literature. Mainly, it is assumed that travellers choose in their self-interest (e.g. optimizing regret, gain or utility). However, criticism on the assumption of selfishness indicates that travellers might be willing to make their route choices altruistically. In this, the higher the perceived cost of acting altruistically, the less frequent this behaviour is performed (Fehr & Fishbacher, 2003). For example, if there exist route alternatives that impose only a small increase in generalized cost to a traveller, this traveller might be willing to use this alternative. Moreover, it is believed that directing part of traffic towards route alternatives with higher generalized cost might not make them dramatically worse off in general. For example, Baets et al. (2014) found that socially desired routes using primary roads as much as possible to improve liveability around secondary and tertiary roads are often feasible route alternatives to currently advised and/or chosen alternatives in the sense that they do not excessively increase travel time and distance. This is in line with the findings by Jahn et al. (2005), who proposed system-optimal routing based on user constraints that impose restrictions on the extra travel costs of each individual. They found that this constrained optimum was close to the pure optimum.

Nonetheless, most often travellers need to be motivated to change their route choice behaviour and nudge them towards socially desired choices. This can be done using certain incentives. Kusumastuti et al. (2011) identified four types of incentives with high potential to change individuals travel behaviour in general, especially if these are bundled; i.e. real-time travel information, feedback and self-monitoring, rewards and social networks. Real-time travel information on, for example, incidents, roadworks or events can be used by travellers to adjust or update their choices accordingly and hence change their travel behaviour (e.g. shift from car to environmental-friendly modes). Feedback on and self-monitoring of personal behaviour helps travellers to reflect on their past behaviour and increases awareness of the consequences of their travel. Based on these, travellers might set personal travel targets (e.g. reduce CO2-emissions) and change their route or mode choices to that purpose. Section 2.5 will further elaborate on these types of incentives and their application to direct choice behaviour.

Rewards feeding the self-interest of individuals are often applied within traffic management. There exist a large number of programmes, collectively referred to as 'Spitsmijden' (i.e. Peak Hour Avoidance) (Spitsmijden, 2013), in which participants earn points every time they avoid driving during peak hours, which can then be exchanged for gifts or financial benefits. It was found that within these programmes, 40% to 70% of the participating individuals did change their travel behaviour (Bliemer, Dicke-Ogenia, & Ettema, 2009). Opposed to 'Spitsmijden', road pricing programmes charge the use of roads during certain moments of the day, e.g. peak hours, and are thereby based on punishments and loss aversion. Therefore, these programmes often lead to resistance. Nonetheless, applications in, for example, Singapore, London and Stockholm show that these programmes induce travel behaviour changes as well (Anas & Lindsey, 2011).

Finally, the use of social networks is important in motivating behavioural change. After all, as road networks are generally quite large and a large group of individuals make use of it, there exist only little social interactions among these individuals. As a result, they might not identify themselves with certain values and interests of the group that interacts within the network and are therefore less likely to act socially (Avineri, 2009b). However, it was found that an individual would be more prone to cooperate when others in the social network are expected to cooperate as well (i.e. conditional cooperation) (Murphy & Ackermann, 2013).

This is especially the case if this entails the majority of individuals since this behaviour will then be regarded as the social norm. Araghi, Kroesen, Molin, and Van Wee (2014) underline this, as they found that people's willingness to compensate for their flight-related carbon emissions depends on the collective participation rate. Social networks can reinforce these expectations and create awareness of social norms. Dugundji and Walker (2005) proposed and tested several methods in order to capture social interdependencies within discrete choice modelling, which seem to be superior to the traditional approach.

2.4.2. Perspective on interacting route choice behaviour and network equilibria

Selfish choice behaviour leads to less efficient use of the existing road network than when travellers cooperate and make social choices by taking into account the additional cost they impose on others. Therewith, a traveller's choice behaviour affects the whole network and defines the equilibrium that establishes within the network. Well-known examples that illustrate network inefficiency due to selfish route choice behaviour are Pigou's example (Pigou, as pointed out by Roughgarden, 2006) and Braess's Paradox (Braess, Nagurney, & Wakolbinger, 2005). Pigou's example entails a parallel two-link road network in which a congested route alternative results in the lowest cost for each individual, although choosing this route alternative contributes to this congestion. Braess's Paradox shows that the addition of road capacity that seems intuitively helpful to the efficiency of the road network might increase the cost experienced by all travellers. This paradox is observed in real-world in for example Boston, London and New York City (Youn, Jeong, & Gastner, 2008).

A network state that results from purely selfish individual choice behaviour and is in line with the concept of 'Homo Economicus' is the user equilibrium. This equilibrium is based on Wardrop's first principle, which states that "the journey times in all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route" (Wardrop, 1952, p. 345) and is consistent with the principles of Nash equilibrium for non-cooperative games (e.g. Correa & Stier-Moses, 2010). On the other hand, purely social choice behaviour leads to system-optimal network conditions. That is, the sum of generalized travel costs within the network is minimized according to Wardrop's second principle.

Within the context of a road network, the Price of Anarchy is defined as the ratio between the selfish user equilibrium and the social system optimum in terms of average generalized travel cost (Roughgarden, 2006). For typical road networks in which delay is a linear function of congestion, the price of anarchy is at most 4/3 (≈1.33) (Roughgarden & Tardos, 2002). This means that individuals waste up to 33% of their travel time by not acting socially. Youn et al. (2008) provide an overview of the price of anarchy under different traffic volumes for the cities of Boston, New York and London.

In order to decrease the price of anarchy, travellers need some external steering in being social as they cannot identify socially desired alternatives themselves. To that end, travel information can be quite helpful. For instance, Stackelberg routing (Korilis, Lazar, & Orda, 1997) assigns a fraction of travellers by a central authority (i.e. leader) as they comply with advice that they received, while the remaining individuals (i.e. followers) choose their route selfishly (Krichene, Reilly, Amin, & Bayen, 2014). In this, the leader anticipates on the (expected) selfish response in order to improve overall network performance (Krichene et al., 2014). One should note that although the collective benefits of a reduction in the price of anarchy for a city can be significant, travellers' average benefits might be small, ranging from 1 to 3 minutes (Çolak et al., 2016). The majority of travellers might not notice these travel time savings as travel time variability caused by events, weather conditions or traffic lights are often higher (Çolak et al., 2016).

Due to day-to-day dynamics and bounded rationality, the network equilibrium established in a real-world road network will not exactly be a user equilibrium, nor a system optimum. However, laboratory experiments have indicated that aggregated route choices are significantly closer to the user equilibrium than the system optimum (e.g. Morgan, Orzen, & Sefton, 2008). In order to explain the established equilibria within existing road networks, several alternative concepts have been introduced based on network assignment models that incorporate behavioural aspects. The first alternative concept is the stochastic user equilibrium (Daganzo & Sheffi, 1977), in which it is assumed that individuals do not have perfect information due to random perception errors. Therefore, at the stochastic user equilibrium, no individual can improve his perceived travel time by unilaterally changing routes. In other words, no individual believes that his travel time can be improved. A second concept introduced is that of the boundedly rational user equilibrium (Mahmassani & Chang, 1987), which assumes that individuals use satisficing rules in making their travel choices. This equilibrium is defined as the "state of a transportation system in which all users are satisfied with their current choices and thus do not intend to switch" (Mahmassani & Chang, 1987, p. 91). In other words, the perceived travel costs of the used routes of all individuals are within their indifference bands. Note that an individual can take any route whose travel costs are within this indifference band and therefore the equilibrium solution is not unique (Zhang, 2011). As a result, changes in the transportation network might permanently relocate the network state, even if they are only temporal (Bie, 2008; Guo & Liu, 2011). After being forced to switch routes because of a network change, travellers might get used to the new route, and due to bounded rationality they will not change back when the benefits from route switching are insufficient (Guo & Liu, 2011). This is observed in reality, for example, during the collapse and reopening of the I-35W Bridge over the Mississippi River in Minneapolis, Minnesota (e.g. Danczyk & Liu, 2010). More recently, four more concepts have been introduced. Site and Filippi (2012) proposed a reference-dependent stochastic user equilibrium that was defined as a network state in which no individual can improve his utility based on gains and losses by unilaterally changing routes, using the current conditions on the network links as reference point which coincides with the chosen route alternative. That is, no individual uses a route alternative that is not his reference alternative. Furthermore, Connors and Sumalee (2009) formulated a perceived value equilibrium based on a cumulative prospect theory. That is, "at equilibrium, all used routes have equal (maximum) perceived value" (Connors & Sumalee, 2009, p. 617). This perceived value is a summary of the overall attractiveness of the alternative under risk. Zhang (2011) introduced a behavioural user equilibrium based on his SILK-theory emphasizing on Search, Information, Learning and Knowledge in the decision-making process. In a behavioural user equilibrium, "all users with imperfect network knowledge stop searching for alternative routes because for each user the perceived search cost exceeds the expected gain from an additional search" (Zhang, 2011, p. 4). Finally, Chorus (2012) demonstrated several equilibrium states using the regret theory under different levels of risk aversion and regret aversion. An in-depth review of these assignment models incorporating aspects of bounded rationality together with their challenges and opportunities is provided by Sun, Karwan, and Kwon (2015).

The aforementioned studies show that based on the assumptions about individual choice behaviour, different equilibria can be determined which to a greater or lesser extent may approach the actual network state within a certain road network. Note that although there exist unique network equilibria in terms of traffic flow, these do not contain unique route patterns.

That is, several combinations of individual's route choices correspond to the established traffic flows within one equilibrium.

2.5. Travel information

The previous section has extended the general choice theories as well as their criticisms to the field of transportation. This section will introduce travel information to this framework. In earlier years, travel information was generally obtained using newspapers, television or radio. However, information came with substantial delay and contained only information on the most congested routes (Dicke-Ogenia, 2012). Therewith, this information was often not that relevant to the traveller's situation. Due to technological developments on data handling and gathering and the presentation of information to individuals, nowadays, travel information is available through, for example, navigation systems, smartphone applications and variable message signs (VMS) along the roads. With these Advanced Traveller Information Systems (ATIS) travel information can be provided for the whole network without considerable delay to each traveller at any time and at any location (Dicke-Ogenia, 2012). It is widely believed that travel information removes perception errors and knowledge limitations among travellers and therewith improves their decision-making (e.g. Bonsall, 1992). As a result, travel information measures are expected to lead to reductions in traffic congestion and thereby to improvements in network efficiency. Section 2.5.1 focusses on how travel information provision influences travellers' choice behaviour and how choice behaviour affects information use (i.e. individual level), whereas Section 2.5.2 focusses on how travel information measures affect the network state (i.e. network level).

2.5.1. Perspective on travel information affecting individual choice behaviour

In general, travel information makes individuals more aware of situations and changes in the road network, especially gradual changes which are difficult to detect. Furthermore, it enables the possibility to save time and provides certainty about the journey (Zhang & Levinson, 2008). Consequently, it reduces the route choice situation from being a risky choice towards a riskless choice. The use of travel information not only reduces trip uncertainty, or possible misperceptions, but also improves travel quality, comfort and an individual's psychological well-being. For the provision of travel information, different information provision strategies can be used. These strategies consist of several aspects; content (e.g. spatial information, information on traffic state or on route characteristics), nature (i.e. descriptive or prescriptive), type (i.e. static or dynamic, qualitative or quantitative), origin (i.e. historical, real-time or predictive), quality, timing (i.e. pre-trip, en-route or post-trip), level of personalization (i.e. non-personalized public, semi-personalized public or personalized) and format (i.e. text-based or pictorial) (Chen, Srinivasan, & Mahmassani, 1999; Dia & Panwai, 2007; Raiyn & Toledo, 2014; Ramos, 2015; Schofer, Khattak, & Koppelman, 1993). Travellers can have different preferences regarding these aspects. For instance, the Dutch government identified five types of travellers within the Dutch population based on their attitude towards mobility (Ministry of Infrastructure and Environment, 2002); i.e. accepters, deliberates, conscious, competitors and enjoyers. Van den Broeke, Van der Horst, and Schotanus (2004) linked these five types with different information needs. Overall, it is concluded that prescriptive, predictive, quantitative real-time delay information is most effective in influencing individuals route choices, especially if this is provided for both the usual route alternative and best route alternative (Ben-Elia, Di Pace, Bifulco, & Shiftan, 2013; Dia & Panwai, 2007; Khattak, Polydoropoulou, & Ben-Akiva, 1996; Schofer et al., 1993). The effect of information depends on the network conditions and the context in which the information is provided. A literature review by Chorus et al. (2006a) indicates that if the current or currently intended route alternative has (expected) bad performance, travellers are more open to travel information and more prone to switch to advised route alternatives, especially if they have a fixed scheduled arrival time. After all, they face a potential deviation from their preferred arrival time and try to control delay damage. This stresses the need for and use of information on arrival time-sensitive trips, such as commuter trips and business trips.

The use of travel information can be framed as a cost-benefit trade-off (Chorus et al., 2006b). The cost of information can be found in the effort to acquire the information and possible monetary cost. The benefits of information depend on the decision strategy a traveller uses (see section 2.4.1; i.e. maximizers, satisficers or habit executioners). Maximizers benefit from information in that it helps them to choose the alternative with maximum payoff (Chorus et al., 2006b). Thus, they address high value to travel information and are prone to search for and comply with travel information. Maximizers with intermediate risk aversion levels do benefit the most from travel information as it helps them to select their optimal route each day (De Palma, Lindsey, & Picard, 2012). On the other hand, travellers with very high or very low levels of risk aversion do not value information and stay uninformed (De Palma et al., 2012). After all, they take respectively the risky route alternative or the safest route alternative every day, even when this alternative might be less beneficial (De Palma et al., 2012). Ben-Elia, Ishaq, and Shiftan (2013) found that travel information on route alternatives together with experiential information results in higher levels of regret aversion among travellers. However, regret aversive travellers benefit from travel information as well as it enables them to choose route alternatives that result in less regret. Satisficers (i.e. individuals who ease their cognitive efforts) derive benefits as information helps them to choose an alternative that is ‘good enough’ (Chorus et al., 2006b). They are less prone to search for and comply with travel information than maximizers. As long as they are satisfied with their current route choice, they are likely to ignore received information. In line with this, if certain received travel information is too complex, individuals might suffer from information overload and start to ignore information on certain attributes in order to lower their cognitive effort (Zhu & Timmermans, 2010). Habit executioners might find benefit in confirmation of their habitual choice, especially under changing travel circumstances, although this occurs not very often (Chorus et al., 2006b). In general, a habit executioner will not actively search for travel information and is not likely to consider new information (Jager, 2003). Consequently, habitual decision-makers are hard to be influenced by providing travel information. However, providing travel information might indirectly break habitual behaviour, for instance, if (part of) the trip is made within another choice context or if the habitual alternative starts to perform very badly, due to, for example, incidents or roadworks (Chorus et al., 2006a; Fujii, Gärling, & Kitamura, 2001).

Information strategies might be designed in such a manner that they nudge travellers towards socially desired route alternatives without restricting their freedom of choice (Avineri, 2009a; Thaler & Sunstein, 2008). Avineri (2009a) illustrates how small adaptations to the presentation of a choice situation influences travel choices. For instance, if a traveller searches for the shortest route alternative, the used route planner can provide as well information on the most economical or eco-friendly route alternatives by default. This might increase awareness of these options and nudges travellers to at least consider them. Moreover, travel information can be provided using loss framing in which the presentation of choice alternatives highlights the negative impacts or effects that come along with (some of) them (Avineri, 2009a). As a result, the tendency for individuals to avoid losses directs them towards a particular choice. Avineri and Waygood (2013) demonstrated this principle on emission-reducing travel choices. Furthermore, negative impacts that are associated with certain travel choices, such as emissions and pollutants, are not always salient. Travel information might make these impacts more visible to travellers (e.g. by introducing an eco-friendly routing option within route navigation systems and trip planners), enabling them to make eco-friendly route choices (Avineri, 2009a). However, Ericsson, Larsson, and Brundell-Freij (2006) found that in about 80% of the trips, the shortest travel time route was the same or almost the same as the eco-friendly route. Therefore, travellers using the eco-friendly route alternative are not necessarily acting selflessly. Additionally, choice outcomes are very sensitive to the set value of travellers' reference points and travel information might be used to influence these (Avineri, 2006). Finally, findings by Sunitiyoso, Avineri, and Chatterjee (2009) suggest that social information on the choices of others, especially if these are relatively close to them, could increase an individual's willingness to contribute and thereby nudge them towards desired behaviour. Djavadian, Hoogendoorn, van Arem, and Chow (2014) provide some initial evidence that travellers are willing to comply with social routing advice, especially when incentives are provided.

2.5.2. Perspective on travel information affecting interacting behaviour and network state

In general, it is believed that travel information reduces traffic congestion due to improved decision-making at the individual level and thereby improves network efficiency. However, at the network level, this improved decision-making might imply that travel information directs the network state towards the inefficient user equilibrium (Ben-Akiva et al., 1991; Emmerink, Verhoef, Nijkamp, & Rietveld, 1996). Ben-Akiva et al. (1991) illustrate the counterproductive effects of information provision on the network state by the fact that the inefficient user equilibrium represents a situation with fully informed travellers as it assumes perfect knowledge. Furthermore, they identified several adverse effects of travel information, such as oversaturation, overreaction and concentration. Thereby, they demonstrate that informing (part of the) travellers is only beneficial to the network state in specific situations. Nonetheless, it is believed that modern state-of-the-art personalized information can overcome these effects (e.g. Adler & Blue, 1998; Bottom et al., 1999). However, as pinpointed by Klein et al. (2018), the road network might be approaching a perfect user equilibrium even more than before due to the rapid increase of real-time community-based routing applications on smartphones (such as Waze (2018)).

Travel information influences the network state differently based on its influence on individual choice behaviour. For instance, Avineri (2006) demonstrated how a change in the perceived value of the reference point in a route choice situation could lead to improved traffic equilibrium. Increasing levels of regret aversion among travellers can have significant impacts on network equilibrium as well, shifting it towards the preference of safer route alternatives as demonstrated by Chorus (2012). Furthermore, it was found that travel information might induce route switching behaviour among individuals, which affects the stability of the network state (Mahmassani & Liu, 1999). This might be explained by regret aversion and loss aversion as well as the desire to minimize generalized travel cost.

The extent to which travel information affects the network state depends on the compliance rate among travellers within the road network. Many studies assume that informed or equipped travellers automatically make rational choices in compliance with the received information. However, travellers do not always use or comply with the received information. They need to accept the information, which highly depends on the information, as it should be credible, relevant, accurate and reliable (e.g. Bonsall, 1992). However, traffic conditions, trip characteristics, driver characteristics and prior experience are important as well (e.g. Yin &

Yang, 2003). Moreover, some travellers might accept the provided information and deliberately do not comply with it, as they assume that others will do so and thereby leave the road free for them (Bonsall, 1992). Typically, only a small minority of all trips are made in compliance with advice. Chatterjee and McDonald (2004) found in their cross-project study that only about 61% of travellers noticed information signs, of which 92% actually read and understood the message. 33% of them complied with the information. This is only 18% of all travellers within the study. In a survey by Kattan, Nurul Habib, Tazul, and Shahid (2011), 21.4% of the respondents stated that they usually switch to suggested route alternatives provided by VMS on accidents or work zones ahead, while 16.4% stated to switch occasionally to suggested route alternatives. Many other studies contain findings on compliance rates towards advice. Chen and Jovanis (2003) found a compliance rate of 89% in their simulator study. Ben-Elia, Di Pace, et al. (2013) found average compliance rates between 62% and 82%, depending on the accuracy level. Note that these rates found by simulator experiments are significantly higher than those obtained by surveys.

Although travel information is provided through several information sources, information will not reach all travellers within the road network. Nonetheless, travel choices of uninformed drivers are affected by travel information as a result of the choice behaviour of the informed travellers (Levinson, 2003). Of course, the benefits for the informed road users tend to be higher. However, one can imagine that the marginal benefits are considerably higher for the first 10% of travellers who comply with the information compared with the last 10% (Rietveld, 2010). As a result, the last 10% might be less prone to comply with the provided information. Enrique Fernandez, Joaquin de Cea, and German Valverde (2009) show that at a 50% market penetration of ATIS, already 90% of the benefits can be achieved.

Several studies incorporated behavioural constructs due to the provision of travel information in their network assignment models. Examples are Dia and Panwai (2007), Van der Mede and Van Berkum (1993) and Zhang (2011).

With respect to social choice behaviour, the effects of travel information on the network level might differ. The few studies that exist on social routing demonstrate that when only a minority of travellers choose their routes socially, or when all travellers start to value social outcomes only slightly, a significant part of potential travel time savings could already be achieved and the network state would become closer to the system optimum (e.g. Avineri, 2009b; Levy, Klein, & Ben-Elia, 2017; Van den Bosch et al., 2011; Xu & Gonzalez, 2017; Çolak et al., 2016). Social routes could also be related to other societal aspects than travel time, such as environmental sustainability, traffic safety, or liveability. Ahn and Rakha (2008) demonstrated that both a user equilibrium and a system optimum based on travel time do not necessarily minimize emissions and fuel consumption. However, they found that a travel-time based system optimum and an eco-friendly system optimum might be close to each other. Opposed to this, Baets et al. (2014) found that routes that contribute to liveability are often feasible route alternatives to currently advised and/or chosen alternatives. According to the author's best knowledge, empirical findings on the effects of travel information on the network level related to social choice behaviour do not yet exist.

2.6. Discussion and conclusions

This literature review builds upon a large and growing body of literature concerning travel information, choice behaviour and network equilibria. It emphasizes the importance of the review of those aspects all together in order to conduct a proper and successful research on the potential and use of travel information to approach a system optimum. To be more concise, it confirms that the conceptual framework as hypothesized in the introduction holds; in order to understand the potential of specific travel information in terms of directing the transport system towards a system optimum at the network level, one needs to understand how both bounded rationality and social choice behaviour interact at the individual level.

Obviously, the notion of bounded rationality in route choice behaviour in general as well as in response to travel information is vastly explored within literature both on the individual level and on the network level, while social choice behaviour has not received much attention yet. Nonetheless, an individual's degree of rationality and social value orientation are recognized as very important in actual choice behaviour. Yet traditional travel information aims at the individual's benefit and thereby stimulates rational selfish choice behaviour, regardless of the individual's social value orientation. As a result, it directs the network state towards the network inefficient user equilibrium. Examples on network efficiency have shown that in order to achieve system-optimal network conditions, (a small) part of the travellers need to act socially and choose route alternatives possibly at their own expense (i.e. they might need to make a detour), while others can continue in their own selfish ways. Depending on their social value orientation, some travellers might actually choose these social route alternatives or can be motivated to do so. In this, some external steering by a central authority is required, as they cannot identify socially desired route alternatives themselves. To this end, travel information that aims at the system's benefit and thereby stimulates social choice behaviour is needed (e.g. information strategies nudging travellers towards the desired route alternative). Although there exist some theories and ideas on how system-beneficial travel information should be designed and used, empirical findings on the effects of and responses to this kind of information do not exist at the moment.

It is crucial to provide system-beneficial travel information and social routing advice to those travellers who are actually open to this kind of social behaviour and are willing to comply with it at the moment they receive it, depending on their used decision rule or strategy and the choice context. For example, if a traveller is social-oriented and possibly interested to behave eco-friendly, he or she should receive social travel information that stimulates him or her to make that social eco-friendly choice. Providing selfish travellers with individual-beneficial travel information might remove perception errors and systematic biases, resulting in more rational and hence more predictable choice behaviour. This makes it easier for the central authority to determine the best assignment strategy. On the other hand, to some extent, selfish travellers might not be aware of the fact that certain received information is not beneficial for themselves or they might not be particularly interested in this. This leaves the possibility to direct them as well to the socially desired route alternatives, provided that they use travel information. Either way, the aforementioned stresses the importance of tailor-made personalized travel information messages targeting on their level of rationality as well as their social value orientation, in order to assign each specific traveller to that route alternative that is intended for him or her under system optimal network conditions.

According to the theories and findings in literature, potential successful system-beneficial information provision strategies could, for example, build upon a traveller's:

- Level of altruism (e.g. highlighting the contribution to network efficiency if the social choice alternative was chosen);
- Loss aversion (e.g. highlighting the loss by contributing to congestion if the usual or shortest route was chosen);
- Feeling for equity (e.g. by telling: Today we ask you to take the possible longer route alternative, tomorrow we will ask someone else);

- Belief or expectations about choices of others (e.g. by telling: 75% of travellers followed the advice and chose to contribute to network efficiency);
- Perception errors or disinterest (e.g. just informing on the advised route and withhold travel time information).

As these strategies are expected to have different effects in different circumstances and for different travellers, it is essential for the traffic manager to obtain knowledge about these effects in order to apply the most suitable information strategy to the prevailing circumstances and present travellers. Therefore, empirical findings on the response to different information strategies, especially in varying circumstances and for travellers with different degrees of rationality and different social value orientations, are necessary to obtain in the future.

Over the years, many researchers have put efforts in incorporating behavioural aspects in network assignment models, mostly related to bounded rationality, some related to the use of travel information, and some related to both. However, hardly any takes individuals' social choice behaviour into account. This review emphasizes the importance of all these aspects in the route choice decision-making process together. Especially when information provision strategies specifically aim at the system's benefit, travellers' social value orientation becomes crucial in their response to the received information message. So, when future application of information provision within travel demand management measures shift from the conventional individual-beneficial strategies towards the system-beneficial strategies, putting effort in including travellers' social value orientation in future network assignment modelling is likely to result in predictions that are both more accurate and more behaviourally realistic.

Overall, the insights and conclusions in this chapter stress the importance of anticipation on individuals' social choice behaviour as well as bounded rationality when applying travel information and social routing advice as a travel demand management measure at the network level. Moreover, it provides initial ideas and future research directions for the development and application of such a measure in order to improve network efficiency of existing road networks.

2.7. Acknowledgement

This work is part of the research programme TRAIL Graduate School, which is financed by the Netherlands Organisation for Scientific Research (NWO).

3. Route choice behaviour in response to conventional information

This chapter is based on: Van Essen, M., Thomas, T., Chorus, C., & Van Berkum, E. (2018). The effect of travel time information on day-to-day route choice behavior: Evidence from a real-world experiment. *Submitted for publication in Transportmetrica B:Transport Dynamics (1st review round).*

3.1. Abstract

Route choice behaviour in response to travel information receives increasing attention within travel behaviour research. This study contributes to the literature by generating insights into the effect of travel information on day-to-day route choice behaviour based on largely explorative analyses using route choice data obtained from a real-world experiment. As such, our study complements confirmatory stated preference and simulator experiments.

We find that travellers' route switching propensity decreases over time, while the percentage of times the shortest route is chosen appears to increase somewhat over time. The provision of travel information leads to a decline in switching propensity and a higher probability that the shortest route is chosen on those OD-pairs for which alternatives with distinct travel times exist. Furthermore, by applying clustering methods on individual route choice evolution patterns, we were able to identify six behavioural profiles, varying from switch-averse to switch-prone. Travel time information seems to influence travellers' propensity to shift from one profile to another across different OD-pairs. Without travel time information, collective shifts mainly take place across switch-averse profiles, whereas in response to travel information collective shifts do occur within, as well as between, switch-averse and switch-prone profiles. Finally, regression analysis indicates that the adoption of a certain behavioural profile results from a combination of situational characteristics as well as personality traits and individual preferences.

3.2. Introduction

Travel information continues to receive broad attention within the travel behaviour research community, driven by the widespread belief that travel information provision leads to reductions in traffic congestion and thereby improves network efficiency, to the extent that travellers choose their routes in accordance with the provided travel information. In this light, it comes as no surprise that many research efforts have been made to study traveller response to travel information in a route choice context (see references further below).

The way travellers choose routes and respond to travel information is a dynamic rather than a static process. For repetitive trips, such as commuting, many travellers may try different route alternatives at first, but after some time they may develop a habit of choosing the same, preferred, route alternative. Some other travellers will use only one route alternative from the start, never trying other routes, while still others may continue switching back and forth from day-to-day and never develop a habit of using one and the same route each day. The question we address in this chapter refers to whether travel information has an influence on the development of this dynamic behaviour. Answering this question is not just a matter of scientific interest; it may help practitioners to develop more effective information strategies that target specific travellers, i.e. those that are susceptible to change their route choices in accordance with the information they receive.

Several valid methods exist to investigate this question, the most prominent of these being stated choice experiments, laboratory experiments and field experiments. The bulk of studies concerning information effect on day-to-day route choices is based on stated choice or laboratory experiments (e.g. Abdel-aty et al., 1997; Mahmassani & Liu, 1999). Such studies are flexible and low-cost, and allow for high levels of experimental control (Kroes & Sheldon, 1988; Verhoef & Franses, 2003). However, it is debated how well findings from such studies can be extrapolated to the real world (e.g. Rakotonarivo, Schaafsma, & Hockley, 2016), especially regarding choices that people repeat on time-scales of 24h or longer, rather than minutes. Field experiments tend to have higher external validity, although they often suffer from smaller sample sizes – resulting in lower statistical power – and lower levels of experimental control. In this study, we use route choice data obtained by a field experiment. Specifically, we observe travellers' route choice behaviours in response to travel information, as well as in the absence of such information, in a day-to-day context where the consequences of their choices are actually experienced by the decision-makers. Hence, this chapter contributes to the literature by obtaining insights into the effect of travel time information on day-to-day recurrent route choice behaviour, with a special focus on real-world contexts. In this, we use an explorative approach (see Section 3.4 for methodological details).

This chapter is structured as follows. First, the research background is provided and relevant literature is discussed (Section 3.3). Subsequently, the methodology is described, focusing on experimental set-up, route characteristics and information accuracy (Section 3.4). Section 3.5 presents empirical analyses and results. Finally, this chapter presents key conclusions and discusses limitations of the study (Section 3.6).

3.3. Background

Travellers can almost always choose from several route alternatives when travelling from a certain origin to a certain destination. As route characteristics are generally associated with uncertainty, no traveller knows the exact arrival time for the different routes upfront, and this holds especially for travellers facing an OD-pair which is relatively new to them (e.g. after having relocated). Hence, travellers have imperfect information about the choice situation. One strategy to cope with such incomplete information is to explore route alternatives in a process of day-to-day route switching behaviour. After some learning period, travellers may increasingly tend to adopt an exploitation strategy using their preferred route alternative in a habitual way. This principle of exploration and exploitation was identified by Senk (2010). The provision of dynamic real-time travel information was found to increase a traveller's learning rate and thereby reduce his or her initial explorative behaviour (e.g. Ben-Elia & Shiftan, 2010). This was found to result in a higher so-called 'maximization rate', i.e. the proportion of occasions in which the on average shortest travel time alternative is chosen (e.g. Ben-Elia & Shiftan, 2010; Van der Mede & Van Berkum, 1993). For review papers on the topic of travel information and route choice behaviour, see e.g. Ben-Elia and Avineri (2015), Chorus et al. (2006b), Van Essen, Thomas, Van Berkum, and Chorus (2016).

Relatively few empirical studies of revealed (as opposed to stated) route choice behaviour in response to travel time information have been reported in literature. Here we discuss a few notable and relatively recent examples. A study by Chatterjee and McDonald (2004) on the effectiveness of variable message signs using field trials from nine European cities showed that up to 50% of travellers for whom the information was relevant diverted from their intended route after having received the information. Similarly, a field study by Shiftan et al. (2011), which was conducted in Haifa, showed that most route choices were made in accordance with received information. Nonetheless, it was found that this high compliance rate decreased as a traveller's level of experience with the different route alternatives grew over time. Furthermore, the study reported that when travellers did not make their choice in accordance with the received information, this was mainly because they had an intrinsic preference for the other alternative (see Chorus et al. (2009) for a theoretical exploration of this situation where advice contradicts intrinsic route preferences). Bad experience with (incorrect) information was found to only account for a small part of these non-compliant choices. Ramos, Frejinger, Daamen, and Hoogendoorn (2012) conducted a field study among commuters in Delft and The Hague using both GPS and travel diaries. They found that travellers were risk-prone in the sense that they preferred to arrive at their destination as early as possible and tended to stick to their preferred routes (which in many cases consisted of the - on average - fastest and most straightforward routes with relatively high levels of travel time unreliability) even if their information device told them to take another route. In their study, Ramos et al. (2012) did not observe a significant difference in route choices and switching behaviours between informed and non-informed drivers. Finally, a field trial by Djukic, Wilmink, Jonkers, Snelder, and van Arem (2016) conducted in Amsterdam, The Netherlands, and using a smartphone application that provides the user with personal route advice, reveals that more than 50% of the users comply with the received advice. Both Ramos et al. (2012) and Djukic et al. (2016) found that travellers are more likely to comply with pre-trip advice than en-route advice.

Overall, an increasing number of studies consider traveller response to travel time information in a route choice context. However, we have seen that only a few of them look at revealed route choice behaviour in real-world settings. None of these pays attention to the day-to-day dynamics in route choice behaviour, while this is essential in assessing the effects of travel time information over time. Our study contributes to the literature by filling in this gap.

3.4. Data

3.4.1. Experimental set-up

A real-world repeated route choice experiment was performed by the Virginia Tech Transportation Institute (VTTI), taking place in Blacksburg, Virginia, USA. The experiment consisted of two parts; in part 1 participants could only rely on their own experiences, whereas in part 2 participants received travel time information on available route alternatives. Part 1 was performed in 2011 by Tawfik (2012), while part 2 was performed in 2013/2014[1].

Participants

In 2011, 20 participants were randomly selected from the extensive participant pool of VTTI (consisting of volunteers that like to participate in traffic-related experiments conducted by VTTI) for part 1 of the experiment. They were contacted by phone in order to check eligibility and willingness to participate. In 2013, we required the same number of participants for part 2 of the experiment. Unfortunately, only 9 participants from part 1 accepted to participate a second time. Therefore, in part 2, 11 additional participants were randomly recruited from the same participant pool. In total, 31 individuals participated in the experiment (11 in part 1 only; 9 in part 1 and in part 2; 11 in part 2 only). Age and gender, including their combinations, were equally distributed among participants for both parts of the experiment (i.e. Age (18-35 years versus 55-69 years) x Gender (Male versus Female)).

Nearly all participants indicated prior to the start of experiment part 1 that they were moderately-to-very familiar with all route alternatives. Participants' familiarity with route alternatives is not known for part 2. However, as participants were recruited in the same area, they may be safely assumed to have a similar level of familiarity. This implies that participants had prior knowledge about local traffic conditions, but not necessarily about how the alternatives within one choice set perform compared to each other. This is emphasized by the fact that prior to the start of experiment part 2 most participants were unable to accurately assess route performance.

Our sample size is limited compared to studies that use simulators or stated preference questionnaires. This results from the required effort and constraints on both time and budget that are associated with real-world experiments. Findings should be interpreted bearing this in mind.

Materials

All routes taken as well as the actual experienced travel times were recorded through a GPS device located in the research vehicles. Moreover, participants were asked to complete pre- and post-task questionnaires. The pre-task questionnaire collected information about participants' socio-demographics and driving experience, whereas the post-task questionnaire collected information about their perceptions of traffic conditions and their preference levels for each route. They also were asked to fill in a Personality Inventory: the NEO-FFI-3. This is a 60-item version of the NEO Personality Inventory-Revised (Costa & McCrae, 2006) that provides a quick, reliable and accurate measure of five domains of personality, i.e. neuroticism, extraversion, openness to experience, agreeableness and conscientiousness. Each of these traits measures six subordinate dimensions.

[1] The author of this thesis was only involved with the data collection of experiment part 2.

Procedure

Participants were asked to complete experimental runs on respectively 20 (part 1) and 11 (part 2) (non-consecutive) days; the number of runs is limited due to time and budget constraints. The runs took place during peak hours on normal weekdays (i.e. morning (7-8 am), noon (12-1 pm) or evening (5-6 pm)). Each participant completed his or her run during the same peak hour each day, enabling us to make a meaningful comparison across different days. Each run consisted of 5 consecutive trips between 5 OD-pairs $(o_1, d_1) \dots (o_5, d_5)$, where $o_{j+1} = d_j$ for $j = 1,2,3,4$. These OD-pairs were the same for all participants and all runs, and they were always done in the same order. Prior to each trip, a research-escort (that always accompanied the participant) provided two route alternatives on a Google Map print-out. Participants were asked to assume that the provided alternatives were the only available routes for that trip. OD-pairs and route alternatives were selected in such a way that variation among choice situations was ensured. For an overview of the OD-pairs and routes used in the experiment, see Figure 3. Additionally, note that only in part 2 of the experiment, the research-escort verbally provided (pre-trip) travel time information to the participant. This information consisted of approximate travel times (e.g. route x takes approximately 8 minutes) during the first 5 runs, and travel time ranges (e.g. route x takes between 7 and 9 minutes) during the last 5 runs. Note that during day 6 no information was provided.

Provided travel times on each route r were based on historical data by calculating the average travel time for the last three instances in time when for OD-pair j route r was chosen during peak hour p by a participant from the experiment. Ranges were estimated based on the variability between days. Hence, the travel time information was updated day-to-day. Since the research objective was to learn about the impact of the provided information only, participants were asked not to use any other sources of information, such as navigation devices or mapping services, neither en-route nor pre-trip.

Participants were asked to behave as in real-life and to drive as if they made a commute trip. Several measures were taken to ensure that the experiment time was not considered as leisure; i.e. participants received a fixed monetary compensation per run, no entertainment (e.g. listen to radio, use cellphone or chat with research escort) was allowed and no scenic routes were included. As such, participants would be motivated to minimize their experiment (and travel) times.

Design

Regarding the design of the analysis, there are two options; within-subject and between-subject. A within-subject analysis would be ideal for small samples as it compares behaviour of the same individuals. In our case, however, this would not be an option as we had to recruit 11 new participants for part 2. Therefore, we conduct a between-subject analysis, comparing two groups of individuals under different circumstances. In our case, this comparison might not be completely independent as 9 participants were involved in both parts of the experiment. Nonetheless, we assume these participants to be independent between both parts as there was a 2-year gap between conducting part 1 and part 2. Over such a long period, participants will most likely not recall their behaviour in the first part of the experiment. In literature, evidence has been found that choice behaviour as well as the value of travel time savings over a long time interval (at least one year) is unstable (e.g. Gunn, 2001; Schaafsma, Brouwer, Liekens, & De Nocker, 2014). Besides, overall traffic conditions have changed and participants gained additional driving experience. Nonetheless, our assumption remains strong and results should be interpreted bearing this in mind.

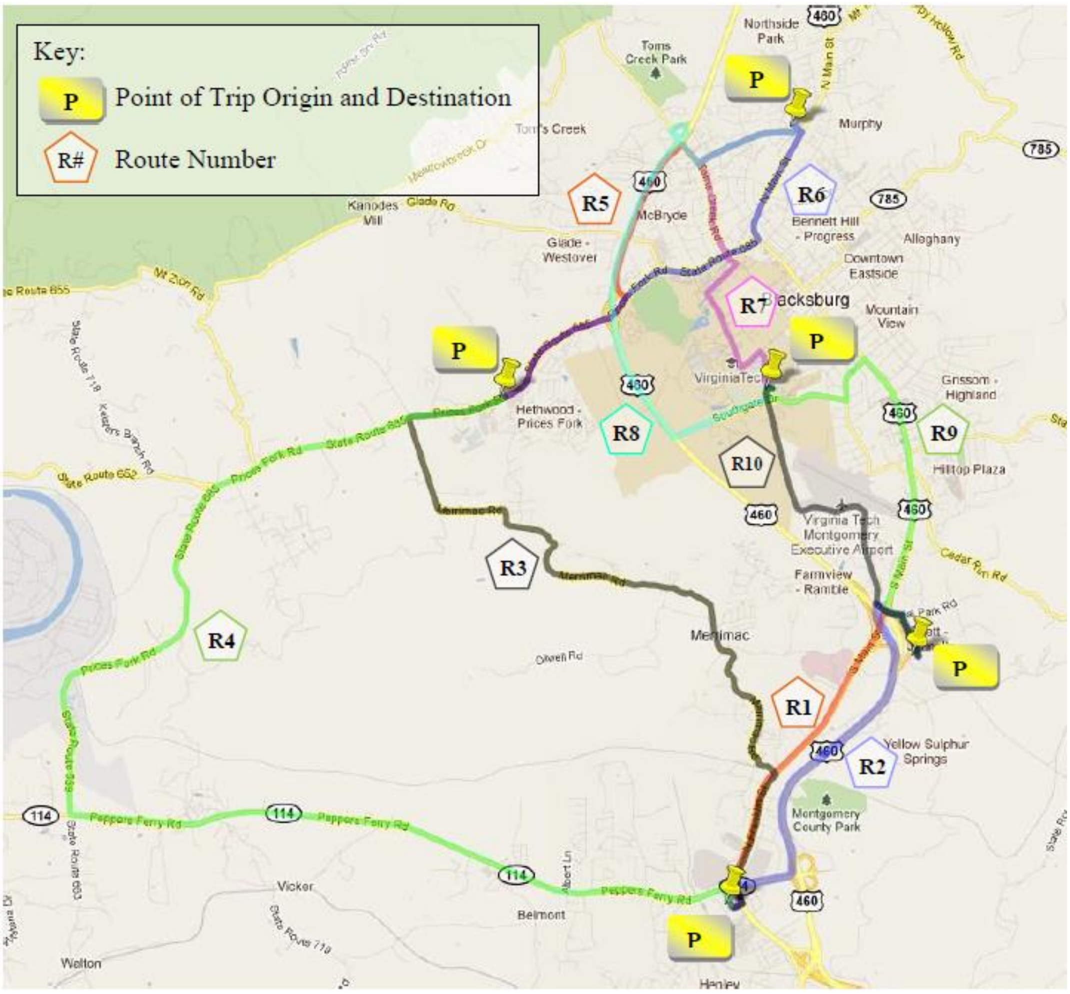


Figure 3. Map of the Blacksburg road network: OD-pairs and routes used in the experiment (Reprinted from Tawfik (2012)).

3.4.2. Route characteristics

Table 1 shows the characteristics of each route alternative based on the data obtained from both experimental parts and a satellite map of the area (Google Maps). The differences in traffic conditions that appear between both parts can be characterized as follows:

- **OD-pair 1:** Both routes have almost equal travel times for both parts although travel times are slightly higher in part 2. The on average shortest route switches between both parts and route 1 becomes less reliable.
- **OD-pair 2:** Travel time for route 4 increases more compared to route 3, while both routes become equally less reliable in part 2. Route 3 continues to be the shortest route alternative.
- **OD-pair 3:** Travel time for route 5 increases more compared to route 6, while still being the shortest route alternative. Both routes become equally less reliable in part 2.
- **OD-pair 4:** Travel times for both routes become almost equal in part 2 as the travel times for route 8 increase. However, route 8 continues to be the shortest route alternative.
- **OD-pair 5:** Travel time for route 10 increases, while it clearly remains the shortest travel time route. Route 9 becomes less reliable, while reliability of route 10 increases.

Table 1. Route characteristics of the route alternatives (adapted from Tawfik (2012)).

OD-pair *j*	**Route *r***	**Avg travel time [min]**		**Avg travel speed [km/h]**		**Travel time variability [min]***		**Dis-tance [km]**	**Number of intersections**		**Left turns**	**Merges and diverges**	**Hori-zontal curves**
		Part 1	Part 2	Part 1	Part 2	Part 1	Part 2		Signa-lized	Unsigna-lized			
1	1	8.5	9.2	36.4	33.1	1.33	1.87	5.1	10	3	3	1	2
	2	8.4	9.3	43.3	38.9	1.68	1.68	6.0	5	4	4	5	3
2	3	15.2	15.8	42.6	42.1	1.36	1.67	11.1	5	2	3	1	30
	4	16.7	18.2	63.2	57.3	1.31	1.69	17.4	2	2	2	2	11
3	5	7.7	8.6	44.5	41.1	0.89	1.00	5.8	5	3	3	2	2
	6	9.3	9.4	37.8	35.1	1.19	1.29	5.5	8	3	2	1	2
4	7	10.2	10.4	29.5	28.9	1.19	1.28	5.0	5	3	4	1	0
	8	9.6	10.3	48.2	45.0	1.02	1.47	7.7	6	2	2	4	1
5	9	10.5	10.5	33.3	33.3	1.21	1.61	5.8	8	4	4	1	1
	10	8.0	8.5	34.0	33.2	1.06	0.98	4.7	3	1	3	2	6

*Standard deviation.

3.4.3. Information accuracy

The provided travel time information is based on historical travel times rather than real-time traffic information, and this was known to participants. This may influence information accuracy, which in its turn could have an effect on travellers' behavioural response. Therefore, we look at the accuracy of the provided travel time information in more detail here. Figure 4 shows the difference between the provided travel time and the travel time experienced by the participant that had received the travel time information. The shown distribution typically resembles a distribution of random variation in travel times (due to for example variation in green times of traffic lights). This natural fluctuation is also present in real-time travel time information. The magnitude of the standard deviation (about 10 - 15% of 10 minutes) is also not very large. This is in line with expectation, as the routes do not show (heavy) congestion during peak hours. Moreover, as participants did not receive feedback on their experienced travel time nor the travel time on the non-chosen alternative, it is likely that they did not perceive (substantial) inaccuracies in travel time information. In general, it is therefore safe to assume that participants viewed the travel information as reliable. However, in a few instances experienced travel times clearly deviated from the expected travel time. Although these instances are very rare (only 0.4% of all observations), they may have had an effect on travellers' route choice. Such outliers happened to 5 different participants, mainly on OD-pair 3 (route 5).

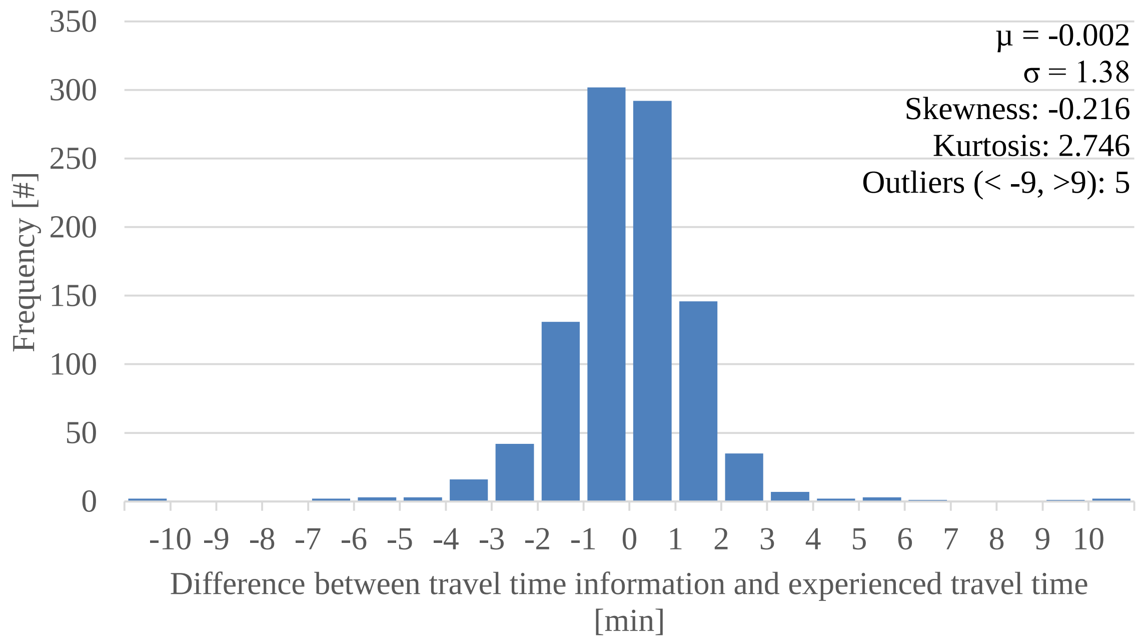


Figure 4. Information accuracy.

3.5. Empirical analyses and results

The question we address in this chapter refers to whether travel information has an influence on the development of dynamic day-to-day route choice behaviour. In order to answer this question, we formulated the following sub-questions:

1) Did travellers use received travel time information and follow the implicit route advice?
2) How does travel time information affect route switching and maximizing behaviour in a real-world context?
3) Can different behavioural patterns or profiles be identified in individuals' day-to-day route choice?
4) Which factors explain an individual's adoption of a certain behavioural profile in their day-to-day route choice and is the provision of travel time information one of them?
5) Does travel time information influence how individual's shift between behavioural profiles across OD-pairs.

In this section, we will address each sub-question. Note that in each analysis we only focus on the role of travel time information on route choice behaviour in general; we do not make a distinction between the different formats that were used in the experiment. As in some instances route alternatives have very similar travel times, the received travel time information might have indicated the longer route to be the shortest and vice versa. We therefore distinguish in our analyses between OD-pairs for which the average travel time difference between route alternatives is similar or smaller than the natural travel time fluctuation (i.e. OD-pairs 1, 3 and 4) and OD-pairs for which the average travel time difference between route alternatives was larger than the natural travel time fluctuation (i.e. OD-pairs 2 and 5) as identified in Section 3.4.3. On the former OD-pairs, participants are most likely unable to distinguish between the shortest and longest route, potentially influencing their response to information.

3.5.1. Did travellers use the received travel time information and follow the implicit route advice?

Method

In response to travel time information travellers might or might not choose the route that was indicated as being the shortest by the information service; that is, the information service implicitly advises to switch routes or stay in order to minimize travel time and the traveller actually 'followed' the advice by either switching or staying. We refer to this as information compliance (even though only descriptive information was provided) and we distinguish between weak and strong compliance; weak compliance refers to the situation where the route chosen at run t-1 was advised and the traveller stuck to this route, whereas strong compliance refers to the situation where the non-chosen route at run t-1 was advised and the traveller switched routes (in line with definitions by Chorus, Arentze, & Timmermans, 2009). Note that for those runs where the information service provided ranges of travel times, the means of these ranges were used to determine which route would be 'advised' in terms of being shortest according to the information.

Results

Table 2 presents the frequencies of choice situations in which based on the travel time information travellers should switch (or stay) compared to their choice at run t-1 in order to choose the shortest travel time alternative and travellers actually switched (or stayed). We observe that overall information compliance occurs in 72% of all choice situations. This suggests that a majority of travellers try to minimize their travel time with help of received travel time information. Nonetheless, only in 43% of these cases participants indicated that travel time minimization was one of the reasons behind their route choice. Moreover, only in 41% of the choice situations in which the provided information suggested a route switch, an actual switch was made (indicating strong compliance); i.e. only about half of all switches (116/222=0.52) were made in compliance with received information. On the other hand, when the information suggested staying at a certain route alternative, in 87% of the choice situations this was actually done (indicating weak compliance). These findings give the impression that habitual behaviour might be present as well. Regarding OD-pairs consisting of similar or distinct travel time alternatives, we observe larger overall and weak compliance rates at OD-pairs with distinct travel time alternatives, while strong compliance rates are comparable. Moreover, the number of cases in which a switch is advised is considerably lower at distinct travel time OD-pairs than similar travel time OD-pairs, indicating that on the former OD-pairs travellers already choose the shortest route alternative more often.

Table 2. Information compliance.

	Traveller:		
Information suggests:	Stayed [#]	Switched [#]	Total [#]
Staying	506	74	580
Switching	166	116	282
Indifferent*	24	9	33
No information**	82	23	105
Total	778	222	1000
	Weak compliance rate	Strong compliance rate	Overall compliance rate
Overall	87%	41%	72%
OD’s with small ΔTT	81%	42%	65%
OD’s with large ΔTT	94%	39%	82%

*i.e. equal travel time predicted for both route alternatives

** i.e. at experimental run 6, no travel time information was provided

3.5.2. How does travel time information affect route switching and maximizing behaviour in a real-world context?

Method

Route switching and maximizing behaviour are aspects of route choice behaviour that might be altered in response to travel time information. A route switch s_{njt} occurs when individual n used another route r for the j-th OD-pair at run t compared to run t-1, while a maximizing choice was made when the chosen route r_{ji} had, on average, the shortest travel time during the specific peak hour at which the choice was made. Note that the travel times on both routes of each OD-pair were not known at the same time since only the experienced travel time on the chosen route alternative was recorded. Therefore, it is uncertain whether the (on average) shortest route alternative was actually the shortest on that specific peak hour on that day. In the analyses, the percentage of switching choices is referred to as switching rate, while the percentage of maximizing choices is referred to as maximization rate. Since the sample size in our experiment is relatively small, we apply non-parametric tests (e.g. Chi-square test and Mann-Whitney test) in order to identify significant results.

Results route switching behaviour

We find that travellers switched routes in 20% of the cases when no information was provided and in 22% of the cases after they received travel time information (this difference is not significant: $\chi^2(1)=0.580$, p=0.446). Figure 5 shows that the number of route switches decreased as the experiments proceeded. This is in line with the effect of exploration and learning as observed by e.g. Senk (2010). A significant difference in switching behaviour with and without travel time information is observed for OD-pairs 2 and 5 which have larger travel time differences (Mann-Whitney test: U=26, z=-2.276, p=0.021); participants switched less in response to travel information on these OD-pairs. Note that switching rates in response to travel time information on OD-pairs with small travel time differences are similar to switching rates obtained in absence of travel time information. Therefore, it seems that travel time information only triggers behavioural response on OD-pairs with travel time differences larger than natural fluctuations, which is an intuitive finding.

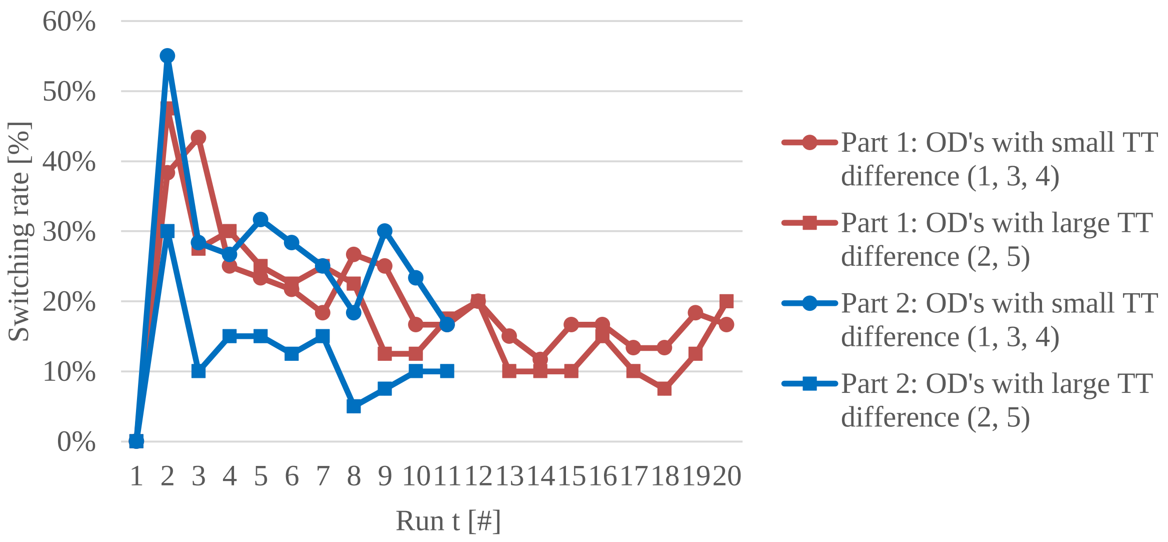


Figure 5. Route switching rate [per OD grouped by travel time difference between alternatives].

Results maximizing behaviour

Often, it is assumed that travellers will choose the route with the shortest travel time. In our experiment, this was true in only 66% of the cases without provision of travel time information. Providing travel time information increased the percentage of choices for the on average shortest route (i.e. maximization rate) to 70%, which can be considered a modest increase although significant ($\chi^2(1)=6.092$, $p=0.014$). This suggests that participants were able to identify (and/or were willing to choose) the shortest alternative more easily in response to travel time information.

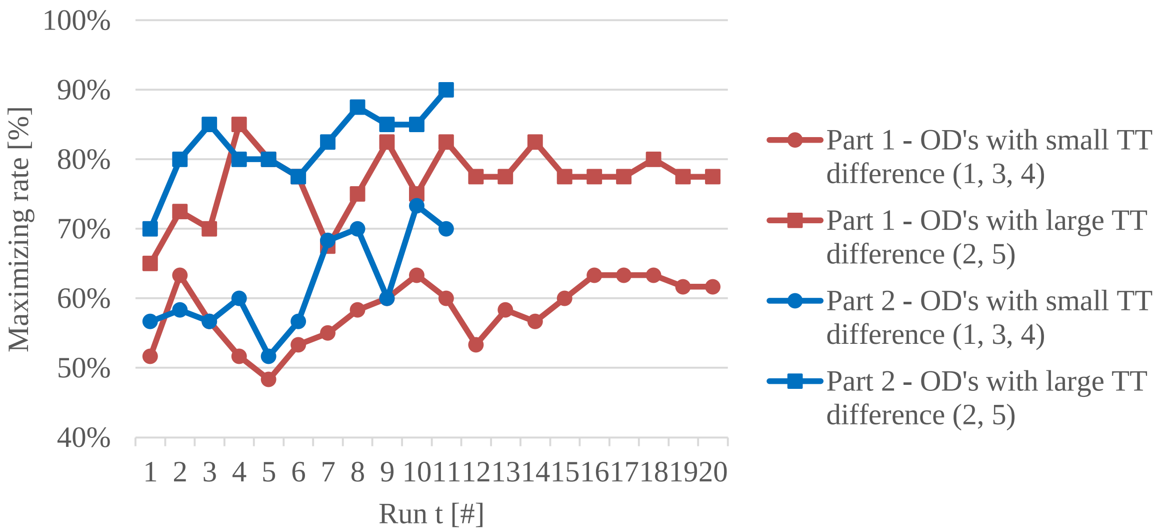


Figure 6. Maximization rate [per OD grouped by travel time difference between alternatives].

Figure 6 shows, for both experimental parts, the percentage of cases at run t in which the on average shortest route alternative was chosen on OD-pairs with similar travel time alternatives and OD-pairs with distinct travel time alternatives. We observe significantly higher maximization rates for OD-pairs with larger travel time differences – both in response to travel time information and when no travel time information is provided – compared to OD-pairs consisting of similar travel time alternatives (Mann-Whitney test: U=13, z=-5.387, p=0.000). This could be explained by the fact that on these OD-pairs the shortest route alternative can be relatively easily identified, even without travel time information. Nonetheless, the maximization rates for OD-pairs consisting of distinct travel time alternatives are significantly higher in response to travel time information than when no information is provided (Mann-Whitney test: U=27, z=-2.217, p=0.028). This indicates that travel information helps travellers in making maximizing choices on these OD-pairs.

A slightly increasing and converging trend is visible for experiment part 1 (over 20 runs, for both OD-categories), which is volatile in the beginning but from run 14 on becomes more regular and consistent. This is in line with earlier findings on switching behaviour in that participants were observed to be experimenting and exploring at first in order to find the best route alternative, while after some experience and learning they were better able to identify those alternatives. In response to travel information (i.e. part 2), similar behaviour was observed. Note that although convergence seems to occur, 20 trials might not be sufficient to reach complete convergence.

3.5.3. Can different behavioural patterns or profiles be identified in individuals' day-to-day route choice?

Method

Day-to-day route choice behaviour is examined by revealing individual route choice patterns $(c_{nj1}, \ldots, c_{nj11})$, leading to the identification of behavioural profiles. The concept of individual day-to-day route choice patterns was proposed by Tawfik et al. (2010). They introduced four different choice patterns or so-called driver types, which were characterized by Vreeswijk et al. (2015) as Stayers, Tryers, Explorers and Switchers. Our research explores if similar patterns can be identified in the context of real-world experiments and if certain patterns occurred more often in response to travel time information. To that end, k-means-clustering was applied using the SPSS software package.

Clustering was applied on 200 patterns (5 patterns for each participant n and for both experimental parts) and based on the following criteria: number of route switches, number of times the preferred route (i.e. most chosen alternative) was chosen and the average switching moment (i.e. average run at which route switches are made ('centre of gravity')), each by participant n on OD-pair j during the first 11 experimental runs t. Note that only the first 11 runs were used as this enables a complete comparison between the behavioural patterns of both experiments. First, automatic k-means-clustering (based on Euclidean distance) was applied using various pre-set number of clusters (i.e. 4, 5 and 6 clusters). Next, refinements were made by hand using behavioural interpretation. This exploratory clustering method resulted in six clusters in which each cluster consisted of a substantial number of observed patterns, while distinctive patterns were separated into different clusters. The results of clustering using 4, 5 and 6 pre-set clusters and a detailed description of the refinements made, can be found in Appendix A.

Many measures to validate the resulting clusters exist. We provided the scores obtained through the most commonly used measures. First, we assessed the correlation between the proximity matrix (i.e. based on Euclidian distance between observations) and the incidence matrix (i.e. whether observations belong to the same cluster). Strong correlations indicate that observations within the same cluster are close to each other. Subsequently, we calculated the between-cluster sum-of-squares to indicate how distinct, or well-separated, each cluster is from the other clusters, and the within-cluster sum-of-squares to indicate cluster cohesion or compactness. The between-cluster sum-of-squares should be as large as possible, while the within-cluster sum-of-squares should be as small as possible in order to indicate well-separated and compact clusters. Note that the sum of both is constant; if one sum-of-squares measure (i.e. between or within) increases the other sum-of-squares measure decreases. Finally, we determined the Silhouette coefficient (Rousseeuw, 1987), which builds on both cohesion and separation. The Silhouette coefficient is calculated for each observation and then averaged for each cluster as well as the whole dataset using the following formula:

$$s_l = \frac{b_l - a_l}{max\{a_l, b_l\}} \qquad (1)$$

where a_l is the average distance of observation l to all other observations in its cluster (i.e. cohesion), b_l is the smallest of the average distances to each of the other clusters observation l is not part of (i.e. the distance to the nearest cluster observation l does not belong to, that is, separation). Observations with an s_l close to 1 are well-clustered (i.e. average distance to assigned cluster is much smaller than to nearest other cluster). When s_l is about zero this is considered an intermediate case (i.e. average distance to assigned cluster and nearest other cluster is approximately equal). The observation is probably misclassified if s_l is close to -1 (i.e. average distance to assigned cluster is much larger than to nearest other cluster).

Results

The six clusters resulting from the clustering analysis are summarized in Table 3; it presents the following information: cluster size (*N*), a cluster description, the average cluster score on the clustering criteria, an illustrative example, and the frequencies of occurrence disaggregated at the OD-level for both parts of the experiment. Overall, the majority of participants had a clear preference for one of the route alternatives and almost never switched; i.e. switch-averse profiles 1, 2 and 3 occur most often for both experiments. On average, slight differences between the choice patterns revealed in experiment part 1 and part 2 were observed. However, these differences are not significant (neither in total nor at the OD-pair level) at a 5% significance level.

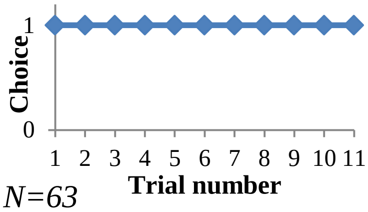
Note that most participants behaved differently across OD-pairs j, e.g. participant n might behave in accordance with a Staying profile on OD-pair 1, but adapting to an Exploring profile on OD-pair 5. That is, 70% of participants (equal for both parts of the experiment) revealed 3 or more different profiles during the experiment. Therefore, in this research the clusters are referred to as profiles and are not directly related to the individual or OD-pair. Moreover, one should realize that different behavioural constructs, such as travel time minimization and habit, could result in the same behavioural choice profile. Furthermore, note that obtained profiles only apply for route choice patterns over a time span of 11 days. After all, some profiles might not manifest strongly without a longer time span, while others that were observed in this study might in that case not manifest at all. Finally, our Staying, Trying, and Switching profiles are consistent with three of the four driver types proposed by Tawfik et al. (2010).

Cluster validation

Now we will shortly indicate the internal validity of the obtained clusters. The correlation between the proximity (or distance) matrix and the incidence matrix is -0.6386. This suggests a moderate to strong correlation, indicating that observations within the same cluster are closer to each other compared to observations from different clusters. Moreover, we find a between-cluster sum-of-squares of 3067 and a within-cluster sum-of-squares of 307. Given the fact that the sum of both is constant (3067+307=3374), and the fact that the between-cluster sum-of-squares should be as high as possible while the within-cluster sum-of-squares should be as low as possible, we consider this result satisfactory. The obtained average silhouette coefficient is 0.56, while the averages for clusters 1, 2, 3, 4, 5 and 6 are 1, 0.45, 0.36, 0.27, 0.28 and 0.35 respectively. These coefficients indicate that observations are intermediate to well-clustered. Only three observations obtained a negative coefficient – although still close to zero (i.e. -0.001 to -0.06). Moreover, the coefficients per cluster indicate that clusters 1 and 2 are the strongest and most pronounced, while clusters 4 and 5 are weakest.

Table 3. Route choice evolution profiles.

#switch=0, #preferred choice =11, switching moment=0

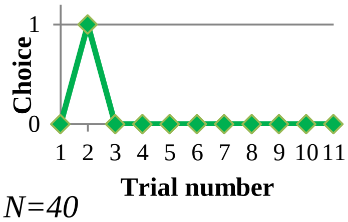


N=63

	No info	Info
OD1:	30%	10%
OD2:	10%	25%
OD3:	15%	25%
OD4:	45%	45%
OD5:	40%	70%
Total:	28%	35%

1: STAYING: the traveller arbitrarily picks a route and continues making the same choice over and over again.

#switch=1.58, #preferred choice=9.68, switching moment=2.66

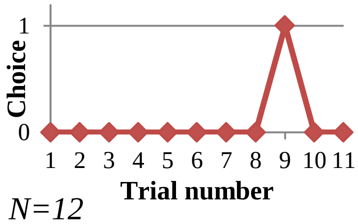


N=40

	No info	Info
OD1:	20%	20%
OD2:	30%	30%
OD3:	40%	15%
OD4:	15%	0%
OD5:	10%	20%
Total:	23%	17%

2: TRYING: the traveller tries both routes once and continues using his or her preferred route.

#switch=1.83, #preferred choice=9.75, switching moment=8.46

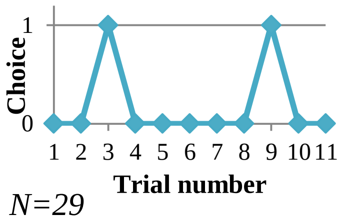


N=12

	No info	Info
OD1:	5%	0%
OD2:	15%	15%
OD3:	10%	0%
OD4:	0%	5%
OD5:	10%	0%
Total:	8%	4%

3: OCCASIONALLY CURIOUS: the traveller arbitrarily picks a route and continues making the same choice, but after some time he or she becomes curious about the other route alternative and tries it once or twice.

#switch=3.72, #preferred choice=8.17, switching moment=6.51

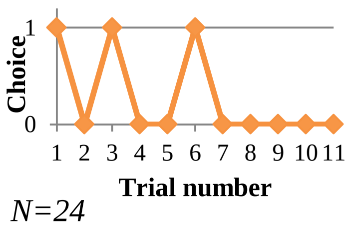


N=29

	No info	Info
OD1:	5%	25%
OD2:	15%	15%
OD3:	5%	20%
OD4:	15%	20%
OD5:	20%	5%
Total:	12%	17%

4: CONFIRMATION SEEKING: the traveller has a clear preference, but once in a while he or she tries the other route to confirm his or her choice.

#switch=3.33, #preferred choice=7.88, switching moment=4.34

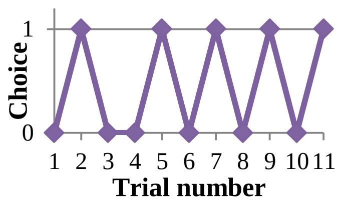


N=24

	No info	Info
OD1:	5%	15%
OD2:	20%	10%
OD3:	10%	25%
OD4:	5%	20%
OD5:	10%	0%
Total:	10%	14%

5: EXPLORING: The traveller first explores both route alternatives before he decides on his preferred route alternative.

#switch=6.22, #preferred choice=6.56, switching moment=6.44



N=32

	No info	Info
OD1:	35%	30%
OD2:	10%	5%
OD3:	20%	15%
OD4:	20%	10%
OD5:	10%	5%
Total:	19%	13%

6: SWITCHING: the traveller has no clear preference and switches between both routes with the same frequency.

3.5.4. Which factors explain an individual's adoption of a certain behavioural profile in their day-to-day route choice and is the provision of travel time information one of them?

Method

To answer this question, we use discrete choice modelling. First, a preliminary multinomial logit model was estimated to identify potential explanatory variables; one of them being the provision of travel time information. The independent variables used are shown in Table 4. Subsequently, a mixed logit model was estimated in order to capture panel effects. After all, participants revealed choice evolution profiles for five different OD-pairs and some of them participated in both experiments. Only the significant variables from the multinomial logit model were included. The mixed logit model was estimated using the Biogeme software package (Bierlaire, 2003) with the 'donlp2'-algorithm (Spellucci, 1993) using 1000 Halton draws. Experiments with lower number of draws indicated that 1000 draws were sufficient to obtain stable parameter estimates. Panel effects were captured by examining three distinct approaches to represent intrinsic individual-specific preferences for revealing a certain route choice evolution profile. The first approach adds a single preference component ('constant') for switching behaviour to the model of profiles 2 to 6, representing a preference for making one or more switches as opposed to making no switch at all (i.e. profile 1). The second approach is similar except that different preference components are added to each of the profile models (i.e. five constants are used instead of one single component), representing a preference for each specific profile except for profile 1 which serves as a normalizing reference alternative. Finally, the third approach adds a single preference component to only the most switch-sensitive profiles (i.e. profiles 4, 5 and 6), representing a preference for switch-prone behaviour as opposed to switch-averse behaviour. The utility functions for each approach are as follows:

Approach 1:

$$U_{np} = ASC_p + \beta_{pm} x_m + v_{Switching,n} + \varepsilon_{np} \qquad v_{Switching,n} = 0 \;\; for\; p = 1 \tag{2}$$

Approach 2:

$$U_{np} = ASC_p + \beta_{pm} x_m + v_{np} + \varepsilon_{np} \qquad v_{np} = 0 \;\; for\; p = 1 \tag{3}$$

Approach 3:

$$U_{np} = ASC_p + \beta_{pm} x_m + v_{switch\_prone,n} + \varepsilon_{np} \qquad v_{switch\_prone,n} = 0 \; for\; p = 1, 2, 3 \tag{4}$$

In which:

U_{np} denotes the random utility associated with behavioural profile p by individual n. β_{pm} denotes the parameter to be estimated that is associated with the m^{th} attribute x_m for each profile p. ASC_p denotes an intrinsic willingness to behave according to profile p. Finally, v_n and ε_{np} are random errors. The former is Normally distributed with a mean of zero and an estimated standard deviation. This error varies across individuals, reflecting unobserved individual preferences. The latter error is distributed i.i.d. Extreme Value type 1 across both individuals and choice tasks, reflecting additional variation in unobserved utility ('white noise').

Table 4. Independent variables used in the logistic regression analysis.

Independent variable	Description	Variable values within dataset
Individual characteristics		
Age_n	Age of participant n	0=18-35 years, 1=55-69 years
$Gender_n$	Gender of participant n	0=male, 1=female
$Education_n$	Education level of participant n	0=No graduate, 1=Bachelor graduate or higher
$Driven\_Miles_n$	Annual vehicle miles travelled by participant n (thousands)	1.5 to 35
N_n	Level of neuroticism of participant n obtained from NEO-FFI personality inventory	5 to 36
E_n	Level of extraversion of participant n obtained from NEO-FFI personality inventory	19 to 43
O_n	Level of openness to experience of participant n obtained from NEO-FFI personality inventory	19 to 41
A_n	Level of agreeableness of participant n obtained from NEO-FFI personality inventory	22 to 44
C_n	Level of conscientiousness of participant n obtained from NEO-FFI personality inventory	26 to 47
Characteristics of choice set – OD-level		
ΔTT_j	Absolute difference in mean travel time between the two alternatives of OD-pair *j*	0.1 to 2.5
$\Delta TT\_variability_j$	Absolute difference in travel time variability between the two alternatives of OD-pair *j*	0.02 to 0.63
$\Delta Distance_j$	Absolute difference in distance between the two alternatives of OD-pair *j*	0.3 to 6.3
$\Delta Speed_j$	Absolute difference in mean travel speed between the two alternatives of OD-pair *j*	0.1 to 20.6
*$\Delta Intersection_j$	Absolute difference in number of intersections between the two alternatives of OD-pair *j*	0 to 8
*$\Delta Left\_turns_j$	Absolute difference in number of left turns between the two alternatives of OD-pair *j*	1 to 2
$\Delta Merges\_Diverges_j$	Absolute difference in number of intersections between the two alternatives of OD-pair *j*	1 to 4
$\Delta Curves_j$	Absolute difference in number of intersections between the two alternatives of OD-pair *j*	0 to 19
Travel time information		
$Info_j$	Whether or not travel time information is provided at choice set *j*	0=no travel time information, 1=travel time information

Results

Table 5 shows the model results from the mixed logit model estimation in order to find explanatory variables for revealed behavioural profiles. At this point, one should realize that the 'choice' to reveal a certain behavioural profile is not equivalent to the choice of a route; profiles encompass the pattern of route switches independent of which specific route was chosen.

Panel effects were captured by examining three distinct approaches to represent intrinsic individual-specific preferences in revealing a certain behavioural profile. The model that captured intrinsic individual-specific preferences for switching by means of a single constant for the most switch-sensitive profiles resulted in the best model fit (likelihood ratio test with regular multinomial logit model: ($\chi^2(1)=25.83$, $p=0.000$). Both individual and situation-specific characteristics are found to be significant for at least one of the profiles. In general, the model suggests that when the difference between the route alternatives in travel time variability, distance and number of left turns becomes larger, a Staying strategy (i.e. pattern 1, the reference category) is more likely to be adopted. This is as expected since greater differences between route alternatives allow for easier identification of the preferred route alternative. However, a somewhat counterintuitive finding is that in case of a higher difference in speed, travellers seem to be willing to switch more often. Furthermore, it seems that travellers who are extravert or open to experience, were, in general, more likely to be switch-prone than their counterparts. This might be explained by the fact that measured dimensions on extraversion and openness to experience encompass 'excitement-seeking', 'activity' and 'actions', which can reasonably be associated with regularly using different route alternatives. Conversely, travellers who score highly on neuroticism or agreeableness seem to be more likely to use a Staying strategy. This might be explained by measured dimensions as 'vulnerability to stress', 'straightforwardness' and 'being easy to satisfy', which seem to be associated with less switching. Note that these findings contradict the findings reported by Tawfik (2012) who found that openness to experience led to more Staying behaviour, while neuroticism led to more Switching behaviour. However, his finding was based on the number of switches made during the first five experimental runs only. Senk (2010) found that travellers tend to be exploring especially on these first five runs, which manifests itself through switching.

Additionally, some other remarks can be made on the model results. First, the variable of educational level became insignificant when accounting for panel effects. Furthermore, one should keep in mind that the difference in number of left turns only changed for OD-pair 4. Therefore, it might be the case that this variable is actually representing other unobserved factors specific to that OD-pair. Moreover, it seems that the effects of variables $\Delta Distance_j$ and $\Delta Speed_j$ become more pronounced when the profile becomes more switch-prone. For the other variables, this trend is less visible. In general, variables tend to be significant for switch-prone profiles more often than for switch-averse profiles. Finally, note that the model does not include variables on travel time information and differences in travel time. The difference in travel time might, however, be captured to some extent indirectly by other variables such as $\Delta Distance_j$. The finding that travel time information seems to be insignificant in explaining revealed profiles is in line with aforementioned findings of the clustering results.

Table 5. Explanatory model for behavioural profiles.

Mixed logit (panel)	Switch-averse				Switch-prone					
	Profile 2: Tryers		**Profile 3: Curious**		**Profile 4: Confirmers**		**Profile 5: Explorers**		**Profile 6: Switchers**	
	Beta	p-value	Beta	p-value	Beta	p-value	Beta	p-value	Beta	p-value
Constant	2.74	0.28	2.87	0.53	0.97	0.82	9.16	0.04	2.98	0.58
ΔTT_ Variability$_j$	-1.03	0.50	-7.58	0.00	-10.2	0.01	-12.3	0.00	-9.28	0.01
A_n	-0.05	0.40	-0.18	0.09	-0.23	0.03	-0.30	0.00	-0.07	0.61
ΔDistance$_j$	-0.45	0.05	-0.48	0.09	-0.94	0.03	-1.38	0.00	-1.53	0.00
E_n	0.06	0.26	0.22	0.00	0.23	0.01	0.12	0.25	0.17	0.04
Education$_n$	-0.21	0.69	-0.53	0.53	-0.89	0.20	-0.74	0.39	-1.35	0.18
N_n	0.01	0.88	-0.13	0.10	-0.12	0.09	-0.20	0.00	-0.04	0.58
O_n	0.02	0.67	0.09	0.36	0.25	0.01	0.24	0.01	0.05	0.60
ΔSpeed$_j$	0.21	0.01	0.19	0.08	0.23	0.09	0.38	0.00	0.42	0.00
ΔLeft_turns$_j$	-3.62	0.00	-3.45	0.03	-2.70	0.02	-3.87	0.00	-4.13	0.00
Sigma Switching Preference	-	-	-	-	1.84	0.00	1.84	0.00	1.84	0.00

Mixed logit (panel)	
Sample size	190
No. of individuals	29
No. of Halton draws	1000
Initial log-likelihood	-326.739
Final log-likelihood	-255.402
Likelihood ratio test	170.065
ρ^2	0.250
Adjusted ρ^2	0.100

Insignificant values using a 5% significance level are displayed in grey.

The mixed logit model indicates how different behaviour profiles become more likely to be adopted if the difference between the route alternatives becomes larger or smaller with respect to certain characteristics. However, if a certain characteristic makes it more likely that a traveller adopts a switch-averse profile (i.e. profiles 1, 2 and 3) and repeatedly chooses the same route alternatives on a certain OD-pair, the model does not indicate *which* route alternative would be preferred. A closer look at the data tells us that those participants who adopted a switch-averse profile, had an overall preference for route alternatives with the least left turns (58%), the least variability in travel time (68%), the shortest distance (54%) and the highest speeds (72%). These findings are in line with expectations.

3.5.5. Does travel time information influence how individuals shift between behavioural patterns across OD-pairs.

Method

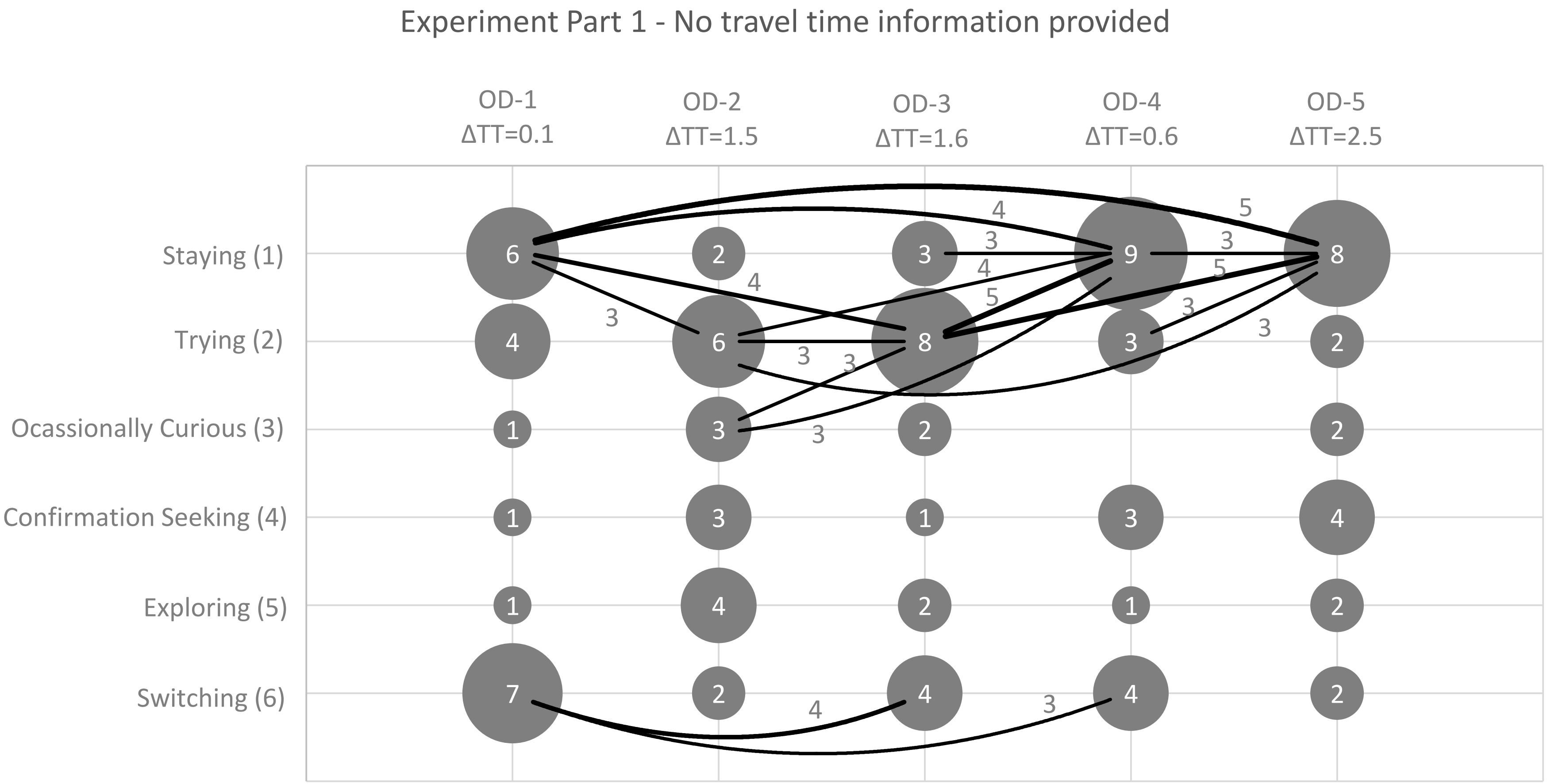
A traveller could reveal a certain behavioural profile at one OD-pair and might adopt another profile at the next OD-pair. Providing travel time information could reinforce collective behaviour. Therefore, we visualize (collective) shifts between each profile over the different OD-pairs for both parts of the experiment and compare them visually. Shifts made by less than three participants were excluded from the figures for reasons of readability; hence, only collective shifts were mapped.

Results

Figure 7 and Figure 8 provide an overview of the number of individuals that revealed a certain profile on a certain OD-pair and visualize collective shifts, each for one part of the experiment. For example; in experiment part 1 there are six participants who reveal behaviour consistent with profile 1 on OD-pair 1, whereas on OD-pair 2, three of these participants shift to profile 2, two participants shift to profiles 3 and 4 respectively, and one participant keeps revealing profile 1. However, shifts made by less than three participants are not shown in the figure for reasons of readability. Furthermore, when those six participants travel on OD-pair 3, four of them shift to profile 2, whereas on OD-pairs 4 and 5, four and five of them respectively keep revealing behaviour consistent with profile 1.

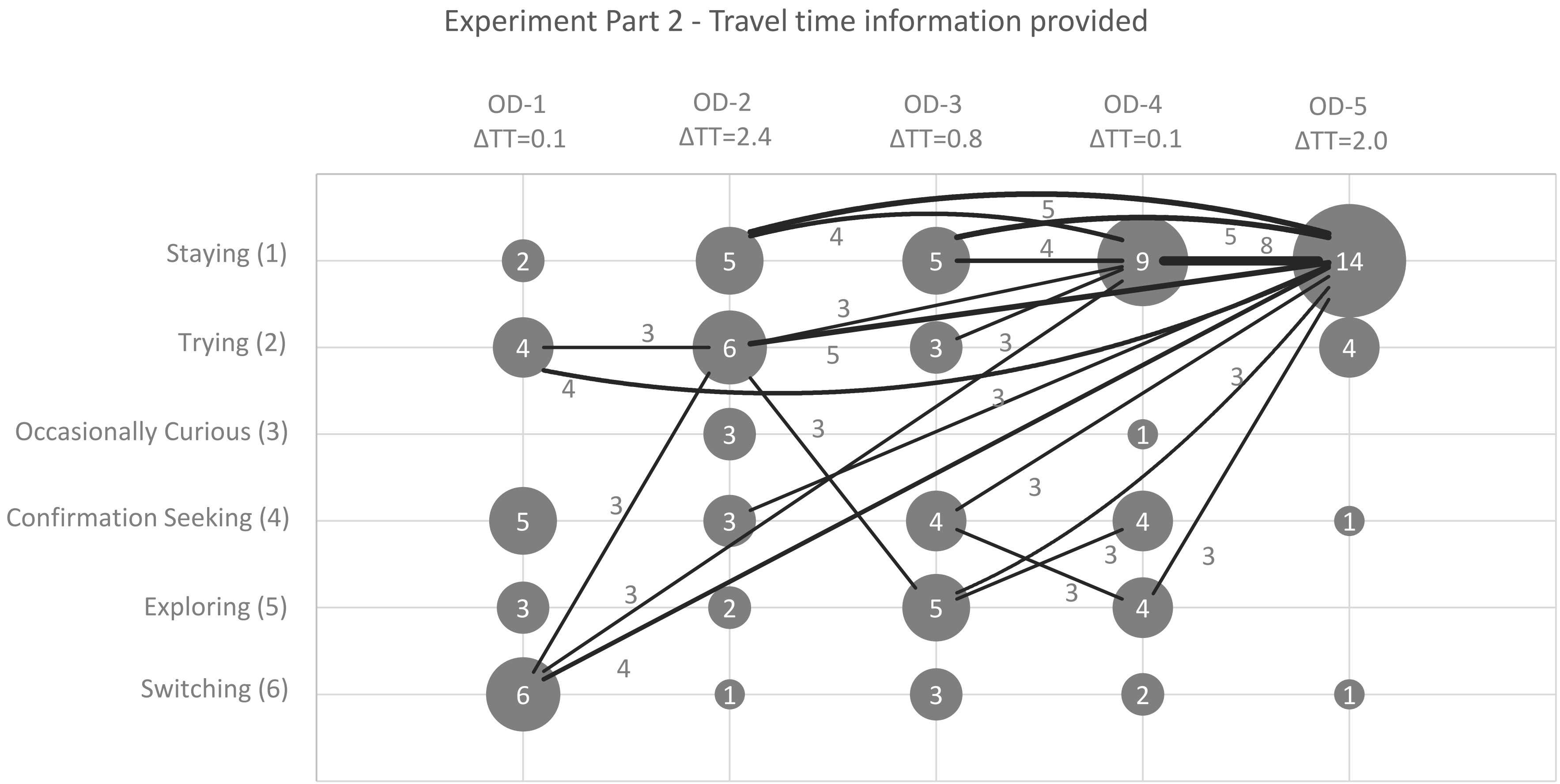
For both parts of the experiment, the revealed profiles vary substantially from one OD-pair to another. It seems that on OD-pairs with relatively similar route alternatives (OD-pairs 1 and 4), participants either stick to their preferred route alternative (i.e. profile 1, 2 and 3) or regularly switch between both alternatives (i.e. profile 4, 5, 6) irrespective of the provision of travel time information. However, for OD-pairs with more distinct route alternatives (OD-pairs 2 and 5), participants collectively shift towards switch-averse profiles when travel time information is provided. That is, in experiment part 2 collective shifts occur within, as well as between, both switch-averse and switch-prone profiles, while in experiment part 1 no collective shifts occur from switch-prone profiles to switch-averse profiles or vice versa. Moreover, in experiment part 1, most collective shifts seem to occur among profiles 1 and 2, indicating that many participants have a clear route preference on most OD-pairs, while only a few collective shifts occur among switch-prone profiles.

Overall, travel time information appears to trigger collective shifts between revealed profiles from one OD-pair to another. However, the characteristics of each OD-pair slightly differ between both experimental parts. This might have affected the shift patterns as well.



Note: each circle shows the number of participants that reveal a certain profile on a certain OD-pair. The lines indicate shifts from one profile to another over the different OD-pairs. The weight of each line indicates the number of individuals that shift in that direction.

Figure 7. Overview of observed choice evolution profiles over all OD-pairs for experiment part 1: no travel time information provided.



Note: each circle shows the number of participants that reveal a certain profile on a certain OD-pair. The lines indicate shifts from one profile to another over the different OD-pairs. The weight of each line indicates the number of individuals that shift in that direction.

Figure 8. Overview of observed choice evolution profiles over all OD-pairs for experiment part 2: travel time information provided.

3.6. Conclusions and discussion

This chapter has explored the effect of travel time information on day-to-day route choices using a unique real-world experiment. The main contribution lies in examining – using a variety of modelling and analysis techniques – day-to-day route choice behaviour in response to travel time information when individuals actually experience the consequences of their choices in reality.

We found that travellers follow the ‘advice’ from received travel time information in 72% of the cases. This suggests that a majority of travellers tries to minimize its travel time with help of received travel time information. Information compliance is highest when travellers could stick to their previously chosen route; nonetheless, habit might be a key factor in this. Moreover, higher compliance rates were observed at OD-pairs with distinct travel time alternatives. Switching propensity decreases with time and experience when no travel time information is provided. This suggests the existence of an exploration phase and a learning effect. Providing travel time information decreases this switching propensity significantly on OD-pairs consisting of alternatives with distinct travel times. Moreover, travellers choose the route with the shortest travel time in 66% of the cases. Travel time information and travellers’ compliance with this information increase this percentage to 70%. Especially on OD-pairs with distinct travel time alternatives, maximization rates increase in response to travel time information. Based on these findings, it seems that travel time information is most advantageous when travel times on route alternatives are distinct. However, its benefit might decrease at travel time differences larger than the 2.5 minutes that occurred in our experiment. After all, large travel time differences can be more easily identified without travel time information.

Moreover, six behavioural profiles are identified varying from switch-averse to switch-prone behaviour. Overall, we do not observe an effect of the availability of travel time information on revealed profiles. Findings from regression analysis confirm this. Regression analysis indicates that the adoption of a certain behavioural profile results from a combination of situational characteristics as well as personality traits and individual preferences – the provision of travel time information does not contribute to explaining observed profiles. However, we do find that the provision of travel time information influences collective profile-shifting behaviour. Without travel time information, collective shifts mainly take place across switch-averse profiles; no collective shifts are observed from switch-prone profiles to switch-averse profiles or vice versa. On the contrary, in response to travel information collective shifts do occur within, as well as between, both switch-averse and switch-prone profiles.

Our field study obtained valuable insights into the effect of travel time information on real-world day-to-day route choice behaviour. Laboratory experiments show that, in general, providing travel time information decreases initial exploration (i.e. switching propensity) and increases maximization rates (e.g. Ben-Elia & Shiftan, 2010) [note that some situations have been identified in which this is not the case (Avineri & Prashker, 2006; Ben-Elia, Erev, & Shiftan, 2008)]. Our findings show that these results still hold when (unobserved) real-world factors, that are present in a field study as opposed to laboratory experiments, influence route choice behaviour. In addition, Tawfik et al. (2010) concluded that drivers’ route choice evolution is not identical and introduced four driver types based on observations in a simulator study. The behavioural profiles found in our field study are consistent with three of the four driver types proposed by Tawfik et al. (2010); i.e. Staying, Trying and Switching. It seems that their Explorers capture not only our Explorers, but also our Occasionally Curious and Confirmation Seekers. This difference might occur due to a difference in clustering criteria (although it is not clear what criteria were used exactly in the mentioned study). Moreover, we find higher frequencies for switch-averse profiles and lower frequencies for switch-prone profiles. The reason for this might be related to participants' familiarity with the road network – an aspect that is not present in the mentioned simulator study. Furthermore, an increasing number of publications conclude that personality traits, demographics, and attitudes might play an important role in route choice behaviour and route switching (e.g. Albert, Toledo, & Ben-Zion, 2011; Tawfik, 2012). Explanatory variables found to be significant in our mixed logit model, support this belief. However, the exact role needs to be further explored. Finally, future research could apply new ICT technologies, such as smartphone applications. These technologies enable the use of larger samples, studied in daily-life circumstances were actual trips are being made without experimenter instructions, and real-time travel information could be provided.

Overall, our results provide a deeper understanding of and insights into the effect of travel time information on real-world day-to-day route choice behaviour, and as such contribute to the design of effective information-based travel demand management measures. For example, traffic authorities might aim to achieve system-optimal network conditions. If personal travel time gain could not motivate a traveller to switch, collective travel time gains – implying a personal travel time sacrifice by part of the travellers – would almost certainly not induce a switch. Information messages and advice aiming at a system optimum should, therefore, be tailor-made to the individuals' route choice behaviour.

3.7. Acknowledgement

This work is part of the research programme TRAIL Graduate School, which is financed by the Netherlands Organisation for Scientific Research (NWO). The authors are grateful to the Virginia Tech Transportation Institute for collecting and sharing the datasets.

4. Route choice behaviour in response to social routing information

This chapter is based on: Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. (2018). Travelers' compliance with social routing advice – evidence from SP and RP experiments. *Submitted for publication in Transportation (2nd review round).*

4.1. Abstract

This study examines to what extent travel information can be used to direct travellers to system-optimal routes that may be sub-optimal for them personally, but contribute to network efficiency. This is done by empirically examining determinants of travellers' compliance with social routing advice. To that end, we conducted both a stated choice experiment and a revealed choice experiment (which also collected stated intentions and motivations for revealed behaviour). Results from the stated choice experiment indicate a significant difference in compliance behaviour across different information frames, societal goals, sizes of travel time sacrifices and personality. These findings are less evident from results based on analysis of revealed choices; i.e. the main motivation for revealed compliance seems to be an intrinsic motivation to contribute to improved throughput, while the main motivation for non-compliance relates to perceived traffic conditions. Moreover, the size of the travel time sacrifice seems not that important as expected. Nonetheless, comparing stated intentions with real-world behaviour suggests that a relation between intention and compliance frequency does exist.

4.2. Introduction

Travel information is expected by many scholars and practitioners alike to be successful in improving road network efficiency by directing the network state from a user equilibrium towards a system optimum. Yet, conventional (personalized) travel information aims at the individual's benefit, stimulating travellers' personal optimization of their own route choices (so-called selfish routing behaviour); this may lead to an inefficient user equilibrium (e.g. Ben-Akiva et al., 1991). Note that the road network might even more than ever before be approaching a perfect user equilibrium due to the rapid increase of real-time community-based routing applications on smartphones (such as Waze (2018)), as properly pinpointed by Klein et al. (2018). As selfish routing tends to result in severe congestion at certain locations in the road network and slow down overall traffic movement, traffic authorities tend to pursue system (or social) optimal network conditions in which the total travel time – and therewith congestion – within the network is minimized. Examples on network efficiency, such as Pigou's example (Pigou, as cited by Roughgarden, 2006) and Braess's Paradox (Braess et al., 2005), have shown that in order to achieve system optimal network conditions, some travellers need to act socially and choose route alternatives possibly at their own expense (i.e. they might need to take a detour), referred to as social routing behaviour. See Levy et al. (2017) and Klein et al. (2018) for two recent theoretical and simulation-based expositions of how different behaviours at the micro-level may lead to system-optimal outcomes.

Several steering approaches in order to direct travellers towards these social routes exist; examples are road pricing and the use of personalized incentives (e.g. discounts or rewards). These conventional steering approaches have shown to be successful in changing behaviour (e.g. Anas & Lindsey, 2011; Ettema et al., 2010), although their social desirability is questioned (e.g. Te Brömmelstroet, 2014; Verhoef et al., 1997). The provision of travel information and social routing advice is another approach that is receiving increasingly attention recently (e.g. Jahn et al., 2005; Van den Bosch et al., 2011; Xu & Gonzalez, 2017; Çolak et al., 2016). However, those studies mainly build upon theoretical assumptions rather than empirical findings. As such, a crucial and unanswered empirical research question in this regard is whether travellers comply with received route advice – or can be motivated to – when the advised route implies a personal travel time sacrifice for the benefit of others (i.e. the system as a whole). To that end, we empirically assess travellers' compliance with social routing advice. Note that we define compliance as a route choice in accordance with received route advice.

We collect empirical data on social route choices in response to social travel information strategies using both a stated choice experiment (SP) and a revealed choice experiment (RP). In order to enrich the information obtained from revealed choices, we combine the RP experiment with the experience-based sampling (ES) method; asking a subject about its behaviour and motivations in a certain situation directly after that particular situation has revealed itself. This method is not often used in travel behaviour research yet, although it is highly useful in assessing route choice behaviour in response to social routing advice in real-world daily-life context. A review of the applied methods and their limitations is provided in Section 4.3. Moreover, we develop and test several information framing strategies that aim to stimulate social route choice behaviour. In line with a recent literature review on the role of social choice behaviour, bounded rationality and travel information in improving road network efficiency (Van Essen et al., 2016), we take into account the degree of rationality in travellers' decision strategy and their intrinsic inclination towards choosing the social route. In addition to this focus on the framing of travel information and personal characteristics, we pay attention to both the size of the travel time sacrifice and the societal goal underlying the information; i.e. we go beyond existing research by not only looking into information messages pursuing a system optimum, but also into messages aiming at other societal benefits, such as traffic safety and environmental sustainability.

In sum, our study contributes to the existing literature by 1) the development of several information framing strategies taking into account personal characteristics, 2) the extended focus on the size of the travel time sacrifice and the societal goal underlying the information, and 3) the collection and use of empirical data on social route choices using both SP and RP in combination with ES. The remainder of this chapter is structured as follows. Section 4.3 provides the research background, whereas Section 4.4 introduces the developed information strategies and describes the experimental set-ups and methodologies. Subsequently, Section 4.5 shows results and findings from the data analysis. Finally, this chapter presents key conclusions and discusses the results in Section 4.6.

4.3. Background

Neoclassical choice theories largely build upon two behavioural assumptions, i.e. individuals are rational in how they choose and selfish in what they choose. This concept is widely criticized by behavioural economists who build upon psychology, social sciences and economics in order to explain deviations from this rational selfish choice behaviour. Main line of criticism is that individuals have cognitive limitations, make errors, have biases or emotions influencing their decision making (e.g. Simon, 1955; Tversky & Kahneman, 1991; Zajonc, 1980), i.e. they are boundedly rational. Moreover, individuals can choose to simplify their decision strategy and seek a satisfactory alternative rather than the optimal alternative, often called satisficing (e.g. Simon, 1955), or make their decisions in a habitual way and just use the alternative that provided the most positive experience in the past (e.g. Verplanken et al., 1997). One potential explanation for such behaviour is that individuals tend to minimize their (cognitive) efforts at the cost of the accuracy of their choice outcome according to some sort of effort-accuracy trade-off framework (Johnson & Payne, 1985). In line with this, several studies found that travellers choose a short travel time alternative, although not necessarily the shortest travel time alternative (e.g. Ciscal-Terry et al., 2016; Vreeswijk et al., 2015; Zhu & Levinson, 2010). These findings indicate that individuals do not necessarily want to use the route alternatives that benefit them the most, are not able to correctly identify these or are not particularly interested in this. Building upon principles of bounded rationality, Avineri (2009a) provides travel-related examples that illustrate how small adaptations to the presentation of travel information could direct travellers to social choice options without them even realizing it. Moreover, many studies found evidence that individuals do not exclusively behave in selfish ways, but that they do care about others' welfare as well (e.g. Georgescu-Roegen, 1954; Ostrom & Walker, 2003; Poteete et al., 2010; Sen, 1977). A traffic-related example of this behaviour is that car drivers often give right of way to others at intersections, merges, or lane changes, accepting a (very) short delay to avoid delay for others (although often imposed by regulations). Although studies within various fields continued this line of research, researchers within the field of transportation started to consider social choice behaviour only more recently, and mostly related to sustainable transportation (e.g. Nilsson & Küller, 2000; Van Vugt et al., 1996). A few recent studies examine the impacts of social choice behaviour on road network efficiency and found that when all travellers start to value social outcomes only slightly, up to 60% of potential travel time savings could be attained (Avineri, 2009b; Levy et al., 2017; Çolak et al., 2016), although lower results are obtained when only a minority of travellers choose their routes (fully) socially; i.e. about 7% (Van den

Bosch et al., 2011). Moreover, Djavadian et al. (2014) provide some initial evidence that travellers are willing to comply with social routing advice, especially when incentives are provided. Besides the study by Djavadian et al. (2014), little empirical evidence and knowledge of social choice behaviour related to specifically route choices exist. Hence, further research on this topic is necessary.

In order to engage in certain behaviour – such as making social route choices – individuals have to evaluate that behaviour positively. It has been suggested that one's attitude towards social choice behaviour is related to the individual's social value orientation, which represents his or her preference for certain outcomes for him- or herself as well as for others (Knight & Dubro, 1984; Platow, 1993). Multiple orientations have been identified although most studies use a three-category typology focusing on cooperative, individualistic and competitive orientations (Platow, 1993). Cooperatives tend to maximize outcomes for both themselves and others, often combined with minimization of the relative differences between those outcomes (i.e. equity/equality); individualists tend to maximize their own outcome, regardless of others' outcome; and competitors tend to maximize the difference between their own outcomes and those of others (e.g. Van Lange, Otten, De Bruin, & Joireman, 1997). However, these personality traits do not tell the entire story: in order to make social choices, individuals need not only to be 'cooperatively oriented', they need to believe that others make social choices as well (Pruitt & Kimmel, 1977). That is, social choice behaviour depends on the individual's belief of the extent to which the collective goal can be achieved (often referred to as 'trust' (e.g. Van Lange, Van Vugt, Meertens, & Ruiter, 1998; Yamagishi, 1988)). Moreover, the opinion of peers and society, as well as the feeling of moral obligations, play an important role (e.g. Ajzen, 1991; Schwartz, 1977). These moral obligations stem from individuals' awareness of the consequences of certain behaviour (e.g. traffic congestion or environmental damage caused by car and road use) and the extent to which they feel responsible for these consequences (Schwartz, 1977).

Findings and examples on non-selfish non-rational choice behaviour lead to increased expectations that travellers might comply with travel information and routing advice that directs them towards a particular route alternative, not for their own sake, but to benefit the road network as a whole. Note that we do not regard bounded rationality as a prerequisite for social choice behaviour. We only want to point out that its existence provides the opportunity to direct travellers towards social routes, especially when they are individually oriented, and that we might want to build upon this.

Several valid methods exist in order to assess travellers' compliance; i.e. stated choice experiments, laboratory experiments (including gamified experiments and experimental economics) or field experiments. Stated choice experiments and laboratory experiments are flexible and low-cost, attribute values can be easily controlled and behavioural responses can be easily observed (Kroes & Sheldon, 1988; Verhoef & Franses, 2003). However, it is debated how well findings from such studies can be extrapolated to the real world (Kroes & Sheldon, 1988), especially when social choices are involved (Levitt & List, 2007). Field experiments tend to have higher external validity, although they often suffer from smaller sample sizes – resulting in lower statistical power – and attribute values which cannot be properly controlled for, potentially even prohibiting statistical inference due to e.g. serial correlation. Because field experiments take place in a dynamic context in which behaviour can change from day-to-day, qualitative data about motivations for certain choice behaviour would be quite useful. To that end, researchers within the field of travel behaviour collect travel diaries or have an observer present during the experiment (e.g. Hoogendoorn-Lanser, Schaap, & Olde Kalter, 2015; Tawfik & Rakha, 2012). Another method, that is not often applied within this field of research, is the experience-based sampling method (Hektner et al., 2007); participants are asked about their behaviour and motivations in a certain situation, directly after this situation revealed itself in daily-life. As such, the behaviour of participants is not influenced by the presence of an observer, while more accurate data can be obtained compared to the use of diaries (i.e. answers are less dependent upon memory). In order to exploit the strengths and mitigate the weaknesses of each approach, we conduct both a stated choice experiment and revealed choice experiment in combination with experience-based sampling; and we compare their results.

4.4. Methodology

4.4.1. Design of system-optimal information strategies

Four system-optimal information strategies have been developed; these strategies aim to influence individuals' route choice behaviour without restricting their freedom of choice, each with the objective to improve network efficiency. Strategies range from low information content (i.e. providing almost no contextual information) to high information content (i.e. providing detailed information on context as well as the importance and consequences of certain choices). Moreover, some strategies capitalize on travellers' bounded rationality, whereas others focus on influencing or reinforcing their attitude towards the social route alternative. Table 6 provides an overview of this classification. Each strategy combines several principles that are, according to literature, potentially successful in changing (travel) behaviour. This is done in such a manner that the strategies are distinct from each other, while remaining realistic, credible and practical (this is the reason why some cells in Table 6 are empty).

Table 6. Overview of strategy classification.

	Low information content	**Moderate information content**	**High information content**
Capitalize on existing bounded rationality	Strategy 1 'Recommendation'	Strategy 2 'Nudge'	-
Focus on influencing attitude towards behavioural change	-	Strategy 3 'Social Reinforcement'	Strategy 4 'Educate'

Now, a short description of each strategy will be provided. The fully detailed operationalization of each strategy will follow in Section 4.4.4.

- **Strategy 1 'Recommendation':** This strategy provides plain advice on the route alternative that the specific individual should choose to the desire of the traffic manager or road authority without any contextual information. Thereby, this strategy capitalizes on individuals' potential perception errors (Carrion, 2013) or disinterest in choosing the shortest travel time alternative. Moreover, it reduces individuals' cognitive effort as it allows them to simply follow the provided recommendation (inspired by the effort-accuracy trade-off framework by (Johnson & Payne, 1985).

- **Strategy 2 'Nudge':** This strategy presents information about the choice situation, and each choice option, in such a manner that individuals are somewhat directed towards the desired choice option without realizing it. The social route alternative is both presented first and emphasized as such, creating awareness of its existence. This is in line with the theory of default settings (e.g. Pichert & Katsikopolous, 2007; Sunstein & Thaler, 2003). Additionally, positive aspects of the social alternative, as well as negative aspects of the non-social alternatives are highlighted to make these salient (Avineri, 2009a) and anticipate on potential loss aversion among travellers (Kahneman & Tversky, 1979). Positive aspects are also emphasized in the label of the social route.

- **Strategy 3 'Social Reinforcement':** This strategy provides objective information about the choice situation and each choice option. Additionally, it provides information on the choices of others by showing the (in our experiment hypothetical) percentage of travellers that choose the social routing option (inspired by Araghi et al. (2014) who applied this principle in the context of carbon footprint offsetting). As a result, this strategy creates awareness about existing social norms regarding certain travel behaviour and it reinforces trust or belief in a successful collective outcome or achievement (i.e. system optimum). Moreover, it puts their sacrifices (e.g. travel time, cost and effort) into perspective as they will know they are not the only ones making these sacrifices. Consequently, both an individual's normative belief and his or her attitude towards the desired social choice are potentially influenced.

- **Strategy 4 'Educate':** This strategy explains the context and importance of the individual's choice behaviour for the desired collective outcome of achieving a system optimum. Moreover, it informs the traveller about each route alternative providing objective information on their characteristics. Finally, it instructs the traveller about the desired behaviour by recommending the social alternative. As a result, this strategy creates consciousness about the context in which route choices take place and raises awareness of the consequences of individual's own behaviour regarding the desired collective outcome.

4.4.2. Stated choice experiment (SP) - Questionnaire

Participants

211 respondents were recruited based on voluntary participation and self-assessment of eligibility; they were asked to only complete the questionnaire if they use a car for their commute at least every now and then. Links to the questionnaire were published on the employee portal of the University of Twente (Enschede, The Netherlands) and through social media (Facebook and Twitter). The survey was online from May to August, 2016. Respondents who completed the questionnaire could participate in a prize draw in which they could win a voucher – three vouchers were available – at the worth of €50,- which could be used at a well-known online shopping platform.

Questionnaire outline

The questionnaire consisted of four parts (see Appendix B for the actual questionnaire). In the first part, respondents were asked to picture a hypothetical commute trip. They were provided with travel information with respect to this commute trip according to one of the information strategies from Section 4.4.1 (i.e. there were four versions of the questionnaire − each containing only one of four information strategies – and each respondent received only one version of the questionnaire). Respondents were told that the information message was received on their smartphone and was sent by their local road authority. They were asked to choose between two route alternatives: their (hypothetical) usual route that takes 28 minutes and some 'similar route' with a slightly higher travel time that contributes to a certain societal goal. A 2x3 full factorial design was used that considers travel time sacrifices imposed on the respondent (i.e. small versus large) and societal goals (i.e. congestion alleviation, traffic safety and environmental sustainability) that are aimed for by the information message; hence, respondents generally made six choices. Note that only three choices were made when the recommend-strategy was applied; this strategy did not provide travel time information and as such the travel time sacrifice did not vary. Travel time sacrifices of 3 minutes and 7 minutes are applied. These sacrifices originate from findings of a field study by Zhu and Levinson (2010) who found that many travellers who did not use their shortest travel time alternative, used alternatives that were less than 5 minutes longer than this shortest travel time alternative. The reason for distinguishing between different societal goals is that it allows us to study whether travellers' inclination to comply with the social routing advice depends on the goal which the government aims to achieve with the advice. The assumed timing of the information message is at trip departure.

The second part of the questionnaire assesses respondents' decision-making styles. More specifically, in line with dual-process theories developed within the field of cognitive psychology, we measure to what extent the respondents apply two different reasoning styles. The first reasoning style encompasses processes that are 'automatic, largely unconscious, and relatively undemanding of computation capacity' (Stanovich & West, 2000, p. 658), whereas the second reasoning style 'encompasses the processes of analytic intelligence' (Stanovich & West, 2000, p. 658). In transport literature, the first reasoning style is often associated with habitual behaviour (e.g. Jakobssen, 2003; Verplanken et al., 1997). Similarly, maximizing behaviour – as opposed to satisficing behaviour – is associated with reasoning style 2. Maximizing versus satisficing decision-making styles are measured by the context-free maximizing tendency scale that was developed by Lai (2010). This measure consists of five statements using a 5-point Likert-scale (Cronbach's α=.69). A high score on this scale implies that the respondent has an intrinsic tendency to maximize, while a low score is associated with the intrinsic tendency to satisfice and choose the option that is 'good' enough. We measure a habit-driven decision style by means of the decisional involvement scale that was developed by Verplanken, Aarts, Van Knippenberg, and Van Knippenberg (1994) to examine habit in mode choice for shopping trips. This measure consists of eight statements using 5-point Likert-scales (Cronbach's α=.82). A high score on the aggregate decisional involvement scale suggests that travellers made their route choices deliberately; no habit is involved. As decisional involvement is known to be highly dependent on the context, statements were presented with the stem 'When I commute by car…' and words related to mode choice were replaced with words related to route choice.

The third part of the questionnaire assesses respondents' social value orientation using the canonical SVO-slider measure developed by Murphy, Ackermann, and Handgraaf (2011). This measure provides respondents with six carefully designed choice situations in which they have to allocate a hypothetical money-budget to themselves and someone else. Importantly, the 'other person' is hypothetical and anonymous, and there is no follow-up in terms of the other person accepting or rejecting the offer (as in the ultimatum game). This SVO-measure has been found to be more reliable than previously used SVO constructs, such as the Ring Measure (Liebrand, 1984) and the Triple-Dominance Measure (Van Lange et al., 1997), and is compatible with a route choice context, in the sense that road users are anonymous and in the sense that reciprocity does not play a role.

The final part of the questionnaire collected information about respondents' actual mobility pattern, both in general and related to their commute trip. Moreover, demographic information (i.e. age, gender, and education) was obtained.

4.4.3. Revealed choice experiment (RP) - Field experiment

Participants

28 participants were voluntarily recruited among employees of companies located at the Business and Science Park Twente and the neighbouring University of Twente in Enschede, The Netherlands. To that end, an advertisement was published on the employee portal of the University of Twente and an email was sent to the secretaries of companies and faculties. Employees were only eligible for participation if they made at least 3 commute trips per week by car during morning peak hour. It was ensured that their usual route to work passed certain predefined locations covering the main inbound routes to the destination area, guaranteeing the existence of an acceptable and realistic detour for their commute trip. Participants were randomly assigned to one of two information strategies; i.e. the 'Recommend'-strategy or the 'Educate'-strategy. The experiment took place during 5 consecutive weeks (January 16th until February 17th, 2017). Participants who completed the experiment could participate in a prize draw in which they could win an Ipad or a voucher – three vouchers were available – at the worth of €50,- and €20,-, which could be used at a well-known online shopping platform.

Experimental set-up

Participants installed the application 'SMART Mobility' (SMART in Twente, 2016) on their personal smartphone. This application automatically collects trip-data, i.e. origin, destination, departure time, arrival time, route and mode (-chain) for each trip. On working days, the smartphone application sends tailor-made information messages containing route advice for the morning commute to its users. The timing of the information message is set to 15 minutes before the user's average commute departure time to ensure that users receive the message before they depart. For two days every working week the social route was advised to each participant, while on the remaining days of the working week their usual route was advised. This is to avoid that participants feel that they themselves have to sacrifice all the time, while never reaping the benefits, and therefore might stop complying with the advice or do not comply at all. Note that the behaviour of drivers who do not participate in the experiment does not change. Hence, actual benefits will not be experienced by participants. However, as demonstrated by Çolak et al. (2016), travel time benefits will be marginal (ranging from 1 to 3 minutes) and might be imperceptible for the majority of travellers due to the natural variability in travel time caused by events, weather conditions and traffic lights. After a commute trip was made, app-users automatically received two questions about the main reason for choosing a particular route and the role that the information message played in that decision using experience-based sampling. Due to small sample size, only two out of four information strategies were applied; i.e. the 'Recommend'-strategy and the 'Educate'-strategy. These strategies were most distinctly classified regarding information content and focus. Moreover, only the commonly used goal to alleviate congestion was implemented.

In order to enable within-subject comparison between stated choice and revealed choice, participants answered a question on their intended behaviour at least one month before the start of the experiment; i.e. a choice situation, tailored to the participants' choice context as would be experienced during the field experiment, was provided. This one month time period was applied in order to limit the influence of the stated intention on the participant's subsequent revealed behaviour during the experiment. Additionally, participants filled out a short questionnaire in order to assess to what extent certain personality traits influenced their actual behaviour. The exact same questionnaires and scales applied in the stated choice experiment were included in order to assess participants' decision styles and attitudes towards social behaviour as well as the extent to which their route choices are deliberate or habit-driven.

Moreover, actual travel times on both the usual and social routes were collected from Google Maps at a 5-minute interval in order to monitor the road network and quantify the actual travel time sacrifices that have been made by the participants.

Datasets

From this field experiment, we obtained two datasets; Stated Intention (SI) and Revealed Preference (RP). The SI-dataset contains the intended behaviour before the start of the experiment provided by 22 participants. Note that these stated intentions are actually stated preferences; we use the term intentions in order to make a clear distinction between this dataset and the SP-dataset obtained from the questionnaire in Section 4.4.2. The RP-dataset contains the actual behaviour of 28 participants (including the 22 participants from the SI-dataset). We obtained 269 route choice observations in which the information message was read before reaching the passage point where the decision whether or not to comply should be made. In 116 of these 269 observations (43%) the social route was advised. Since 3 participants either did not read the information message or did not undertake a commute trip on days that the social route was advised, the number of participants reduces to 25 for analyses that only consider these specific days.

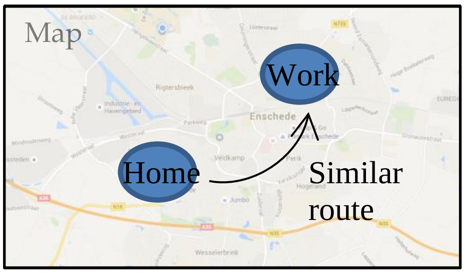
4.4.4. Operationalization of information strategies

Table 7 provides an overview of our operationalization of each information strategy. In the SP-experiment, each message was embedded in a picture of a smartphone screen in order to increase realism.

Table 7. Overview of operationalization of information strategies.

Strategy 1 ‘Recommendation’ in SP

Introduction: Imagine that you are about to undertake a trip to your work location by car. In the following message the information service on your smartphone advises you to take another route than usual today:

Map shown:	Message content:
	*“The route shown contributes to congestion alleviation within the road network in your region. Consequently, we advise you to take this route.* *The advised route might result in a slightly longer travel time compared to your usual route.”*

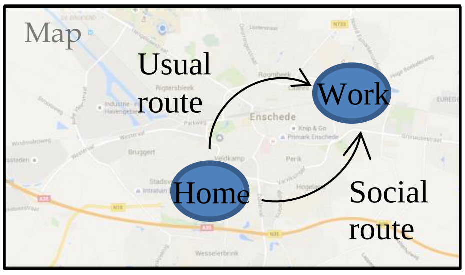
Strategy 1 ‘Recommendation’ in SI and RP

No introduction

Map shown (Tailor-made map):	Message content:
	*“If you are driving to work today, we advise you to take the route following below. This route contributes to congestion alleviation within the road network in your region.”*

Strategy 2 ‘Nudge’ in SP *(not included in SI or RP)*

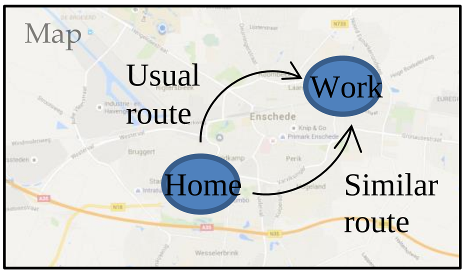
Introduction: Imagine that you are about to undertake a trip to your work location by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:

Map shown:	Message content:
	*“Social route: your travel time is 31 minutes and you contribute to congestion alleviation in your region.* *Your usual route: your travel time is 28 minutes, however, you add to congestion. This results in additional delays experienced by other users of this route.”*

Strategy 3 'Social Reinforcement' in SP *(not included in SI or RP)*

Introduction identical to Strategy 2.

Map shown:



Message content:

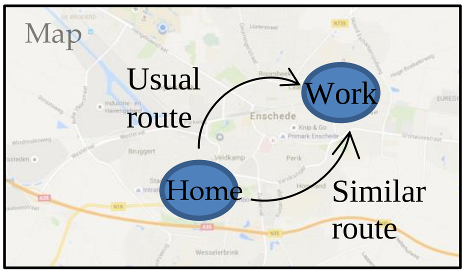
"Your usual route takes 28 minutes. The similar alternative takes 31 minutes, however, when you take this route, you contribute to congestion alleviation in your region. For that reason, we ask you to take the similar alternative.

In other regions, we have asked travellers to choose a particular route alternative for the same reason. On average, 72% of travellers complied with our request. This had a big effect on the throughput in these regions. Do you take part to achieve this in your region as well?"*

Strategy 4 'Education' in SP

Introduction identical to Strategy 2.

Map shown:



Message content:

"When everybody chooses the fastest route alternative (your usual route), this could lead to delays and congestion on this route. Consequently, everyone ends up with additional travel time. When part of the travellers take a short detour using a similar alternative (social route), the remaining travellers on this route could drive on faster. As a result, we expect to reduce congestion and improve throughput significantly. You can contribute by complying with our advice:"

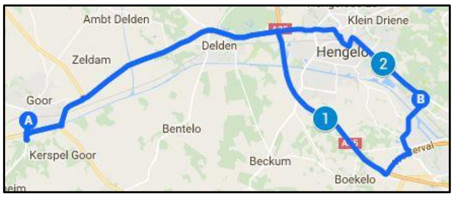
	Your usual route (fastest route)	Similar route (social route)
Estimated travel time	28 minutes	31 minutes

"We advise you to take the similar route today. This is the social alternative."

Strategy 4 'Education' in SI and RP

No introduction

Map shown (Tailor-made map using 'Route 1' and 'Route 2'):



Message content:

"When everybody chooses the fastest route alternative (your usual route), this could lead to delays and congestion on this route. Consequently, everyone ends up with additional travel time. When part of the travellers take a short detour using a similar alternative (social route), the remaining travellers on this route could drive on faster. As a result, we expect to reduce congestion and improve throughput significantly. You can contribute by complying with our advice:"

	Route 1 (usual route)	Route 2 (social route)
Estimated travel time	35 minutes**	39 minutes**

"If you drive to work today, we advise you to take route 2. This is the social alternative."

**This number is fixed throughout the experiment.*
***Provided travel times are tailored to the participant's choice context and are obtained from Google Maps.*

4.4.5. Outline of empirical analysis

Our analysis consists of four parts. First, we provide compliance rates for each dataset to gain some initial insights and understanding. Note that compliance is measured as the event where the respondent or participant chooses the social route in line with received advice. As such, compliance might occur for some other reason than the received advice as well (we elaborate further on this in Section 0). Subsequently, we compare findings between the SP, SI and RP datasets. Wardman (1988) identified two approaches to test the external validity of stated preferences that are mainly used in transportation contexts. The first approach is to compare stated intentions regarding a certain event with the actual behaviour after the event has occurred; these are so-called 'before and after' studies. A second approach is the comparison of travel behaviour models based on stated preferences and revealed preferences. We apply both approaches. For the first approach, SI and RP choices are compared in a descriptive way. For the second approach, choices made in SP and RP are analyzed by means of estimating discrete choice models on information compliance. Finally, we conduct qualitative analyses of motivations to comply with the received route advice to obtain insights into the reasons behind observed behaviour.

Model specification

We estimated Mixed Logit models accounting for panel effects, taking into account that respondents and participants (in both experiments) made multiple choices and hence might carry some of their preferences across choice tasks.

Three models were estimated; one model based on the SP-dataset, one model based on the RP-dataset and one joint SP/RP-model based on both datasets. In the joint SP/RP-model both datasets are combined by scaling the utilities in one dataset in order to allow for differences in error term variance across datasets. We included three attributes in each model, i.e. the information strategy that was provided (4 levels in SP: Recommendation, Nudge, Social reinforcement, Education – 2 levels in RP: Recommendation, Education), the societal goal that was pursued by the information content (3 levels in SP: alleviate congestion, increase safety, reduce emissions – 1 level in RP: alleviate congestion) and the travel time sacrifice that was needed in order to comply with the information (continuous). Moreover, we included three two-level attributes related to personality traits (i.e. Social Value Orientation (individualist versus cooperator), Maximizing Tendency (maximizer versus satisficer), Decisional Involvement (habit executioner versus non-habit executioner)). Note that these are all dummy coded, except for the continuous travel time sacrifice. As not all strategies included information on travel times – in such cases, no explicit sacrifice was provided – travel time sacrifice was interacted with a dummy for the presence of travel time information.

The utility function of compliance for the SP-model and the RP-model (note that the utility of the non-compliance option is fixed at zero for normalization purposes):

$$U_{nt} = ASC + \sum_m \beta_m x_m + \nu_n + \varepsilon_{nt} \tag{5}$$

In which:

U_{nt} denotes the total utility associated with compliance by individual n in context t. β_m denotes the parameter to be estimated that is associated with the m^{th} attribute x_m. ASC denotes an intrinsic willingness to comply with the advice. Finally, ν_n and ε_{nt} are random errors. The former is Normally distributed with a mean of zero and an estimated standard deviation. This error only varies across individuals; it is constant within individuals and across tasks, reflecting a stable inclination of the individual (not) to comply with the information. The latter error is distributed i.i.d. Extreme Value type 1 across both individuals and choice tasks, reflecting additional variation in unobserved utility (‘white noise’).

Note that the societal goal attribute is not included in the RP-utility function, because only one goal was applied in the RP-experiment. Moreover, the Maximizing Tendency attribute is not included in the RP-utility function due to insufficient variability in the obtained RP-data.

The applied utility function of compliance for the joint SP/RP-model:

$$U_{nt} = e^{(\mu \times SP)} \times \left(\text{ASC} + \sum_m \beta_m x_m + \nu_n + \varepsilon_{nt}\right) \tag{6}$$

In which:

μ represents the scale factor that is applied to the SP-dataset in order to obtain the same variance in both datasets. SP indicates to which dataset the observation belongs (i.e. SP or RP) and is dummy-coded. Note that μ equals zero when there is no difference in variance of unobserved utility between the two datasets.

The models are estimated using the Biogeme software package (Bierlaire, 2003) with the ‘donlp2’-algorithm (Spellucci, 1993) using at least 1000 Halton draws. Experiments with less draws indicated that 1000 draws were sufficient to obtain stable parameter estimates.

4.5. Results

4.5.1. Descriptive characteristics of samples

Table 8 describes the samples from both the stated choice and revealed choice experiment and provides information on segmentation of measured personality traits. That is, each personality trait is described by its extremes, resulting in two categories per trait. As the social value orientation measure specifies three categories of which competitors are rarely present in a route choice context, this category is combined with individualists; i.e. they both aim to enhance outcomes for themselves (either absolute or relative). This two-category typology is used by other studies as well (e.g. Van Lange, Schippers, & Balliet, 2011).

There is no evidence that samples are different regarding gender ($\chi^2 = 0.0, DF = 1, p = 0.978$), social value orientation ($\chi^2 = 2.4, DF = 2, p = 0.295$), decision-making strategy ($\chi^2 = 1.4, DF = 1, p = 0.243$) or decisional involvement ($\chi^2 = 0.1, DF = 1, p = 0.756$). However, participants in the RP-experiment seem slightly older ($\chi^2 = 4.9, DF = 2, p = 0.088$) and higher educated ($\chi^2 = 7.8, DF = 2, p = 0.020$) compared to respondents in the SP-experiment.

Table 8. Descriptive characteristics of samples.

Descriptive characteristics of samples			
	Stated choice (N=211)	*Revealed choice (N=28)*	
Assigned to information strategy:			
1: Recommendation	25%	50%	
2: Nudge	25%	n/a	
3: Social Reinforcement	24%	n/a	
4: Education	26%	50%	
Gender			
Female	43%	43%	
Male	57%	57%	
Age			
16-34	50%	32%	
35-54	39%	61%	
>55	11%	7%	
Education			
Lower education	1%	0%	
Secondary school or vocational education	27%	4%	
Professional education	72%	96%	
Staff category			
University: academic	n/a	39%	
University: supportive	n/a	43%	
Company employee	n/a	14%	
No answer	n/a	4%	

Descriptive characteristics of samples			
	Stated choice (N=211)	*Revealed choice (N=28)*	
Social value orientation	*based on SVO-slider measure by Murphy et al. (2011)*		*Segmentation:*
Individualist	36%	21%	Non-cooperator
Competitor	1%	0%	Non-cooperator
Cooperator	63%	79%	Cooperator
Decision-making strategy	*Based on context-free maximizing tendency scale by Lai (2010)*		*Segmentation: Average score on statements… (1-5)*
Maximizer	76%	86%	*> 3*
Satisficer	24%	14%	*≤ 3*
Decisional involvement	*Based on decision involvement scale by Verplanken et al. (1994)*		*Segmentation: Average score on statements…(1-5)*
Habit Executioner	46%	43%	*< 3*
Non-habit Executioner	54%	57%	*≥ 3*

4.5.2. Compliance rates

Compliance rates for SP, SI and RP-samples are provided and compared (see Table 9). To enable comparison, the SP-dataset is reduced to only those observations that are similar to the RP-observations; i.e. only observations that contain a ‘recommendation’-strategy or ‘education’-strategy and involve the congestion alleviation goal are included.

For the RP-experiment, we observe higher compliance rates when the usual route is advised (88%) compared to when the social detour was advised (31%); this is as expected. When we compare compliance rates for the social detour for SP and RP, we observe significant differences; compliance in RP (31%) is significantly lower than compliance in the reduced SP (57%) ($\chi^2 = 12.8, DF = 1, p = 0.000$). Nonetheless, compliance rates for taking the detour are similar between SI (41%) and RP (31%) ($\chi^2 = 0.313, DF = 1, p = 0.576$). This suggests a correspondence between what individuals say they would do and what individuals actually do, in the context of the field experiment. Note that Djavadian et al. (2014) obtained slightly lower compliance rates (21%-28%) in their laboratory study using strategies based on information and incentives.

Table 9. Compliance rates.

SP (reduced dataset)	Usual route chosen	Social route chosen		Total [#]
Advice 'Social route'	Non-compliance	Compliance		
Total	43% (70)	57% (93)		163
Overall (full dataset)	54% (601)	46% (506)		1107
SI	Usual route chosen	Social route chosen		Total [#]
Advice 'Social route'	Non-compliance	Compliance		
Total	59% (13)	41% (9)		22
RP	Usual route chosen	Social route chosen	Some other route chosen	Total [#]
Advice 'Social route'	Non-compliance	Compliance	Non-compliance	
Total	59% (68)	31% (36)	10% (12)	116
Advice 'Usual route'	Compliance	Non-compliance	Non-compliance	
Total	88% (135)	3% (5)	8% (13)	153

4.5.3. Stated intention (SI) versus actual behaviour (RP)

Figure 9 shows to what extent participants behaved in line with their intention during the field-experiment; note that, since SI entails one choice, while RP contains multiple choices, these cannot be compared one to one. 41% stated to choose the social route. Of these, 89% actually chose the social route at least once when they faced this situation in reality; 56% did this even 3 times or more. On the other hand, 59% stated to stick to their usual route. 38% of them did indeed not choose the social route alternative in real-life, whereas 46% chose the social route only once. Overall, participants who intended to take the social route, did this in 56% of the cases, while others chose the social route in only 17% of the cases. These findings indicate that there exists a relation between intention and compliance frequency.

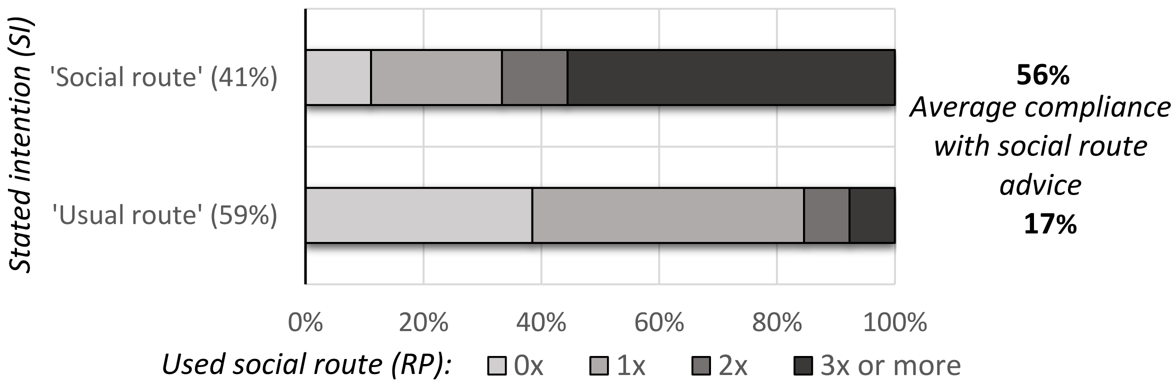


Figure 9. Stated intention versus actual behaviour.

4.5.4. Modelling results

Table 10 shows the estimation results for the SP-model, RP-model and joint SP/RP-model in order to identify explanatory factors for compliance. The SP-model suggests that travellers have an intrinsic preference for either compliance or non-compliance, which strongly varies among respondents (see the estimate for sigma of ν_n). Information strategies based on nudging, social reinforcement and education significantly and positively contribute to information compliance compared to a ‘recommend’-strategy. Apparently, travellers need moderate to high information content in order to choose the social route. Moreover, travellers are found to be more likely to comply with the information when information messages pursue the goal of alleviating congestion compared to the goals of increasing safety or reducing emissions. This might be explained by the fact that congestion and travel time are – in the traveller’s perception – directly related and therefore alleviating congestion could be perceived as a more meaningful and achievable goal by travellers. Furthermore, the higher the travel time sacrifice, the lower the likelihood of information compliance. This is in line with intuition and findings reported in literature (e.g. Fehr & Fishbacher, 2003). Finally, travellers are most likely to comply with the received advice when they are cooperatively oriented and when they make their route choices in a deliberate manner (i.e. non-habitual). Again, this is in line with expectations; cooperators are willing to contribute, while habits are hard to break. Note that the decision-making strategy (i.e. maximizer versus satisficer) seems to have no significant effect on information compliance. This might be explained by the fact that the maximizing tendency is a quite general personality trait; a person could be in general a maximizer, but when it comes to his route choice specifically, he might be a satisficer. Moreover, one could argue that the combination of maximizing tendency with decision involvement or social value orientation might result in opposite behaviour. That is, a cooperative maximizer is presumed to maximize collective outcome and is therefore likely to comply, whereas an individualistic maximizer is presumed to maximize his own outcome and is therefore not likely to comply. Similarly, a habitual satisficer is presumed to stick to his habitual route and therefore not likely to comply, whereas a non-habitual satisficer is presumed to be more willing to switch routes and therefore is more likely to comply.

The RP-model suggests information compliance is explained by individuals’ intrinsic inclination to (not) comply, which shows strong variation among participants. Other aspects do not seem to significantly influence travellers’ compliance; no difference between the ‘recommend’-strategy and the ‘education’-strategy can be observed and the size of the travel time sacrifice and personality traits do not show any effect. This results in a somewhat lower goodness of fit for the RP-model. We refrain from drawing too strong conclusions regarding the difference between responses in the two experiments; due to the small sample size of the RP-experiment, the RP-parameters have such large standard errors that differences between parameters (across experiments) cannot be established statistically.

The joint SP/RP-model shows results similar to the abovementioned findings. Note that the scale factor is not significantly different from zero; this suggests that the variance of unobserved utility or random noise within both the SP-dataset and RP-dataset are similar. β-estimates are lower than the β-estimates of the SP-model, while they are higher than the β-estimates of the RP-model; this is as expected. Moreover, attributes related to the societal goal and social value orientation (i.e. cooperator vs non-cooperator) become insignificant.

Table 10. Model results SP-model, RP-model and joint SP/RP-model.

Parameters	**SP**		**RP**		**Joint SP/RP**	
	β_m	p-value	β_m	p-value	β_m	p-value
Constant	-0.587	0.32	-0.952	0.30	-0.794	0.13
Sigma of ν_n (inclination to comply)	2.08	0.00	1.20	0.02	1.62	0.00
Scale factor μ					0.265	0.43
Strategy (reference: Recommendation)						
Nudge	2.99	0.00			2.55	0.01
Social Reinforcement	2.70	0.00			2.31	0.01
Education	2.99	0.00	0.142	0.93	2.36	0.00
Goal (reference: Alleviate congestion)						
Increase traffic safety	-0.508	0.03			-0.314	0.13
Reduce emissions	-0.549	0.01			-0.345	0.08
Travel Time Sacrifice						
Travel time sacrifice	-0.470	0.00	0.120	0.67	-0.355	0.00
Personality Characteristics						
Cooperator (reference: Non-cooperator)	0.835	0.02	-0.330	0.72	0.521	0.10
Maximizer (reference: Satisficer)	0.416	0.29			0.373	0.27
Habit Executioner (reference: Non-habit Executioner)	-1.41	0.00	-0.342	0.71	-0.986	0.01
# of observations	1107		116		1223	
# of individuals	211		25		236	
# Halton draws	1000		1000		1000	
Null LL	-767.314		-80.405		-847.719	
Final LL	-592.303		-66.086		-663.988	
Rho-squared	0.228		0.178		0.217	

Insignificant values using a 5% significance level are displayed in grey.

4.5.5. Analysis of motivations

Using experience-based sampling, a total of 21 participants, in 153 cases, provided a motivation for (not) following the received advice or, in case of following the advice to use their usual route, whether or not the advice played a role in the decision. Participants could select a pre-determined answer or select 'other' and provide their own answer. Results are shown in Figure 10.

When the usual route was advised, travellers to an equal degree ignored the advice or felt strengthened in their choice. The main stated reason for not following this advice related to avoiding heavy traffic on that route. These findings indicate that participants did not always fully trust the advice provided by the information system. When the social route was advised, travellers mainly followed this advice because they (stated that they) wanted to contribute to improved network conditions. However, various motivations are provided for not following social route advice; none of them is clearly standing out. First, note that only 3 out of 13 travellers mentioned a too large travel time sacrifice, while the same number of travellers dislikes the social route based on other aspects than travel time. This suggests that travel time sacrifice is not that important in motivating travellers to take the social route as one might expect, at least within the bounds that occur in our experiment (sacrifices: 2-7 minutes). Moreover, people do not seem to divert to the social route when there is no heavy traffic on their usual route or if they believe the social route will be congested. This supports the earlier mentioned trust issue and indicates that people need to perceive that their effort of switching routes will contribute. This is emphasized by the number of travellers stating that they do not think their choice would influence traffic conditions. Finally, none of the travellers indicated that they did not want to contribute to improved road network conditions.

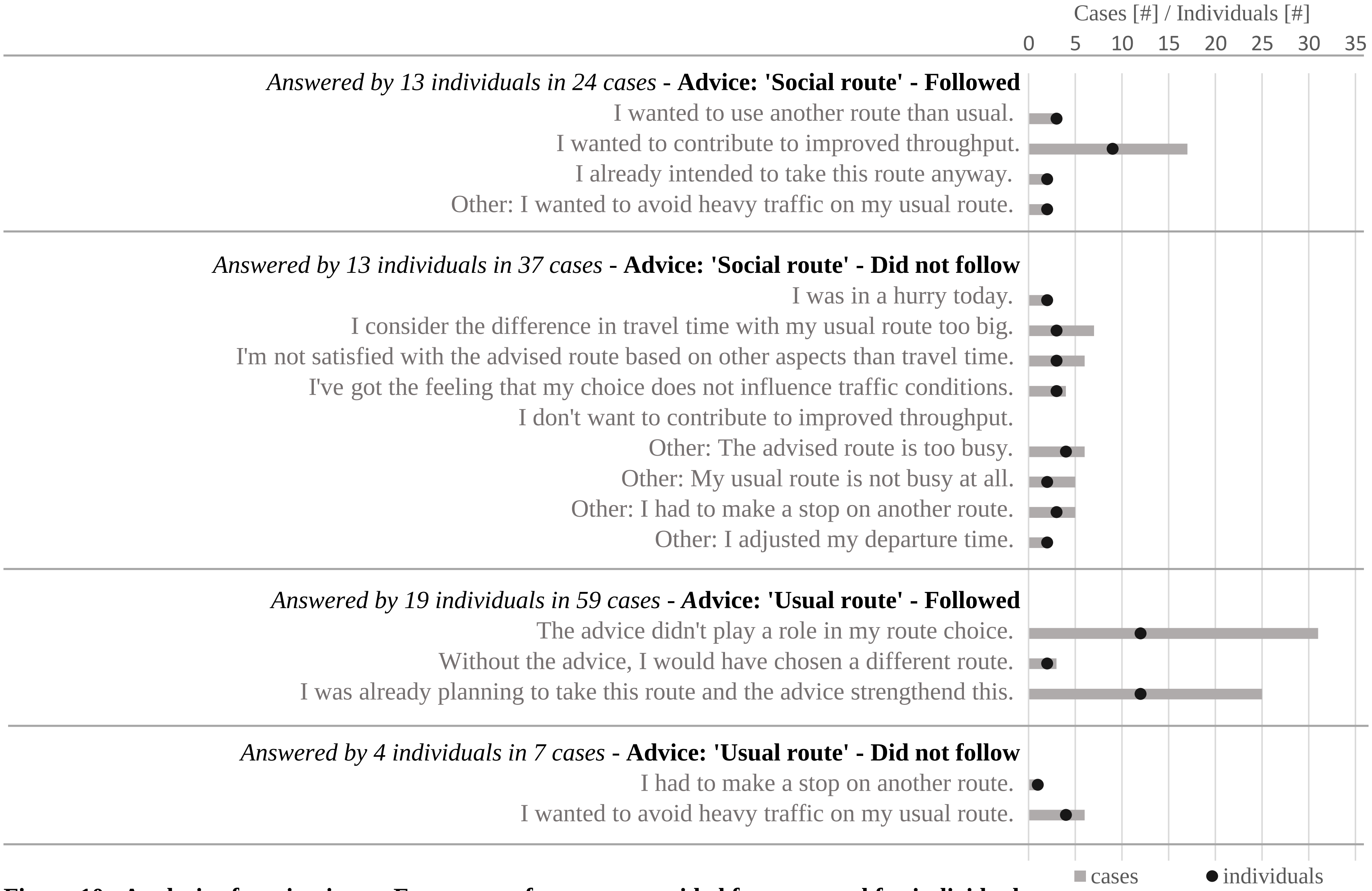


Figure 10. Analysis of motivations – Frequency of answers provided for cases and for individuals.

4.6. Conclusion and discussion

This chapter contributes to literature on social routing by empirically studying determinants of travellers' compliance with system-optimal travel information and social routing advice. To that end, four distinct information strategies were developed and tested by conducting both a stated choice experiment and a revealed choice experiment in combination with experience-based sampling. We use different societal goals underlying the information and focus on various latent personality characteristics.

Based on the stated choice experiment, we find that travellers sometimes agree to choose the social route over their usual route when they are being advised or asked to do so. A large variation was found in terms of travellers' intrinsic inclination to comply with social routing information. Overall, it seems that travellers' compliance with received information significantly depends on the framing of the information message, its societal goal and the size of the travel time sacrifice. More specifically, we find that travellers are most likely to choose the social alternative when small travel time sacrifices are involved, when information messages are aiming at alleviating congestion, and when these messages are framed according to the 'Nudge'-strategy, 'Social Reinforcement'-strategy or 'Education'-strategy. Moreover, travellers are most likely to comply with the received advice when they are cooperatively oriented and when they make their choices in a non-habitual manner. Results from the revealed choice experiment suggest that in daily-life people comply less with the advice than would be expected based on stated choice. The main motivation for revealed compliance seems to be an intrinsic motivation to contribute to improved throughput and, as such, the applied social information strategies seem to have their intended effect. However, findings between SP and RP appear to be to some extent inconsistent. Note that such inconsistencies between lab- and field experiments have been reported in other studies as well, especially when social preferences are involved (see Levitt and List (2007) for an overview). Nonetheless, compliance rates from stated intentions and revealed choices do bare similarity, and a relation between intention and compliance frequency does appear to exist. A reason for this combination of empirical findings might be that context-related aspects, such as familiarity with routes or trust in the information system, are present in both SI and RP, while absent in SP. Finally, analysis of motivations reveals that travel time sacrifice is not that important as expected, while perceived traffic conditions seem to be key. More specifically, compliance rates were low when (perceived) traffic conditions on route alternatives give the impression that there is no need to take a detour (i.e. both alternatives are believed to be busy or both alternatives are believed to be not busy at all). Whether or not our findings are general, or are partly explained by particularities of our data collection efforts (e.g. small sample size), is an important topic for further research.

The findings reported in this chapter result from a unique combination of a stated choice experiment and a revealed choice experiment that included the collection of motivations using experience-based sampling. Insights from both methods complement each other and provide a more rich understanding of compliance behaviour in response to social routing advice. Future research could implement the principles of social routing in a large-scale living lab integrating research in real-life communities and settings in which participants are not aware of taking part in an experiment. Additionally, the use of real-time advice accompanied by navigation instructions might result in higher compliance rates, especially among travellers who are unfamiliar with the surrounding road network. Moreover, dynamics in compliance behaviour over a longer time span would provide valuable insights on the long-term effects. Finally, future research should translate the observed (daily-life) compliance rates to the network level in order to indicate to what extent network efficiency could be improved. Overall, with this work we can identify the potential of applying travel information as a travel demand management measure in order to improve network efficiency.

4.7. Acknowledgement

This work is part of the research programme TRAIL Graduate School, which is financed by the Netherlands Organisation for Scientific Research (NWO). The authors would like to acknowledge the (technical) support of Mobidot who offered their smartphone application for data collection.

5. Impacts on network performance and equity

This chapter is based on: Van Essen, M., Thomas, T., Eikenbroek, O., & Van Berkum, E. (2018). Travelers' compliance with social routing advice: Impacts on road network performance and equity. *Submitted for publication in IEEE Transactions on Intelligent Transportation Systems (1st review round).*

5.1. Abstract

Information-based demand measures using social routing advice are receiving increasingly attention as they are expected to be successful in reducing traffic congestion. Such measures direct travellers towards routes that benefit the road network. As such, some travellers need to act socially and take a detour. This study explores impacts on network performance and equity that result from the application of a social routing service. We complement existing work by using a large-scale real-world road network, by assessing impacts on the individual level and by discussing our findings in light of observed individual compliance behaviour obtained from a small-scale field experiment. Our results show that 3.6% of total travel time within our road network could be reduced when all trips are made in compliance with received advice. However, based on observed compliance behaviour, a social routing service is expected to direct only a minority of travellers towards social routes. As such, potential travel time savings would only be achieved to some extent. We show how the attained travel time savings vary with the assumed compliance rate; e.g. to achieve 50% of the potential travel time savings, about 30% of travellers need to be willing to take a detour. Moreover, we find that the lower the compliance among travellers, the more social travellers need to compensate for the selfish behaviour of others by taking longer detours. Finally, we demonstrate that impacts on network performance and equity highly depend on the spatial distribution of social travellers among origins and destinations.

5.2. Introduction

Improving road network efficiency is often the main objective of traffic authorities. To that end, authorities aim to direct the network state from a user equilibrium − entailing an equal distribution of travel time among travellers, resulting from the personal optimization of their own route choices − towards a social system optimum in which the total travel time within the road network is minimized. In this, it may occur that some travellers need to choose route alternatives with higher travel times (i.e. they need to take a detour) to the benefit of the system as a whole, resulting in a less equitable − though social − network state. In other words, travellers need to act socially and choose social route alternatives. Conventional steering approaches to direct travellers towards these social routes are road pricing and the use of personalized incentives. However, with advances in information & communication technology (ICT) the application of real-time traffic management using personalized information strategies becomes more promising. As a result, the application of information-based travel demand using social routing advice is receiving increasingly attention.

Several studies consider the possible impacts of social routing. Many of them assume full market penetration of a social routing service (e.g. Jahn et al., 2005; Çolak et al., 2016). Some of those even assume full compliance to social routing advice (e.g. Angelelli, Arsik, Morandi, Savelsbergh, & Speranza, 2016; Basu, Yang, Lianeas, Nikolova, & Chen, 2017; Jahn et al., 2005), while others take into account the extent travellers are – collectively – assumed to value social outcomes (e.g. Avineri, 2009b; Çolak et al., 2016). The assumption of full market penetration and full compliance might hold in the case of autonomous vehicles. In other cases, it is unlikely that all travellers will use an information service for their trip, let alone a social routing service, or follow the recommended (social) routes.

In assessing the possible impacts of social routing, most studies use simplistic road networks consisting of a single origin and destination and only two or three route alternatives (e.g. Avineri, 2009b; Levy et al., 2017) or similar small-scale networks (e.g. Van den Bosch et al., 2011). A study by Çolak et al. (2016) shows differences in the percentage of potential savings achieved between a single commodity network compared to five real-world city networks. This suggests that studies using small road networks might not capture all route dynamics that play a role in real networks. Furthermore, most studies on the potential impacts of social routing consider only network efficiency. While network efficiency is important to traffic authorities, travellers are more concerned with their travel time (sacrifice) and its (un)fair distribution among them. As such, some recent studies propose social routing algorithms that take into account fairness and equity (Angelelli et al., 2016; Basu et al., 2017; Jahn et al., 2005; Levy et al., 2017). Finally, most studies present their findings on a relatively aggregated level, while especially the impacts on the individual traveller are of importance to the successful application of a social routing service.

Our study tries to overcome these shortcomings by a combination of aspects. First of all, our study pays attention to the potential impacts of social routing on both network efficiency and equity. Moreover, we use a large-scale, real-world road network to enhance external validity and apply several compliance rates. In addition, we pay special attention to the spatial distribution of social travellers among origins and destinations as this relates to network equitability and might influence network performance. Finally, we discuss our findings in light of observed individual compliance behaviour and market penetration obtained from a small-scale field experiment. This field experiment assessed whether travellers are willing to take a detour to the benefit of the road network when they are being asked or advised to do so in daily-life (Van Essen, Thomas, Van Berkum, & Chorus, 2018). By these efforts, we complement abovementioned studies and are able to identify the potential of information-based demand measures using social routing advice in improving road network efficiency.

The remainder of this chapter is structured as follows. First, Section 5.3 provides the research background. Subsequently, Section 5.4 describes the used methodologies for traffic assignment. We present the results with respect to network performance and equity in Section 5.5 and we interpret these results in light of the observed compliance behaviour obtained from a field experiment in Section 5.6. Finally, this chapter presents key conclusions in Section 5.7.

5.3. Background

When all travellers choose their routes socially – consistent with the pure system optimum – up to 25% of total travel time could theoretically be saved compared to a user equilibrium given linear latencies (i.e. the ratio between the selfish user equilibrium and the social system optimum in terms of average travel time, in which delay is a linear function of congestion, is at most 4/3 (≈1.33) (Roughgarden & Tardos, 2002)). In real-world networks, however, savings up to only 10% of total travel time would typically be attained (see e.g. Boyce & Xiong, 2004; Jahn et al., 2005). Note that potential travel time savings highly depend on the prevailing congestion level (e.g. Youn et al., 2008). Due to low compliance rates in response to social routing advice aforementioned potential travel time savings might never actually be achieved in reality, although part of the potential savings could be attained.

Route assignment strategies aiming at system optimal network conditions face equity issues. From the perspective of route guidance and traffic assignment, interpersonal equity refers to the distribution of travel time among travellers in a certain road network. To be more specific, comparable groups or individuals are treated similarly (i.e. horizontal equity) (Thomopoulos, Grant-Muller, & Tight, 2009), e.g. individuals travelling between the same origin and destination should have similar travel times. Moreover, individuals have internal standards, based on both previous experience and common knowledge, to which they compare their own outcomes as well, i.e. intrapersonal equity (Pritchard, 1969). As a result, a route advice that burdens a certain individual with a longer travel time than he is used to, will not be easily accepted. These equity issues might be important in the acceptance of and compliance with system-optimal route guidance. Pigou's example (Pigou, as cited by Roughgarden, 2006) shows that in a system optimum, travel times on the detour route are twice as high as travel times on the shortest route. In more realistic road networks, Jahn et al. (2005) found detours with travel times of 1.2 to 2.1 times as high. On the other hand, Levy et al. (2017) demonstrated that, although a static system optimum is unfair, alternating single travellers between sacrificing and gaining travel time on the long-term results in an equitable outcome that leads to overall travel time savings for all travellers.

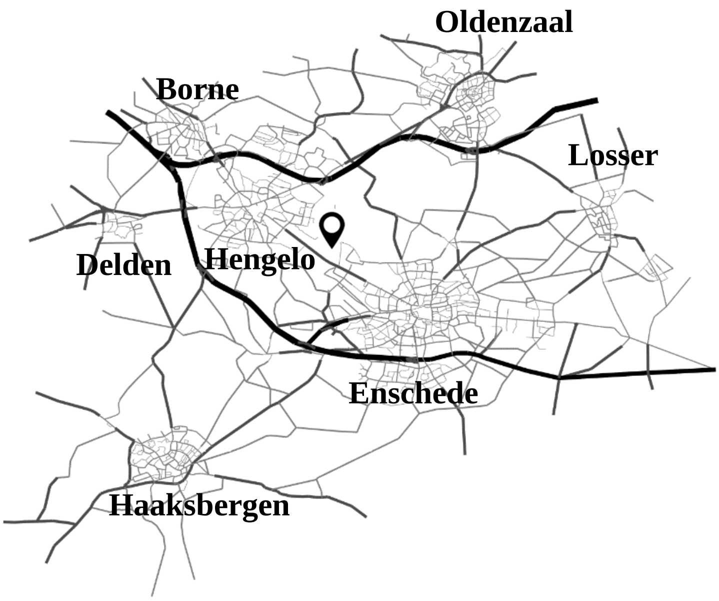
Several studies propose routing assignment strategies that compromise the pure system optimum in order to reduce inequity among travellers. For example, Jahn et al. (2005) propose a routing assignment strategy that involves user constraints which impose restrictions on the extra travel cost for each traveller. In order to determine acceptable route alternatives, they use a fixed tolerance factor that is applied on a so-called static normal length (hence, congestion is not taken into account). Similarly, Angelelli et al. (2016) propose a proactive route guidance system to minimize congestion in which the total inconvenience of drivers is bounded; i.e. only those routes are considered for which the relative difference with respect to the shortest travel time route is below a given threshold. However, knowledge about how inequitable the pure system optimum would be and whether this would lead to unacceptable travel times is limited. We use an explorative approach to assess the impacts of social routing at different compliance rates when no constraints are applied.

5.4. Methodology

We perform a traffic assignment in which we simulate the impacts of an social routing navigation service and conduct a cross-sectional analysis providing a scope that is manageable for a given day.

5.4.1. Traffic assignment

The road network used for traffic assignment entails part of the region of Twente (i.e. consisting of 7 small to medium-sized municipalities with a combined population of 346,948), The Netherlands, as illustrated in Figure 11. The road network is obtained from the Multi-Modal Transport Model Twente Region 2010 (Van der Honing, Kwant, & Tempert, 2011). We considered a very busy morning peak (7:00-9:00) − in line with the real-world experiment (see Section 5.6) – where calibrated demand from 2010 is increased by 50%. To save computational time, we removed all trips from those origin-destination (OD) pairs with a demand below 0.01; this resulted in a decrease of the total demand by only 0.9%, while the number of OD-pairs halved. One should note that the demand in the transport model represents trips rather than travellers at a given day.



Links [#]	**12,974**
Zones [#]	**1,178**
OD-pairs [#]	**352,202**
Demand [#]	**170,685**

Highway
Provincial road
Local road

Business & Science Park and University of Twente

Figure 11. Road network used for traffic assignment and study area field experiment.

We applied a static (multiclass) traffic assignment using the Disaggregate Simplicial Decomposition method as introduced by Larsson and Patriksson (1992). This algorithm is more efficient than commonly used optimization algorithms, especially for large-scale applications like ours. Moreover, the algorithm provides an overview of used route alternatives in equilibrium state without additional time-consuming calculation efforts. Calculations were done using the Matlab Software Package extending Matlab codes provided by Josefsson (2004).

We applied three different methods of assigning traffic:

- Selfish assignment leading to a user equilibrium network state (UE): This network state roughly represents the current traffic conditions (general assumption). Trips are made selfishly and take the shortest route.
- Social (non-selfish) assignment leading to a system optimal network state (SO): This network state represents the desired traffic conditions by the traffic authority. Trips are made socially and take the route with the lowest marginal travel time.
- Multiclass assignment leading to a mixed equilibrium network state (ME): This network state represents the traffic conditions when a social routing service is applied. We implement compliance behaviour by introducing two user classes; the first class consists of selfish trips (i.e. non-complying trips), while the second class consists of social trips (i.e. complying trips). Applied shares of social trips: 10%, 30%, 50%, 70% and 90% of total demand for each OD-pair. One should realize that not each social trip results in a detour.

We applied the commonly used Bureau of Public Roads (BPR) function (Bureau of Public Roads, 1964) to calculate travel cost for selfish trips and the marginal BPR-function (Spiess, 1997) to calculate travel cost for social trips; used parameter values are set to its traditional values α=0.15 and β=4 (e.g. Caggiani & Ottomanelli, 2011). The used settings and resulting performance of each assignment are shown in Table 11, background on settings can be found in Josefsson (2004).

Table 11. Settings and performance of assignments.

Settings for all assignments												
Tolerance sequence	1^{e}-3											
Max failures	1											
Iterations before failure	50											
Line search tolerance	10^{-8} times mean demand for OD-pairs											
Termination	Terminated when no new routes could be found for all classes											
	UE	**SO**	**ME-(10%)**		**ME-(30%)**		**ME-(50%)**		**ME-(70%)**		**ME-(90%)**	
Performance												
Total TT [min]	1,697,400	1,636,700	1,687,400		1,665,100		1,654,400		1,646,200		1,639,500	
# Iterations	18	52	17		65		75		100		79	
			Selfish trips	*Social trips*	*Selfish trips*	*Social trips*	*Selfish trips*	*Social trips*	*Selfish trips*	*Social trips*	*Selfish trips*	*Social trips*
Tolerance reached	0.00099	0.0012	0.0010	0.0006	0.0003	0.0009	0.0002	0.0010	0.0001	0.0010	0.0003	0.0010
Abs. avg. route cost diff.*	0.0016	0.0027	0.0048	0.0270	0.0099	0.0287	0.0045	0.0040	0.0033	0.0024	0.0043	0.0019
Abs. route cost diff. (90^{th} pctl)*	0.0072	0.0065	0.0159	0.0801	0.0347	0.0703	0.0144	0.0103	0.0036	0.0050	0.0048	0.0053
Rel. avg. route cost diff.*	0.00012	0.00016	0.00039	0.0013	0.0007	0.0015	0.0004	0.0002	0.0004	0.0001	0.0005	0.0001
Rel. route cost diff. (90^{th} pctl)*	0.00042	0.00034	0.0010	0.0037	0.0022	0.0038	0.0008	0.0005	0.0005	0.0002	0.0007	0.0003
# routes found	697,787	1,055,784	682,374	967,913	656,221	1,076,604	647,494	1,102,654	645,833	1,103,781	647,922	1,082,401
# routes used	409,003	484,389	393,763	389,587	377,923	445,663	368,421	468,148	357,158	474,728	354,216	487,131

*Costs are in minutes. Marginal route cost in case of SO and for social trips in ME.

5.4.2. Outline of analysis

Our analysis consists of three parts, i.e. impacts on network performance, impacts on equity and an elaboration on those impacts taking the distribution of detour trips among OD-pairs into consideration.

Impacts on network performance

First, we compare the total travel time within each network state to identify whether an information-based demand measure reduces the total travel time with respect to the current traffic conditions (i.e. user equilibrium) and to what extent potential travel time savings could be achieved. Subsequently, we look into the roads taken for different network states. Thereby, we identify towards which specific roads traffic needs to be directed to enable an efficient road network. In this, we make a distinction between lower hierarchy and higher hierarchy roads, identifying cut-through traffic. Finally, we look into the volume-to-capacity (v/c) ratio on each link in the road network for each network state. The v/c-ratio measures how well a certain road section can deal with the assigned traffic flow. High v/c-ratio's indicate higher congestion levels. As such, we identify which roads benefit under which situation and to what extent, expressed in (congested) vehicle kilometres.

Impacts on equity

Many general measures of equity exist, e.g. the mean of outcome differences, the range of outcome differences, the variance of outcome differences or the Gini coefficient. We consider multiple measures, as Ramjerdi (2006) argued that different measures might lead to different conclusions. Moreover, we distinguish two important situations for comparison; 1) comparison of travel times that would be experienced within a specific network state to travel times experienced in the current situation (i.e. user equilibrium), and 2) comparison of travel times of detours to travel times of shortest routes within the specific network state. The first is relevant as travellers do not like to be worse off than their current situation, whereas the second is relevant as travellers do not like to be worse off than their neighbour travelling to the same destination. Note that we refer to losses when comparing travel times between a specific network state and the user equilibrium, while we refer to sacrifices when we compare travel times with the shortest travel time within a specific network state.

First, we calculate Gini coefficients – a commonly used measure for outcome inequality − for each abovementioned comparison; this results in two Gini-coefficients for each network state. The first coefficient indicates the inequality of the distribution of travel time gains and losses among travellers in the specific network state compared to the user equilibrium, while the second coefficient indicates the inequality of the distribution of travel time sacrifices among travellers within the specific network state. We apply a normalization method that is able to deal with negative values (in our case travel time losses) as introduced by Raffinetti, Siletti, and Vernizzi (2015). A coefficient of 0 represents perfect equality (i.e. all travel time differences are zero), while a coefficient of 1 represents perfect inequality (i.e. one traveller experiences the total amount of loss, one traveller experiences the total amount of gain and all other travellers experience no difference). Subsequently, we look more detailed at the distribution of travel time gains and losses for each network state compared to the travel time in the current situation (i.e. UE) as well as the distribution of travel time sacrifices within the specific network state.

Elaboration considering the share of detour trips among OD-pairs

We elaborate on the impacts on network performance and equity taking the distribution of detour trips among OD-pairs into consideration. As such, we illustrate the importance of this distribution in improving road network efficiency. First, we provide an example showing the origins at which travellers need to take a detour at the system optimum for one specific destination. Subsequently, we assess the cumulative distribution of OD-pairs (i.e. all origins and all destinations) on which a certain fraction of trips entails a detour.

5.5. Traffic assignment results

5.5.1. Impacts on road network performance

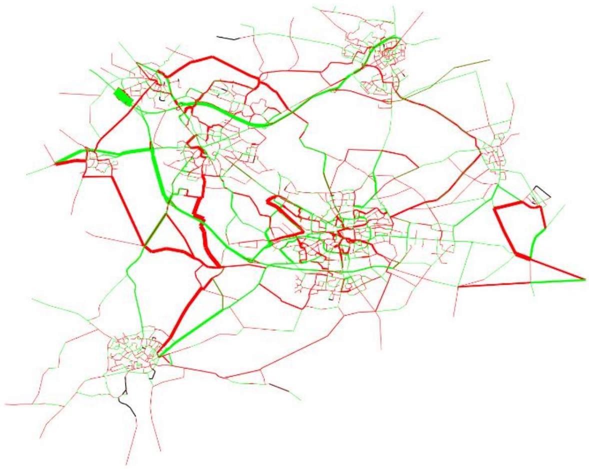
Potential travel time savings

Table 12 shows the total travel time within our road network for each scenario. We observe that up to 3.6% of the total travel time at User Equilibrium could be potentially saved. Compared to the findings by Van den Bosch et al. (2011) on a small network − they found that a social trip share of 20% resulted in a travel time reduction of 7% of potential travel time savings – our results indicate higher travel time savings (i.e. 35% travel time savings at a social trip share of 20% based on interpolation). Moreover, compared to the dynamic findings of Levy et al. (2017) on a binary route network − they found that a social trip share of 30% resulted in a travel time reduction of approximately 20% of potential travel time savings, while social trip shares between 60% and 90% resulted in about full travel time savings (i.e. 100%) − our results show a more gradual trend in which most savings are achieved at low social trip shares.

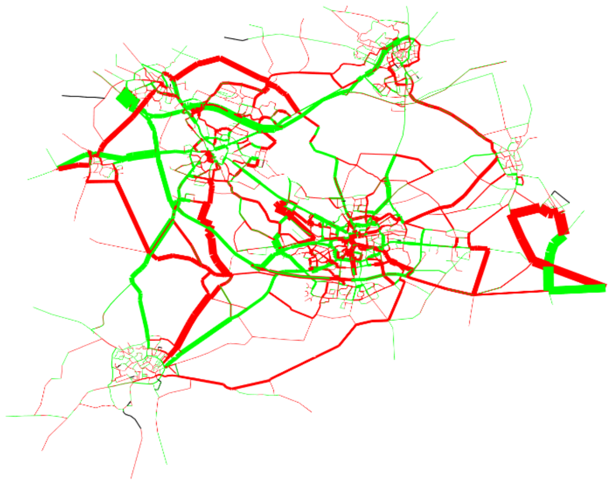
Table 12. Total travel time within Twente Network for each scenario.

Assignment	Total travel time [min]	Potential travel time savings at network state [%]	% of total potential travel time savings achieved [%]
UE	1,697,400	-3.6	0
ME-10%	1,687,400	-3.0	16
ME-30%	1,665,100	-1.7	53
ME-50%	1,654,400	-1.1	71
ME-70%	1,646,200	-0.6	84
ME-90%	1,639,500	-0.2	95
SO	1,636,700	0	100

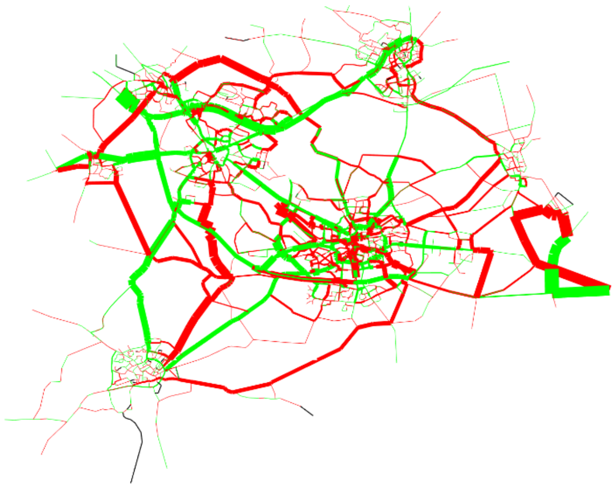
Roads taken



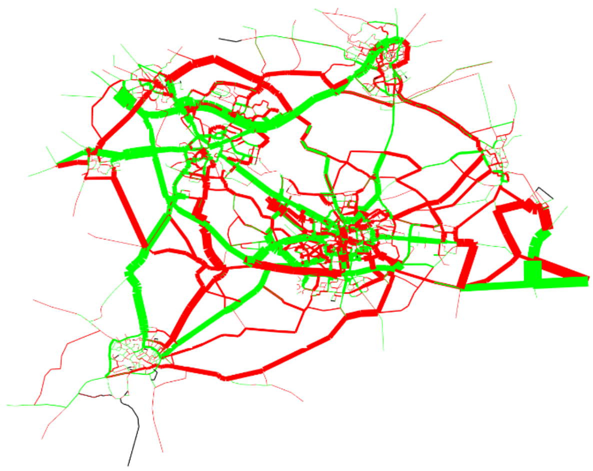
a) Flow difference Mixed Equilibrium (10%) versus User Equilibrium



b) Flow difference Mixed Equilibrium (30%) versus User Equilibrium



c) Flow difference Mixed Equilibrium (50%) versus User Equilibrium



d) Flow difference System Optimum versus User Equilibrium

Red: more flow in ME/SO than UE, Green: less flow in ME/SO than UE, Black: no change in flow. Thickness indicates the size of flow difference.

Figure 12. Flow difference for: a) Mixed Equilibrium (10%) versus User Equilibrium, b) Mixed Equilibrium (30%) versus User Equilibrium, c) Mixed Equilibrium (50%) versus User Equilibrium, and d) System Optimum versus User Equilibrium.

Figure 12 shows the flow differences on all road network links for the Mixed Equilibria and System Optimum compared to the User Equilibrium. We observe that in order to increase road network efficiency travellers need to divert from the main roads, such as the highway and a considerable number of provincial roads, towards the more local roads. This observation is supported by Table 13, which distinguishes between road hierarchy levels based on speed limit while presenting differences in vehicle kilometres travelled between the specific network state and the user equilibrium. Note that the total vehicle kilometres travelled increases at higher network efficiency. These findings are in line with findings by Boyce and Xiong

(2004), who compared SO-routes with UE-routes for several OD-pairs. The observed trend is present for all equilibria although it appears to be stronger at higher social trip shares, as expected.

Table 13. Difference in vehicle kilometres (veh-km) differentiated by link hierarchy level for each network state compared to the User Equilibrium.

	Hierarchy level	*Δ veh-km [x10⁶]*	*Total Δ veh-km [x10⁶]*
ME-10%	Low*	+10.8	+9.9
	High**	-0.9	
ME-30%	Low*	+27.6	+21.5
	High**	-6.1	
ME-50%	Low*	+34.4	+20.2
	High**	-14.2	
ME-70%	Low*	+39.4	+18.6
	High**	-20.8	
ME-90%	Low*	+42.9	+16.8
	High**	-26.1	
SO	Low*	+44.1	+16.1
	High**	-28.0	

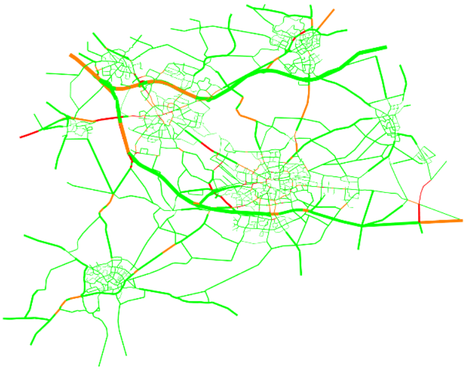
**Links with* a *speed limit of 30 or 60 km/h* (i.e. local roads and collector roads)
***Links with a speed limit of 50, 80, 100 or 110 km/h* (i.e. arterials and freeways)

Volume-to-Capacity Ratio

Figure 13 shows the volume-to-capacity (v/c) ratio on each link in the road network for several network states. In this, we use a V/C ratio classification that is loosely based on Hartgen and Fields (2006), among others:

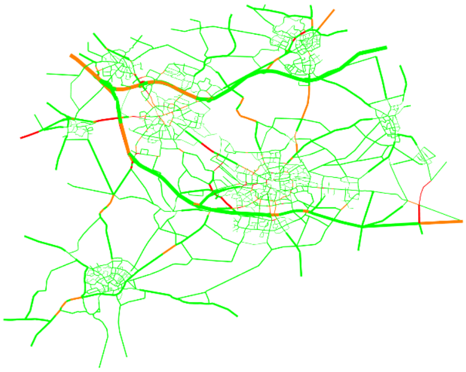
- < 0.7 (green): Reasonably constant traffic conditions with some influence by others, only incidental congestion.
- 0.7-0.9 (orange): Unstable traffic flow which could easily result in structural congestion. Comfort and convenience levels of drivers decline noticeably and manoeuvrability is restricted.
- > 0.9 (red): Bad traffic conditions with structural congestion on a daily basis, highly sensitive to small disturbances in traffic flow.

We observe a decrease in number of links on which structural congestion occurs when moving from a User Equilibrium towards a System Optimum; this entails a reduction of $87x10^6$ vehicle kilometres on daily congested roads (v/c ratio: >0.9) and another $35x10^6$ vehicle kilometres on roads with unstable traffic flows (v/c ratio: 0.7-0.9). From Figure 14 it seems that this decrease mainly occurs on links within the main city areas, such as those on inner city ring roads and on in- or outbound routes. In other words, it seems that the throughput on major city roads increases, while throughput on provincial roads and highways remains the same. Hence, city centres seem to benefit the most.



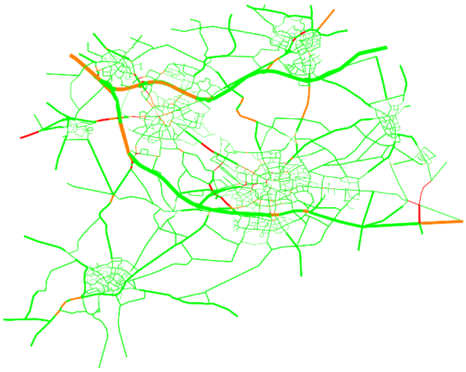
V/C ratio	Links [#]	Veh-km [x10^6]
<0.7 (green)	8,474	903
0.7-0.9 (orange)	518	316
>0.9 (red)	226	129
Total	9,218	1,348

a) User Equilibrium



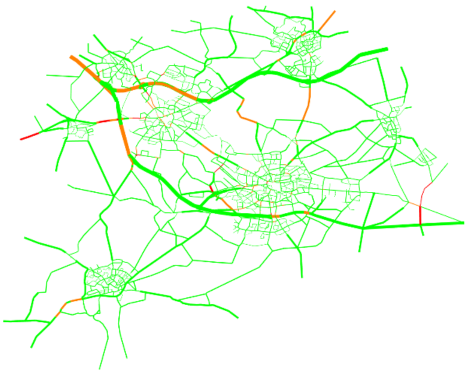
V/C ratio	Links [#]	Veh-km [x10^6]	Veh-km [x10^6] compared to UE
<0.7 (green)	8,599	941	+38
0.7-0.9 (orange)	488	301	-15
>0.9 (red)	197	116	-13
Total	9,284	1,358	+10

b) Mixed Equilibrium (10%)



V/C ratio	Links [#]	Veh-km [x10^6]	Veh-km [x10^6] compared to UE
<0.7 (green)	8,675	998	+95
0.7-0.9 (orange)	454	300	-16
>0.9 (red)	145	71	-58
Total	9,274	1,369	+21

c) Mixed Equilibrium (30%)



V/C ratio	Links [#]	Veh-km [x10^6]	Veh-km [x10^6] compared to UE
<0.7 (green)	8,766	1,040	+137
0.7-0.9 (orange)	427	281	-35
>0.9 (red)	78	42	-87
Total	9,271	1,363	+15

d) System Optimum

Green: v/c-ratio <0.7, Orange: v/c-ratio 0.7-0.9, Red: v/c-ratio >0.9

Figure 13. Intensity over capacity ratios on road network links for several network states.

Green: v/c ratio improved to a better classification category in SO, Red: the v/c ratio deteriorated to a worse classification category in SO, Black: worse V/C classification category (hence improvement possible) and no difference between SO and UE, Grey: best v/c classification category and no difference between SO and UE.

Figure 14. V/C ratio difference plot for the System Optimum compared to the User Equilibrium.

5.5.2. Impacts on equity

Table 14 shows the Gini coefficients obtained for each network state based on the travel time gains and losses travellers experience compared to the user equilibrium and the travel time sacrifice social travellers have to make compared to the shortest travel time route within the specific network state. As expected, each network state suffers from inequality. Gini coefficients decrease at larger shares of social trips. Moreover, equity within network states seems to be worse than equity with respect to the user equilibrium. This observation is supported by findings of Jahn et al. (2005). Since compliance is expected to be higher under equitable conditions, it might be easier to arrive at a certain network state than to maintain it. That is, network states are unstable.

Note that out of all network states, the system optimum is the most equal regarding gains and losses compared to the user equilibrium, while it is the least equal regarding travel time sacrifices within the network state. As we can observe when we look more detailed at the distribution of travel time gains, losses and sacrifices (e.g. Table 15 and Table 16), this might be explained by the fact that almost 40,000 travellers experience a travel time loss at the system optimum compared to the user equilibrium, while only about half of them actually take a detour compared to their neighbours travelling on the same OD-pair.

Table 14. Gini coefficients based on travel time gains and losses compared to the user equilibrium and travel time sacrifice compared to the shortest travel time route within the specific network state.

	Gini coefficient	
	Compared to User Equilibrium	Within network state
ME-10%	0.83	0.96
ME-30%	0.83	0.94
ME-50%	0.81	0.92
ME-70%	0.79	0.90
ME-90%	0.78	0.89
SO	0.78	0.96

Travel time gains and losses compared to the User Equilibrium

Figure 15 shows the cumulative distribution of travellers' net travel time benefit in each network state compared to their travel time in the User Equilibrium. We find that most travellers do not experience any meaningful change in travel time; in each network state, more than 80% of travellers experience a travel time difference within a range of only 1 minute, whereas even more than 95% of travellers experience a travel time difference within a range of 2 minutes. Moreover, we clearly observe that travellers who benefit outnumber those who sacrifice in each network state (ratio's: 2.7:1 in SO, 3.7:1 in ME-10%, 2.6:1 in ME-30%, 2.5:1 in ME-50%, 2.6:1 in ME-70% and 2.7:1 in ME-90%). It seems that the Mixed Equilibrium (10%) is closest to a User Equilibrium as its distribution of gains and losses is most steep; its overall benefit is close to zero and the standard deviation is lowest (see Table 15). However, compared to the System Optimum it has higher losses, while gains are much lower (both on average and at maximum). A similar, although less extreme trend is visible for the other equilibria. In the system optimum losses are smallest, while gains are highest.

Note that Çolak et al. (2016) found an average benefit of 1 to 3 minutes for the system optimum, depending on the real-world city considered. We found an average benefit of only 0.35 minutes. Similarly, they found larger travel time gains and losses (at system optimum). These differences might be because they focus on metropolitan cities while our study considers a small-sized region.

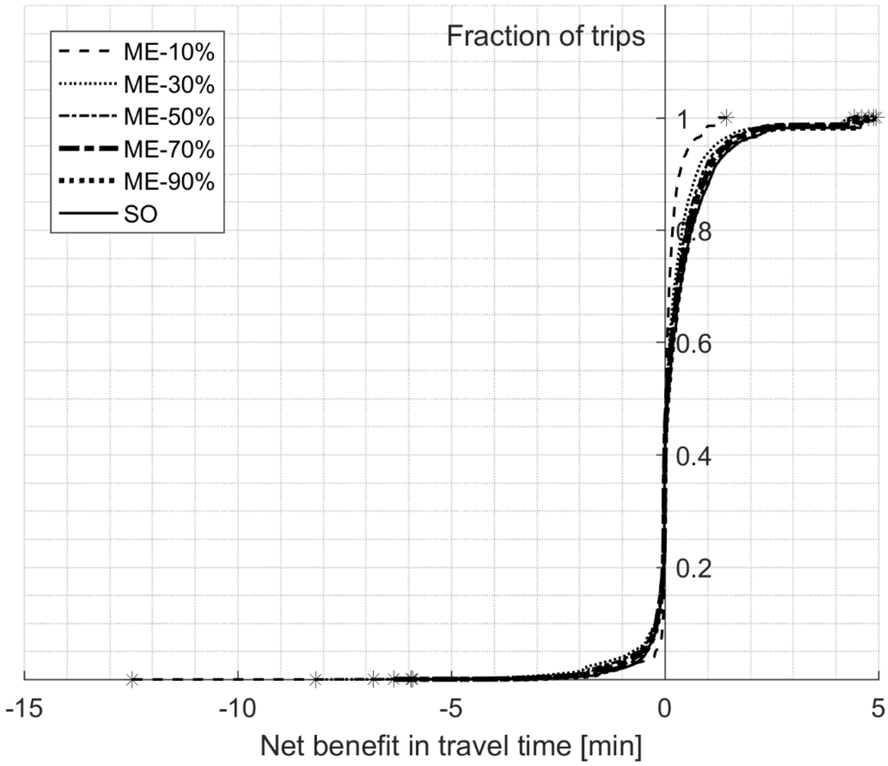


Figure 15. Cumulative distribution of net benefit in travel time in System Optimum and Mixed Equilibria compared to the travel time in User Equilibrium. Negative values refer to an increase in travellers' travel time, whereas positive values refer to a decrease in travellers' travel time.

Table 15. Average and 99th percentile of travel time losses and gains with respect to the travel time in User Equilibrium.

	Travel time loss			Travel time gain			Overall Average Benefit [minutes]**
	Travellers [#]	Average [minutes]	99th percentile [minutes]*	Travellers [#]	Average [minutes]	99th percentile [minutes]*	
ME-10%	26,640	0.46	5.49	97,933	0.22	0.72	0.05 (0.49)
ME-30%	38,119	0.55	4.07	98,254	0.53	1.66	0.19 (0.89)
ME-50%	39,525	0.46	3.26	99,415	0.61	2.02	0.25 (0.90)
ME-70%	39,529	0.40	3.00	101,850	0.65	2.25	0.30 (0.90)
ME-90%	38,602	0.34	2.55	105,030	0.67	2.39	0.33 (0.90)
SO	38,600	0.32	2.48	105,850	0.68	2.29	0.35 (0.91)

**the maximum loss and gain are about twice the value of the 99th percentile [minutes]*
***Standard deviation [minutes] between brackets*

Travel time sacrifices within the specific network state

Figure 16 shows the cumulative distribution of these losses among travellers for each of the network states. We observe that the majority of travellers (70% to 90% depending on the network state) do not need to sacrifice any travel time as they can use the shortest route. Moreover, only about 2% to 8% of travellers need to sacrifice more than 1 minute of travel time by taking the detour, while only 1% to 4% of travellers need to sacrifice more than 2 minutes. It seems that the number of losers is similar for the System Optimum and Mixed Equilibrium (10%), while the number of losers in other Mixed Equilibria is considerably higher. On average, losses in the System Optimum are smallest (see Table 16). Note that only about 12% of travellers need to take a detour in order to achieve a system optimum.

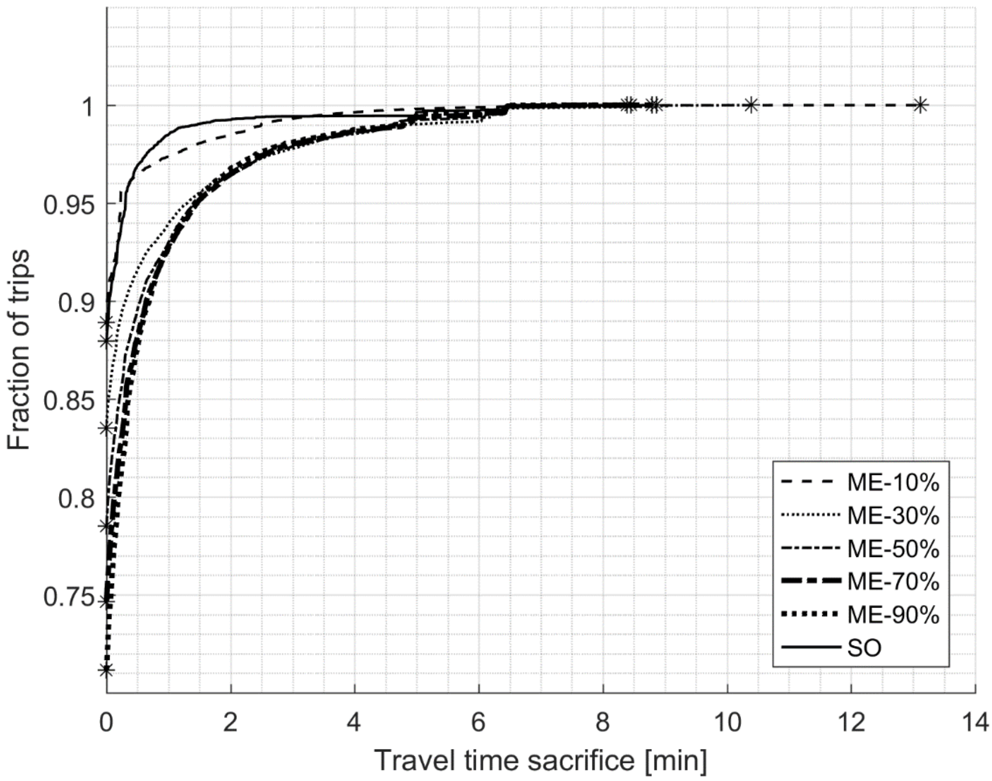


Figure 16. Cumulative distribution of travel time sacrifice with respect to the shortest travel time route within the specific network state.

Table 16. Average and 99th percentile of travel time losses with respect to the shortest travel time route within the specific network state.

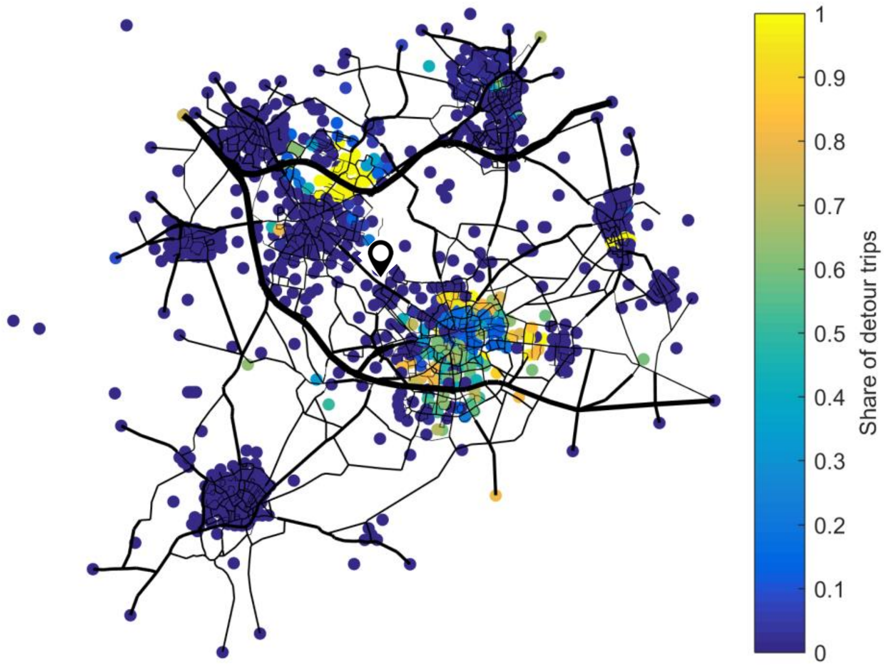
	Travel time sacrifice		
	Travellers [#]	Average [minutes] *	99th percentile [minutes] **
ME-10%	18,955	0.78 (1.24)	6.90
ME-30%	28,138	1.27 (1.71)	6.15
ME-50%	36,703	1.09 (1.47)	5.35
ME-70%	43,249	0.98 (1.33)	5.40
ME-90%	49,264	0.87 (1.22)	4.91
SO	20,535	0.63 (1.21)	3.59

**Standard deviation [minutes] between brackets*

*** the maximum sacrifice is about twice the value of the 99th percentile [minutes]*

5.5.3. Spatial distribution of detour trips

If only about 12% of travellers need to take a detour in order to achieve a system optimum, then why do mixed equilibria with more than 12% of social trips not result in system optimal conditions? The main reason for this might be found in the spatial distribution of detour trips within a system optimum. Figure 17 shows for each origin the share of total trips to the University and Business & Science Park that entail a detour at System Optimum. It illustrates that most origins of social trips are centred at the city of Enschede and to the north of the city of Hengelo. It is highly unlikely that travellers who are willing to act social and take the detour are starting their trip at exactly these origins.



Business & Science Park and University of Twente

Figure 17. Share of detour trips among origins of trips that have the University or Business & Science Park as destination at System Optimum.

Now, take a look at Figure 18 showing the share of detour trips considering all OD-pairs. We find that at the system optimum less than 20% of the OD-pairs contain detour trips. Note that the share of detour trips on these OD-pairs is considerably high. When the share of detour trips is restricted, as in the mixed equilibria, we see that a larger fraction of OD-pairs is affected. Hence, its seems that these additional OD-pairs need to compensate for the fact that not enough travellers are willing to take this detour on those OD-pairs at which a specific (high) share of detour trips is necessary to achieve the system optimum. This also explains why a network state with a social trip share of 30% does not result in a system optimum, while only 12% of trips have to take a detour in order to achieve a system optimum.

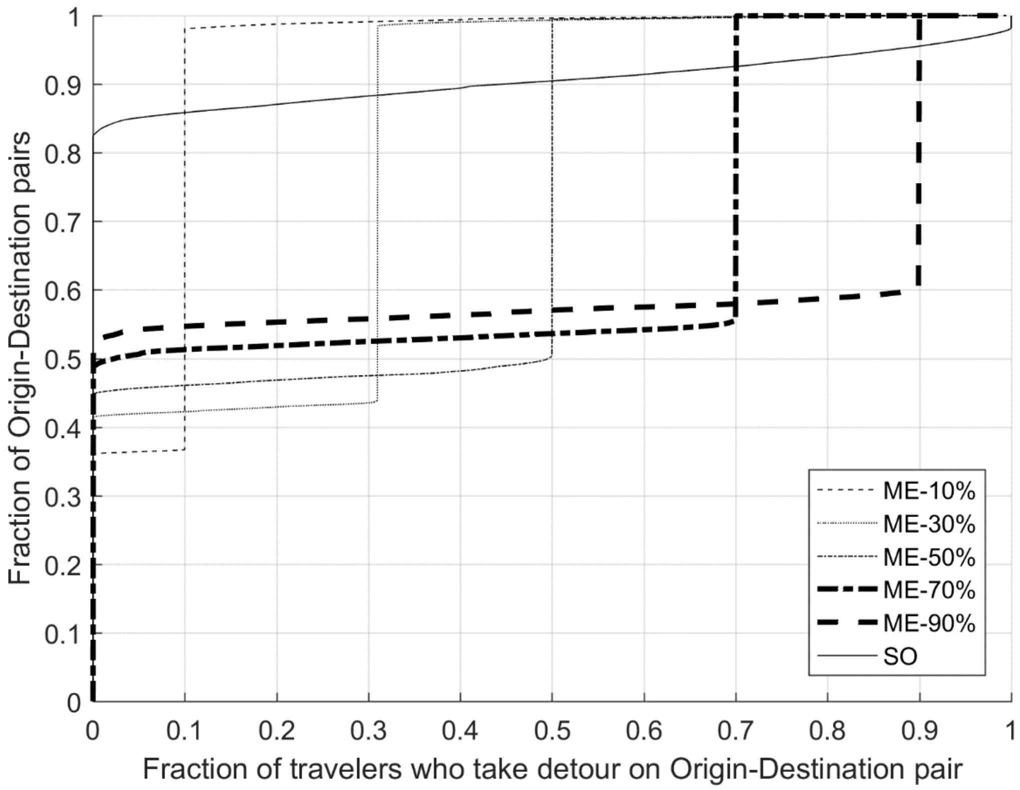


Figure 18. Cumulative distribution of OD-pairs on which a certain fraction of travellers needs to take a detour.

From the abovementioned, the distribution of social travellers among OD-pairs is crucial in achieving the system optimum. As such, the prevailing distribution of social travellers within a real-world road network affects both network performance and equity when the information-based demand measure is applied.

5.6. Traffic assignment results in light of observed compliance behaviour

Now, we assess the traffic assignment results in light of the observed compliance behaviour from the field experiment. We introduce the field experiment and its set-up and discuss realistic shares of social trips based on observed compliance behaviour as well as their implications.

Overview field experiment

We conducted a real-world experiment on individual compliance with social routing advice; for details on this experiment and its findings, see Van Essen et al. (2018). The experiment took place in Twente, the Netherlands, during 5 consecutive weeks. Participants (29 employees of the Business and Science Park and/or University of Twente) were randomly assigned to one of two information strategies; i.e. a 'Recommend'-strategy or an 'Educate'-strategy. The 'Recommend'-strategy has low information content and capitalizes on aspects of bounded rationality such as limited mental resources and decision time *('In order to alleviate congestion, please use this route today')*, while the 'Educate'-strategy has high information content and focusses on creating awareness and changing attitudes towards social behaviour. This strategy consisted of three elements: 1) explain the importance of social behaviour, 2) provide a map with both the usual and social alternative and inform on estimated travel times for both alternatives, 3) provide route advice for that day. Participants installed the smartphone application 'SMART Mobility' (SMART in Twente, 2016) on their personal smartphone which automatically collected trip-data, i.e. origin, destination, departure time, arrival time, route and mode (-chain) for each trip. On working days, this application sent tailored information messages containing social route advice for the morning commute to its users. For two days every working week the social route alternative was advised to each participant, while on the remaining days of the working week their usual route was advised. Stated intentions based on a choice situation tailored to the participants real-life choice context were collected one month before the start of the experiment.

Note that in our interpretation we will ignore the fact that two distinct information strategies were applied in the field experiment as no significant differences in compliance rate between both information strategies were observed (Van Essen et al., 2018). Moreover, note that we were not able to determine the maximum sacrifice participants were willing to make from the field experiment as travel time sacrifices resulted from the participants' daily-life context (sacrifices ranged from 2 to 7 minutes). The traffic assignments in this chapter are unconstrained by travel time sacrifice. In other words, traffic assignment assumes that social travellers will comply with the social routing advice at any magnitude of travel time sacrifice.

Observed compliance behaviour and assumed share of social trips

It is difficult to directly link the observed compliance behaviour from the field experiment to a social trip share for traffic assignment. After all, the field experiment ran for several weeks, while our traffic assignment represents a given day. Moreover, participants did not commute or did not read the information message every day. However, using several assumptions we can derive social trip shares that would be realistic to expect at a given day.

Let us start with setting the upper boundary; a preceding stated choice experiment conducted among 2011 respondents resulted in a strong compliance rate − i.e. the compliance rate when the social detour was advised − of 57%. Of course, it is quite easy to state that one would choose the detour and contribute to network efficiency from behind a computer. However, when the actual consequences of such a choice (i.e. higher travel times) are experienced in reality, one might not that easily choose the detour. As a consequence, the observed strong compliance rate from the field experiment is only 31%.

In the experiment, all participants received social routing advice. In reality, only a minority of travellers would use a social routing service and receive such advice. Therefore, we might want to take into account a market penetration rate. This rate could be based on participants' stated intention to choose the social route alternative as provided before the start of the experiment. After all, those participants are positive about the concept of social routing and therefore most likely willing to use such an information service outside of participation in the experiment. This results in a market penetration rate of 41%. If we now take into account the observed strong compliance rate from only those participants (i.e. 56%), this results in a social trip share of 23%.

In the experiment, social routing advice alternated between participants' usual route and some longer route alternative (i.e. the detour). Observed strong compliance behaviour might result from the frequency at which the detour route was advised to participants. As our traffic assignment represents only one given day, we could introduce some alternation rate; only some part of the travellers would receive the advice to take a detour on a given day, while another part would receive this detour advice the next given day. Note that this might not exactly hold as the trips in the transport model do not represent individual travellers. Hence, trips at a certain given day and a certain other (e.g. next) given day are not necessarily made by the same person. In the experiment, however, 43% of the advice messages entailed a detour. If we would combine this with the market penetration rate of 41% and the observed strong compliance rate of 56%, this would result in a social trip share of only 11%.

One could argue which assumptions might hold and several combinations could be made. Due to the low sample size of the field experiment, one should take these shares rather lightly. Overall, observed compliance behaviour seems to be represented most realistically by social trip shares between 10% to 30%. This is still a broad range. Hence, in order to provide a conservative estimate of the impacts of a social routing service, we take the social trip share of 10%; as such we take into account compliance behaviour, market penetration and alternation of detour advice. In that case, 16% of potential travel time savings would be achieved. Moreover, 10% of daily congested vehicle kilometres and another 5% of vehicle kilometres in unstable traffic flows would already be avoided. However, the resulting network state would be far from equitable as a minority of travellers would experience high travel time losses (i.e. with respect to UE) as well as large sacrifices (i.e. with respect to shortest travel time route within the specific network state). Some travellers lose up to 5.5 minutes, while the majority of travellers will experience a travel time difference (i.e. gain or loss) of less than 2 minutes compared to the user equilibrium. Moreover, less than 4% of travellers need to sacrifice more than 2 minutes (some even up to up to 7 minutes) compared to their neighbour on the shortest route. On average, travellers who take the detour would only sacrifice 0.78 minutes.

5.7. Conclusion and discussion

This chapter shows the impacts of social routing on network efficiency and equity in a large-scale road network. Several network states were determined; a User Equilibrium (roughly representing current traffic conditions), a System Optimum (the desired traffic conditions by the traffic authority), and Mixed Equilibria based on different social trip shares (i.e. 10%, 30%, 50%, 70% and 90% of trips are made socially), representing traffic conditions when a social routing service is implemented. We expect that a social routing service as implemented in the field experiment would result in 10% to 30% of the trips being made socially; in order to provide a conservative estimate on the impacts, we assume a social trip share of 10%.

When looking at network efficiency, we observe that 3.6% of total travel time at the current traffic conditions could potentially be saved in our research area during the morning peak. To put this into perspective: a total of 60,700 minutes could be collectively saved each (working) day, corresponding to annual regional economic benefits of about €2,600,000,- (based on a value of time of €10,- an hour (Kouwenhoven et al., 2014)). The information-based demand measure is expected to achieve about 16% of these potential travel time savings, whereas individual benefits are marginal; the majority of travellers experience a travel time gain of less than 2 minutes. Most travellers would not notice these travel time differences as travel time variability caused by events, weather conditions or traffic lights are often higher (Çolak et al., 2016). Nonetheless, their driving comfort might increase due to the improved throughput. Observed network impacts indicate that at the desired network state structural congestion and unstable flows would be reduced, especially on major city roads. However, trips seem to be redirected through minor local roads, increasing cut-through traffic. Hence, liveability in these areas is negatively affected. One should realize that these findings might be dependent on the network used. However, in many networks the alternatives to arterial roads are local roads. As such, these findings are likely to be generalizable. Moreover, these findings provide evidence for the need to pursue a societal optimum – where not only travel time savings are considered, but also liveability as well as other societal relevant issues – rather than the traditional system optimum. One should realize that this might be at the expense of network efficiency.

Regarding equity impacts, we observe that network states resulting from lower social trip shares are on average closer to the User Equilibrium than network states resulting from higher social trip shares; most travellers experience a net benefit close to zero. However, in those network states a few travellers experience large travel time losses (up to 5.5 minutes). Those extremes might be problematic when it comes to compliance. After all, travellers are more likely to comply with social routing advice when travel time sacrifices are small. From that point of view, a system optimum would be more beneficial to all travellers, i.e. average losses are smallest and the maximum loss is lowest, while average travel time gains are highest. Moreover, the detours travellers have to make compared the shortest travel time route their neighbours are using, are smallest under system optimal conditions. Hence, it seems that the lower the share of social trips, the more social travellers need to compensate for the selfish behaviour of others by taking longer detours and sacrificing more travel time. Policymakers should be aware of this as it forms an important barrier in initiating a shift towards the System Optimum.

In order to achieve a system optimum only 12% of travellers need to take a detour. However, all those social travellers need to be concentrated on only a few specific OD-pairs; i.e. on these OD-pairs a large share of travellers need to take a detour, while on other OD-pairs none of the travellers needs to do so. It seems highly unlikely that on these specific OD-pairs the share of social travellers would be large enough. This emphasizes the fact that the distribution of social travellers among origins and destinations is crucial in achieving a desired network state.

Note that route flows within static cases of traffic equilibrium are non-unique; i.e. there can be many route flow solutions. Whether or not our findings are general, or are partly explained by particularities of the route flows produced by the applied algorithm, is an important topic for further research.

Overall, the application of a social routing service as implemented in the field experiment is expected to be positive in reducing total travel time within the network and in keeping cut-through traffic limited compared to a system optimum, whereas individual travellers seem to be less fortunate as higher sacrifices and lower gains are experienced compared to a system optimum. Our findings emphasize the importance for future research in social routing to not only pay attention to potential travel time savings, but also consider impacts on equity, among others. Moreover, we provided insights into network impacts that result from the application of an information-based demand measure providing social routing advice using findings obtained by a field experiment in a daily-life context. As such, we identify the potential of applying travel information as a measure in order to improve road network efficiency.

5.8. Acknowledgement

This work is part of the research programme TRAIL Graduate School, which is financed by the Netherlands Organisation for Scientific Research (NWO).

6. Conclusions, implications and future research

In this thesis, the potential of information-based demand measures to improve road network efficiency by rerouting travellers using social routing information is examined. To that end, a literature study, stated-choice and revealed-choice experiments and network simulation were conducted. This chapter presents conclusions that can be drawn from the findings of this research (Section 6.1), discusses research implications relevant to policy-makers (Section 6.2) and provides recommendations for future research (Section 6.3).

6.1. Conclusions

1) ***What role do (conventional) travel information, bounded rationality and non-selfish behaviour play in the route choice behaviour of travellers and network efficiency?***

This thesis hypothesized that in order to understand the potential of specific travel information in terms of directing the transport system towards a system optimum at the network level, one needs to understand how both bounded rationality and non-selfish behaviour interact at the individual level. Findings from literature, as presented in the literature review, seem to confirm this hypothesis; individuals' degree of rationality and selfishness are recognized to be important in actual (route) choice behaviour. This is strengthened by findings from the stated-choice experiment; these indicate that travellers who are cooperatively oriented are more likely to comply with social routing advice, while travellers who make their route choices in a habitual way are less likely to comply. Moreover, there exists a general consent among studies that selfish choice behaviour tends to lead to an inefficient user equilibrium, while social choice behaviour might result in a system optimum. Due to day-to-day dynamics and bounded rationality, the actual network state within a road network will not exactly be a user equilibrium (nor a system optimum), although studies have indicated that established network states are closer to the user equilibrium than a system optimum. Yet, conventional (personalised) travel information – as currently provided to travellers – aims at the individual's benefit and therewith stimulates rational selfish choice behaviour. After all, the field experiment providing conventional travel information shows that the provision of travel time information leads to a decline in switching propensity and a higher probability that the shortest route is chosen. As such, conventional travel information directs the established network state towards a perfect user equilibrium. Hence, to achieve system optimal network conditions, travel information that stimulates non-selfish choice behaviour should be provided; the topic of this thesis.

2) To what extent do travellers comply with social routing advice and what are their main motivations for (non-)compliance?

Based on both the stated choice experiment and the SMART field experiment, it is found that travellers are willing to (sometimes) choose the social route over their usual route when they are being advised or asked to do so. In the stated choice experiment, a large variation was found in terms of travellers' intrinsic inclination to comply with the social routing information. Overall, it seems that travellers' compliance with received information significantly depends on the framing of the information message, its societal goal, the size of the travel time sacrifice and personality. More specifically, it is found that travellers are most likely to choose the social alternative when small travel time sacrifices are involved, when information messages are aiming at alleviating congestion, and when these messages are framed according to the 'Nudge'-strategy, 'Social Reinforcement'-strategy or 'Education'-strategy. Moreover, travellers who are cooperatively oriented are more likely to comply with social routing advice, while travellers who make their route choices in a habitual way are less likely to comply. However, results from the revealed choice experiment suggest that in daily-life people comply less with the advice than would be expected based on stated choice. Moreover, compliance seems merely the result of individuals' generic inclination to comply, rather than being influenced by information frames or particular societal goals. Overall, in 31% of the daily-life cases travellers complied with the advice to take the social route alternative, whereas for the hypothetical cases a compliance rate as high as 57% was observed. Such inconsistencies between stated choice and revealed choice experiments often occur when social preferences are involved (e.g. Levitt & List, 2007).

Analysis of motivations for revealed behaviour shows that an intrinsic motivation to contribute to improved road network conditions is the main stated reason for compliance. This is in line with results obtained from a discrete choice model on revealed behaviour. Hence, the applied social information strategies seem to have their intended effect. When travellers did not comply with social routing advice, various motivations are provided. Most motivations relate to perceived traffic conditions. That is, compliance rates were low when (perceived) traffic conditions on route alternatives gave the impression that there was no need to take a detour. This indicates that users of the information service did not fully trust the advice – hence, the advised route should be an intuitive and plausibly social alternative at the prevailing traffic conditions – or doubted their individual influence on traffic conditions. When the social routing service takes into account the intuitiveness and plausibility of the advised alternatives, compliance rates might increase.

Finally, findings from the stated choice experiment indicate that compliance rates in response to social routing advice increase when travel time differences between route alternatives are small (although findings from the revealed choice experiment could not confirm this), whereas in response to conventional travel information the opposite is observed in the real-world experiment conducted in the USA. This suggests that travellers (are willing to) take the detour when travel time differences are more or less imperceptible, while they take the shortest route to their own benefit when travel time differences are perceivable.

3) To what extent could a system optimum be achieved by the application of information-based demand measures using social routing and what are the implications for individual travellers?

3.6% of total travel time within the research area (part of the Twente Region) could be potentially saved during the morning peak hour; this corresponds to regional economic benefits of about €2,600,000,- each year. A social routing service is expected to be able to direct 10% of travellers towards social routes based on compliance behaviour as observed in the field experiment; in this, several assumptions regarding compliance, market penetration and detour advice frequency are considered. As such, 16% of potential travel time savings could be achieved. However, individual benefits will be marginal; the majority of travellers experience a travel time gain of less than 2 minutes. Such travel time differences are unperceivable for most travellers as travel time variability caused by events, weather conditions or traffic lights are often higher (Çolak et al., 2016).

In response to the social routing service, it is expected that structural congestion will reduce by 10%, while another 5% of vehicle kilometres in unstable traffic flows will be avoided. As a consequence of the improved throughput, driving is likely to become more comfortable and to require less effort. These benefits might be easier to perceive by travellers compared to the aforementioned travel time benefits.

When the share of social travellers increases, average travel time losses decrease and average travel time gains increase (when compared to travel times in the current situation (i.e. the user equilibrium)). Moreover, average travel time sacrifices (i.e. difference in travel time of travellers who have to take the detour with the travel time of the shortest route within the same network state) decrease as well. Hence, it seems that the lower the share of social trips, the more social travellers need to compensate for the selfish behaviour of others by taking longer detours and accepting longer travel times.

Only 12% of travellers within the road network need to take a detour in order to achieve a system optimum. Considering the expected share of social trips, this seems to be (nearly) feasible. However, all social travellers need to be concentrated on only a few specific OD-pairs; i.e. on these OD-pairs a large share of travellers need to take a detour, while on other OD-pairs none of the travellers needs to do so. It seems most improbable that on these specific OD-pairs the share of social travellers would be large enough. Hence, the distribution of social travellers over OD-pairs is decisive in establishing a system optimum.

Main objective: ‘to empirically determine the potential to use current state-of-the-art, personalized travel information and social routing advice to make more efficient use of the existing road network’.

Several studies provide theoretical evidence for the effective application of social routing by showing positive network impacts (e.g. Avineri, 2009b; Van den Bosch et al., 2011; Xu & Gonzalez, 2017; Çolak et al., 2016). Others provide ingenious algorithms to support the technical application of social routing (e.g. Angelelli et al., 2016; Jahn et al., 2005). This thesis complements these studies providing empirical evidence on the potential of social routing advice from a behavioural point of view. Findings suggest that travel information and social routing advice do have potential to improve road network efficiency, provided that its organizational implementation has been tackled. Results suggest that travellers are willing to comply with social routing advice and take a detour to the benefit of the road network. As a consequence, network efficiency will be improved to a certain extent, although a perfect system optimum seems out of reach. Moreover, individual benefits are small and might not be perceived. Nonetheless, travellers might perceive impacts on several societal aspects that are associated with improved network efficiency, such as accessibility, sustainability, safety and liveability (for more detail, see Section 6.2).

Our findings and conclusions are generalizable to the extent that the considered road network should contain congestion, while it is not saturated; i.e. there should be room for efficiency improvements. Moreover, in some societies people are traditionally more pro-social than in others; this might affect compliance rates. As a result, network impacts will increase or decrease as well.

6.2. Research implications for transport policy

The findings on the potential of travel information and social routing advice to improve road network efficiency have several implications for transport policy.

First of all, roads are regarded as a public good that is provided and maintained by the government. As such, people feel that congestion is the problem of the government and should, therefore, be solved by the government as well. Hence, it is important to create awareness among travellers about how their travel choices affect the network state and how they can contribute to congestion reduction. One straightforward way is to inform them, e.g. by applying information-based demand measures. In this thesis, a social routing app was used. This fits the current trend of smartphone applications that are nowadays being developed with the aim to solve societal issues, e.g. apps that reduce food waste by food sharing or apps that challenge people to do something good for society each day.

Several design considerations for information-based demand measures could be derived from the findings. First of all, it is crucial to provide social routing information to those travellers who are actually open to this kind of non-selfish behaviour and are willing to comply with it at the moment they receive it. As such, it is essential to provide social routing advice tailored to the combination of user and trip. In order to tailor information to the user, information about individual user characteristics is necessary. A straightforward approach is to create user profiles by asking a few questions upon registration for the social information service, although users might not be really keen on this. Other approaches might be to use a self-learning algorithm or to extract user characteristics from social media or Google.

It is found that travellers are most likely to comply with the received routing advice when they are cooperatively oriented and when they undertake a trip for which they make their route choices in a non-habitual manner. If a user is identified as being cooperative, the service might provide information messages in line with the 'Educate'-strategy[2] that builds upon the user's attitude towards social routes; hence, the user consciously chooses whether or not to take the social route. If, however, the user is identified as being individualistic, a strategy that capitalizes on bounded rationality, such as the 'Recommend'-strategy, might be applied; the

[2] Note that the 'Educate'-strategy is still quite general; to further increase compliance, one might consider tailoring this strategy to the specific route that is being advised, explaining why specifically this route would contribute to network efficiency.

user receives information on only the social route (possibly with travel time information, although not the case in the presented experiments) and has to determine based on previous experience and perception whether he or she accepts to take the advised route alternative. In response to this strategy, even individualists might comply with social route advice.

Moreover, if the user makes the trip habit-driven while using a routing information service, the habit might be to just follow the provided route advice. In that case the 'Recommend'-strategy might be most suitable as only one route option is provided and the traveller is not tempted to consider other route alternatives. In addition, the service might apply a lower frequency of advising the detour. By providing the advice to take another route than usual every once in a while, the user might become curious for this route and might be willing to comply with the advice after some time, especially if he or she is also cooperatively-oriented. As such, the service might be able to break existing habits. However, one should realise that this study does not provide direct evidence for this, as the frequency of detour advice was not assessed. Finally, the user profile might keep track of a users' compliance frequency over the past. Based on the compliance frequency and route choice pattern for regular trips, users' categorisation related to social orientation and habit might be slightly adjusted.

Besides providing social routing information tailored to the user and the trip, it is essential to tailor it to the context as well. It is found that perceived traffic conditions were the main motivation for non-compliance. That is, compliance rates were low when (perceived) traffic conditions on route alternatives give the impression that there is no need to take a detour (i.e. both alternatives are believed to be busy or both alternatives are believed to be not busy at all). Hence, travellers seem most likely to comply with social routing advice when their usual route is (believed to be) busy or even congested, while the detour alternative is (expected to be) less crowded.

An important barrier in initiating a shift towards the System Optimum is the fact that at lower shares of social trips, social travellers need to compensate more for the selfish behaviour of others than when a larger share of trips is made socially; i.e. they have to take longer detours and need to sacrifice more travel time. Moreover, equity within network states (i.e. comparing travellers' travel time to the travel time of their neighbours travelling to the same destination) seems to be worse than equity with respect to the user equilibrium (i.e. comparing travellers' travel time to their assumedly current experienced travel time). As such, it might be easier to arrive at a certain network state than to maintain it. After all, they might accept the travel time difference with their current experienced travel time (in user equilibrium), establishing a more efficient network state, but once they find out that the travel time difference with their neighbours travel time travelling to the same destination is larger they might not any longer accept this detour and compliance decreases.

The application of an information-based demand measure based on social routing is expected to have different impacts on the long term and short term. On the short term, improved network efficiency entails less congestion and increased throughput in the existing road network. This results in several potential societal impacts:

- *Accessibility Impacts:* Most travellers experience (to some extent) travel time reductions. Hence, more destinations (e.g. jobs, shopping areas, natural areas) come within their reach. Nonetheless, travel time reductions are marginal and accessibility impacts would be small. However, as travellers experience a decrease in driving effort and an increase in driving comfort, they might still perceive improved accessibility.

- *Environmental Impacts:* Less congestion results in fewer stop-and-go movements, leading to fewer emissions per kilometre travelled (e.g. Barth & Boriboonsomsin, 2008). Nonetheless, total kilometres travelled will slightly increase (about 1%) as a result of rerouting (as was found in Chapter 5).
- *Safety Impacts:* Less congestion results in less (rear-end and multi-vehicle) crashes as these seem more likely to occur under unstable traffic conditions (Christoforou, Cohen, & Karlaftis, 2011; Golob, Recker, & Pavlis, 2008). On the contrary, note that the severity of accidents seems to be lower once congestion occurs (Golob et al., 2008).
- *Liveability Impacts:* Better mobility leads to improved liveability in many cities. However, to approach system optimal network conditions, car drivers seem to be directed towards routes on lower-hierarchy urban roads (as was found in Chapter 5). These are often not meant for these purposes, hence, some neighbourhood areas might suffer from cut-through traffic and experience an increase in traffic noise and a decrease in air quality and safety when going out on the streets. Liveability in these areas is negatively affected.

Abovementioned impacts provide evidence for the need to pursue a societal optimum − not only considering network travel time savings, but taking into account liveability as well as other societal relevant issues − rather than the traditional system optimum minimizing total travel time. One should realize that this would be at the expense of network efficiency. Obtained findings could be used to optimise the road network with respect to environmental sustainability, traffic safety or liveability as well. The stated choice experiment assessed the effect of societal goals (i.e. environmental sustainability and traffic safety, in addition to congestion alleviation) on compliance behaviour. Note that lower compliance rates would be expected using the societal goals related to environmental sustainability and traffic safety compared to the goal to alleviate congestion. A reason for this might be that congestion and travel time sacrifices are – in the traveller's perception – directly related and therefore alleviating congestion could be perceived as a more meaningful and achievable goal by travellers.

On the long term, however, improved network efficiency might lead to increased car traffic demand; improved traffic conditions might attract users of other transport modes. Hence, a strong focus on measures that increase the attractiveness of the more sustainable modes, such as public transportation and bike, are essential while social routing should rather be considered as a complementary measure. In fact, the principles used in social routing might be suitable to motivate travellers to switch towards sustainable modes as well.

Finally, I shortly like to address some considerations for the business model of a social routing service. Since social routing advice might not directly benefit its receivers, it should be freely available for them; after all, there exists low (or even no) willingness-to-pay for social routing advice among travellers. As social routing is a public affair, the provision of social routing information would most likely be a task of the (local) government. The cost of service development, maintenance and infrastructure might be covered by the economic gains associated with travel time reductions. Moreover, valuable route choice data (possibly combined with user data) could be obtained from the service deployment. Besides developing a social routing service from scratch, agreements with commercial travel information services could be made, appealing to their corporate social responsibility. As such, commercial services could implement a social routing option (besides the generally available options, such as shortest travel time, shortest distance or most fuel-efficient route) within their software to facilitate or even motivate their existing users to choose social routes.

6.3. Recommendations for future research

The findings reported in this thesis show the potential of social routing information. As such, they motivate future research into social routing, especially from a behavioural point of view.

A unique combination of a stated choice experiment and a revealed choice experiment using experience-based sampling was conducted. This combination of data collection methods exploits the strengths and mitigates the weaknesses of each approach. In line with this, future research could implement the principles of social routing in a large-scale living lab integrating research in real-life communities and settings in which participants are not aware of taking part in an experiment. This would provide a larger sample size consisting of authentic choice behaviour. Moreover, this approach enables data collection over a longer time span. Assessment of dynamics in compliance behaviour would provide valuable insights on the long-term effects.

Information messages consisted of travel times based on historical data and a static map presenting route alternatives. Future research could implement real-time advice accompanied by turn-by-turn navigational instructions. This might result in higher compliance rates, especially among travellers who are unfamiliar with the surrounding road network. Moreover, the experiments only considered commute trips. As 24% of trips during morning peak and even 62% of trips during evening peak in The Netherlands entail trip purposes other than commute (Statistics Netherlands (CBS), 2016), future research could broaden the scope using different trip purposes.

There might be circumstances in which travellers might be more willing to comply with social routing advice, such as during accidents or events. Xu and Gonzalez (2017) showed that social routing during mega-events could achieve considerable collective travel time savings. Future research into compliance behaviour under such circumstances would be useful. Obtained insights might be used to establish a more robust road network and keep congestion to a minimum in situations that are associated with an increase in congestion.

Amini, Peiravian, Mojarradi, and Derrible (2016) show that network topology influences network performance under varying traffic volumes. Related to social routing, Youn et al. (2008) show that potential travel time savings vary with traffic volumes. In line with these findings, future research might assess compliance behaviour in response to social routing advice and its network impacts using several combinations of traffic demand and network topology. As such, insights into the robustness of findings will be obtained.

In the near future, (full) autonomous vehicles are expected to be an important element of modern transportation. As such, system optimal routing of autonomous vehicles might be a worthy research direction. Several studies suggested assigning autonomous vehicles to routes that benefit the road network (e.g. Bagloee, Tavana, Asadi, & Oliver, 2016). As drivers are released from physical and mental actions associated with driving, they will be able to spend their in-vehicle travel time more useful and productive; taking a detour might not bother them. Nonetheless, drivers acceptability and preferences regarding social routes using autonomous vehicles are yet unknown.

Bibliography

Abdel-aty, M. A., Kitamura, R., & Jovanis, P. (1997). Using stated preference data for studying the effect of advanced traffic information on drivers' route choice. *Transportation Research Part C: Emerging Technologies, 5*(1), 39-50. doi:10.1016/S0968-090X(96)00023-X

Adler, J. L., & Blue, V. J. (1998). Toward the design of intelligent traveler information systems. *Transportation Research Part C: Emerging Technologies, 6*(3), 157-172. doi:10.1016/S0968-090X(98)00012-6

Ahn, K., & Rakha, H. (2008). The effects of route choice decisions on vehicle energy consumption and emissions. *Transportation Research Part D: Transport and Environment, 13*(3), 151-167. doi:10.1016/j.trd.2008.01.005

Ahn, K., & Rakha, H. (2013). Network-wide impacts of eco-routing strategies: A large-scale case study. *Transportation Research Part D: Transport and Environment, 25*(December 2013), 119-130. doi:10.1016/j.trd.2013.09.006

Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational behavior and human decision processes, 50*(2), 197-211. doi:10.1016/0749-5978(91)90020-T

Albert, G., Toledo, T., & Ben-Zion, U. (2011). The role of personality factors in repeated route choice behavior: behavioral economics perspective. *European Transport, 48*(2011), 47-59.

Allais, M. (1953). Le comportement de l'homme rationel devant le risque, critique des postulates et axiomes de l'ecole americaine. *Econometrica, Journal of the econometric society, 21*, 503-546. doi:10.2307/1907921

Amini, B., Peiravian, F., Mojarradi, M., & Derrible, S. (2016). Comparative Traffic Performance Analysis of Urban Transportation Network Structures. *Transportation Research Record, 2594*, 159-168. doi:10.3141/2594-19

Anas, A., & Lindsey, R. (2011). Reducing Urban Road Transportation Externalities: Road Pricing in Theory and in Practice. *Review of Environmental Economics and Policy, 5*(1), 66-88. doi:10.1093/reep/req019

Angelelli, E., Arsik, I., Morandi, V., Savelsbergh, M., & Speranza, M. G. (2016). Proactive route guidance to avoid congestion. *Transportation Research Part B: Methodological, 94,* 1-21. doi:10.1016/j.trb.2016.08.015

Antoniou, C., Balakrishna, R., & Koutsopoulos, H. N. (2011). A synthesis of emerging data collection technologies and their impact on traffic management applications. *European Transport Research Review, 3*(3), 139-148. doi:10.1007/s12544-011-0058-1

Araghi, Y., Kroesen, M., Molin, E. J. E., & Van Wee, B. (2014). Do social norms regarding carbon offsetting affect individual preferences towards this policy? Results from a stated choice experiment. *Transportation Research Part D: Transport and Environment, 26*, 42-46. doi:10.1016/j.trd.2013.10.008

Arrow, K. J. (1963). *Social Choice and Individual Values* (2nd ed.). New Haven, CT, USA: Yale University Press.

Avineri, E. (2006). The effect of reference point on stochastic network equilibrium. *Transportation Science, 40*(4), 409-420. doi:10.1287/trsc.1060.0158

Avineri, E. (2009a). *Nudging travellers to make better choices*. Paper presented at the International Choice Modelling Conference, March 30th till April 2nd, 2009, Harrogate, UK. Retrieved from http://www.icmconference.org.uk/index.php/icmc/icmc2009/paper/viewFile/148/50

Avineri, E. (2009b). Social value orientation and the efficiency of traffic networks. In R. Kitamura, T. Yoshii, & T. Yamamoto (Eds.), *The expanding sphere of travel behaviour research* (pp. 725-743). Bingley, UK: Emerald.

Avineri, E., & Prashker, J. P. (2006). The impact of travel time information on travelers' learning under uncertainty. *Transportation, 33*(4), 393-408. doi:10.1007/s11116-005-5710-y

Avineri, E., & Waygood, E. O. (2013). Applying valence framing to enhance the effect of information on transport-related carbon dioxide emissions. *Transportation Research Part A: Policy and Practice, 48*, 31-38. doi:j.tra.2012.10.003

Bachmann, C., Roorda, M., Abdulhai, B., & Moshiri, B. (2013). Fusing a bluetooth traffic monitoring system with loop detector data for improved freeway traffic speed estimation. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations, 17*(2), 152-164. doi:10.1080/15472450.2012.696449

Baets, K., Vlassenroot, S., Boussauw, K., Lauwers, D., Allaert, G., & De Maeyer, P. (2014). Route choice and residential environment: introducing liveability requirements in navigation systems in Flanders. *Journal of Transport Geography, 37*(2014), 19-27. doi:j.jtrangeo.2014.04.005

Bagloee, S. A., Tavana, M., Asadi, M., & Oliver, T. (2016). Autonomous vehicles: challenges, opportunities, and future implications for transportation policies. *Journal of Modern Transportation, 24*(4), 284-303. doi:10.1007/s40534-016-0117-3

Barth, M., & Boriboonsomsin, K. (2008). Real-World Carbon Dioxide Impacts of Traffic Congestion. *Transportation Research Record: Journal of the Transportation Research Board, 2058*, 163-171. doi:10.3141/2058-20

Basu, S., Yang, G., Lianeas, T., Nikolova, E., & Chen, Y. (2017). Reconciling Selfish Routing with Social Good. In V. Bilò & M. Flammini (Eds.), *Algorithmic Game Theory. SAGT 2017. Lecture Notes in Computer Science* (Vol. 10504, pp. 147-159). Cham: Springer International Publishing.

Bekhor, S., Chorus, C. G., & Toledo, T. (2012). Stochastic User Equilibrium for Route Choice Model Based on Random Regret Minimization. *Transportation Research Record: Journal of the Transportation Research Board, 2284*, 100-108. doi:10.3141/2284-12

Ben-Akiva, M., de Palma, A., & Kaysi, I. (1991). Dynamic network models and driver information systems. *Transportation Research Part A: General, 25*(5), 251-266. doi:10.1016/0191-2607(91)90142-D

Ben-Akiva, M., & Lerman, S. (1985). *Discrete Choice Analysis: Theory and Application to Travel demand*. Cambridge, MA, USA: MIT Press.

Ben-Elia, E., & Avineri, E. (2015). Response to travel information: A behavioural review. *Transport reviews: A transnational transdisciplinary Journal, 35*, 352-377. doi:10.1080/01441647.2015.1015471

Ben-Elia, E., Di Pace, R., Bifulco, G. N., & Shiftan, Y. (2013). The impact of travel information's accuracy on route-choice. *Transportation Research Part C: Emerging Technologies*, *26*, 146-159. doi:10.1016/j.trc.2012.07.001

Ben-Elia, E., Erev, I., & Shiftan, Y. (2008). The combined effect of information and experience on drivers' route-choice behavior. *Transportation, 35*(2), 165-177. doi:10.1007/s11116-007-9143-7

Ben-Elia, E., Ishaq, R., & Shiftan, Y. (2013). "If only I had taken the other road...": Regret, risk and reinforced learning in informed route-choice. *Transportation, 40*(2), 269-293. doi:10.1007/s11116-012-9426-5

Ben-Elia, E., & Shiftan, Y. (2010). Which road do I take? A learning-based model of route-choice behavior with real-time information. *Transport Research Part A: Policy and Practice, 44*(4), pp. 249-264. doi:10.1016/j.tra.2010.01.007

Bie, J. (2008). *The dynamical system approach to traffic assignment: the attainability of equilibrium and its application to traffic system management.* (PhD-thesis), The Hong Kong University of Science and Technology, Hong Kong.

Bierlaire, M. (2003). *BIOGEME: A free package for the estimation of discrete choice models.* Paper presented at the 3rd Swiss Transportation Research Conference, Ascona, Switzerland.

Bliemer, M., Dicke-Ogenia, M., & Ettema, D. (2009). *Rewarding for avoiding the peak period: A synthesis of three studies in the Netherlands.* Paper presented at the 12th International Conference on Travel Behaviour Research, Jaipur, India, 2009.

Bonsall, P. W. (1992). The influence of route guidance advice on route choice in urban networks. *Transportation, 19*(1), 1-23. doi:10.1007/BF01130771

Bottom, J., Ben-Akiva, M., Bierlaire, M., Chabini, I., Koutsopoulos, H. N., & Yang, H. (1999). Investigation of route guidance generation issues by simulation with DynaMIT. In A. Ceder (Ed.), *International Symposium Pergamon on Transportation and Traffic Theory* (pp. 577-600). Oxford, UK: Pergamon Press.

Bovy, P. H. L. (2009). On Modelling Route Choice Sets in Transportation Networks: A Synthesis. *Transport reviews: A transnational transdisciplinary Journal, 29*(1), 43-68. doi:10.1080/01441640802078673

Boyce, D., & Xiong, Q. (2004). User-Optimal and System-Optimal Route Choices for a Large Road Network. *Review of Network Economics*, *3*(4), 371-380. doi:10.2202/1446-9022.1058

Braess, D., Nagurney, A., & Wakolbinger, T. (2005). On a Paradox of Traffic planning. *Transportation Science, 39*(4), 446-450. doi:10.1287/trsc.1050.0127

Bureau of Public Roads. (1964). *Traffic Assignment Manual*: Department of Commerce, Urban Planning Division, Washington, DC, USA.

Caggiani, L., & Ottomanelli, M. (2011). Calibration of Equilibrium Traffic Assignment Models and O-D Matrix by Network Aggregate Data. *Soft Computing in Industrial Applications: Advances in Itelligent and Soft Computing* (Vol. 96). Heidelberg: Springer, Berlin.

Carrion, C. (2013). *Travel time perception errors: causes and consequences.* (PhD-thesis), University of Minnesota. Retrieved from http://hdl.handle.net/11299/155609

Chatterjee, K., & McDonald, M. (2004). Effectiveness of using variable message signs to disseminate dynamic traffic information: Evidence from field trails in European cities. *Transport reviews: A transnational transdisciplinary Journal, 24*(5), 559-585. doi:10.1080/0144164042000196080

Chen, P. S.-T., Srinivasan, K. K., & Mahmassani, H. S. (1999). Effect of Information Quality on Compliance Behavior of Commuters Under Real-Time Traffic Information. *Transportation Research Record: Journal of the Transportation Research Board, 1676*(1), 53-60. doi:10.3141/1676-07

Chen, T. Y., Chang, H. L., & Tzeng, G. H. (2001). Using a weight-assessing model to identify route choice criteria and information effects. *Transport Research Part A: Policy and Practice, 35*(3), 197-224. doi:10.1016/S0965-8564(99)00055-5

Chen, W.-H., & Jovanis, P. P. (2003). *Analysis of Driver En-Route Guidance Compliance and Driver Learning With ATIS Using A Travel Simulation Experiment*. Paper presented at the Transportation Research Board, 81th Annual Meeting, Washington, D.C.

Chorus, C. G. (2010). A new model of random regret minimization. *European Journal of Transport and Infrastructure Research, 10*(2), 181-196.

Chorus, C. G. (2012). Regret theory-based route choices and traffic equilibria. *Transportmetrica, 8*(4), 291-305. doi:10.1080/18128602.2010.498391

Chorus, C. G. (2014). Capturing alternative decision rules in travel choice models: a critical discussion. In S. Hess & A. Daly (Eds.), *Handbook of Choice Modelling* (pp. 290–310). Cheltenham, UK: Edward Elgar Publishing.

Chorus, C. G., Arentze, T. A., & Timmermans, H. J. P. (2009). Traveler compliance with advice: A bayesian utilitarian perspective. *Transportation Research Part E: Logistics and Transportation Review, 45*(3), 486-500. doi:10.1016/j.tre.2008.10.004

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

Chorus, C. G., Molin, E. J. E., & Van Wee, B. (2006b). Use and Effects of Advanced Traveller Information Services (ATIS): A Review of the Literature. *Transport reviews: A transnational transdisciplinary Journal, 26*(2), 127-149. doi:10.1080/01441640500333677

Christoforou, Z., Cohen, S., & Karlaftis, M. G. (2011). Identifying crash type propensity using real-time traffic data on freeways. *Journal of Safety Research, 42*(1), 43-50. doi:10.1016/j.jsr.2011.01.001

Ciscal-Terry, W., Dell'Amico, M. D., Hadjidimitriou, N. S., & Lori, M. (2016). An analysis of drivers route choice behaviour using GPS data and optimal alternatives. *Journal of Transport Geography, 51*(2016), 119-129. doi:10.1016/j.jtrangeo.2015.12.003

Connors, R. D., & Sumalee, A. (2009). A network equilibrium model with travellers' perception of stochastic travel times. *Transportation Research Part B: Methodological, 43*(6), 614-624. doi:10.1016/j.trb.2008.12.002

Correa, J. R., & Stier-Moses, N. E. (2010). Wardrop Equilibria. In J. J. Cochran (Ed.), *Wiley Encyclopedia of Operations Research and Management Science* (pp. 1-12). Hoboken, NJ, USA: John Wiley & Sons, Inc.

Costa, P. T., & McCrae, R. R. (2006). Revised NEO personality inventory (NEO PI-R): Manual. *Oxford [u.a.]*.

Daganzo, C. F., & Sheffi, Y. (1977). On Stochastic Models of Traffic Assignment. *Transportation Science, 11*(3), 253-274.

Danczyk, A., & Liu, H. (2010). *Unexpected cause, unexpected effect: Empirical observations of Twin Cities traffic behavior after the I-35W Bridge collapse and reopening*. Paper presented at the TRB 89th Annual Meeting, 10-14 January, 2010, Washington, DC. Available online at http://www.ce.umn.edu/~liu/I-35W/Empirical_Findings_I-35W_Final.pdf

De Borger, B., & Fosgerau, M. (2008). Discrete choices and the trade-off between money and time: A test of the theory of reference dependent preferences. *Journal of Urban Economics, 64*(1), 101-115.

De Palma, A., Lindsey, R., & Picard, N. (2012). Risk aversion, the value of information and traffic equilibrium. *Transportation Science, 46*(1), 1-26. doi:10.1287/trsc.1110.0357

Dia, H., & Panwai, S. (2007). Modelling drivers' compliance and route choice behaviour in response to travel information. *Nonlinear Dynamics, 49*(4), 493-509. doi:10.1007/s11071-006-9111-3

Dicke-Ogenia, M. (2012). *Psychological Aspects of Travel Information Presentation, A psychological and ergonomic view on travellers' response to travel information.* (PhD-thesis), Rijksuniversiteit Groningen and Technische Universiteit Delft.

Djavadian, S., Hoogendoorn, R. G., van Arem, B., & Chow, J. Y. J. (2014). Empirical Evaluation of Drivers' Route Choice Behavioral Responses to Social Navigation. *Transportation Research Record: Journal of the Transportation Research Board, 2423*, 52-60. doi:10.3141/2423-07

Djukic, T., Wilmink, S., Jonkers, E., Snelder, M., & van Arem, B. (2016). *Exploratory analysis of traveller's compliance with smartphone personal route advice: a field trial Amsterdam*. Paper presented at the 95th Annual Meeting of the Transportation Research Board, 10-14 January, 2016, Washington, DC, USA.

Dugundji, E. R., & Walker, J. L. (2005). Discrete Choice with Social and Spatial Network Interdependencies: An Empirical Example Using Mixed GEV Models with Field and Panel Effects. *Transportation Research Record: Journal of the Transportation Research Board, 1921*, 70-78. doi:10.3141/1921-09

Ellsberg, D. (1961). Risk, Ambiguity, and the savage axioms. *Quarterly Journal of Economics, 75*(4), 643-669. doi:10.2307/1884324

Emmerink, R. H. M., Axhausen, K. W., Nijkamp, P., & Rietveld, P. (1995). Effects of information in road transport networks with recurrent congestion. *Transportation, 22*(1), 21-53. doi:10.1007/BF01151617

Emmerink, R. H. M., Verhoef, E. T., Nijkamp, P., & Rietveld, P. (1996). Information Provision in Road Transport with Elastic Demand: A Welfare Economic Approach. *Journal of Transport Economics and Policy, 30*(2), 117-136.

Enrique Fernandez, J. L., Joaquin de Cea, C., & German Valverde, G. (2009). Effect of advanced traveler information systems and road pricing in a network with non-recurrent congestion. *Transport Research Part A: Policy and Practice, 43*(5), 481-499. doi:10.1016/j.tra.2008.12.001

Ericsson, E., Larsson, H., & Brundell-Freij, K. (2006). Optimizing route choice for lowest fuel consumption - Potential effects of a new driver support tool. *Transportation Research Part C: Emerging Technologies, 14*(6), pp. 369-383. doi:10.1016/j.trc.2006.10.001

Ettema, D., Knockaert, J., & Verhoef, E. T. (2010). Using incentives as traffic management tool: empirical results of the 'peak avoidance' experiment. *Transportation Letters, 2*(1), 39-51. doi:10.3328/TL.2010.02.01.39-51

European Commission. (2017a). *Horizon 2020 - Work Programme 2018-2020 - 11. Smart, green and integrated transport*. Retrieved from http://ec.europa.eu/research/participants/data/ref/h2020/wp/2018-2020/main/h2020-wp1820-transport_en.pdf

European Commission. (2017b, December 15th, 2017). Intelligent transport systems - Action Plan and Directive. Retrieved from https://ec.europa.eu/transport/themes/its/road/action_plan_en

Fehr, E., & Fishbacher, U. (2003). The nature of human altruism. *Nature, 425*(6960), 785-791. doi:10.1038/nature02043

Fehr, E., & Schmidt, K. M. (1999). A theory of fairness, competition, and cooperation. *Quarterly Journal of Economics, 114*(3), 817-868.

Fujii, S., & Gärling, T. (2003). Application of attitude theory for improved predictive accuracy of stated preference methods in travel demand analysis. *Transportation Research Part A: Policy and Practice, 37*(4), 389-402. doi:10.1016/S0965-8564(02)00032-0

Fujii, S., Gärling, T., & Kitamura, R. (2001). Changes in drivers' perceptions and use of public transport during a freeway closure: Effects of temporary structural change on cooperation in a real-life social dilemma. *Environment Behavior, 33*(6), 796-808. doi:10.1177/00139160121973241

Garling, T., & Axhausen, K. W. (2003). Introduction: Habitual travel choice. *Transportation, 30*, 1-11. doi:10.1023/A:1021230223001

Georgescu-Roegen, N. (1954). Choice, Expectations and Measurability. *The Quarterly Journal of Economics, 68*(4), 503-534.

Gigerenzer, G. (2015). *Simply Rational: Decision Making in the Real World*. Oxford, UK: Oxford University Press.

Gillies, D. B. (1959). Solutions to general non-zero-sum games. In A. W. Tucker & R. D. Luce (Eds.), *Contributions to the Theory of Games IV* (pp. 47-85). Princeton, NJ, USA: Princeton University Press.

Godbout, J. (2000). *The World of the Gift*. Montreal, Quebec, Canada: McGill-Queen's Press.

Golob, T. F., Recker, W., & Pavlis, Y. (2008). Probabilistic models of freeway safety performance using traffic flow data as predictors. *Safety Science, 46*(9), 1306-1333. doi:10.1016/j.ssci.2007.08.007

Gunn, H. (2001). Spatial and temporal transferability of relationships between travel demand, trip cost and travel time. *Transportation Research Part E: Logistics and Transportation Review, 37*(2-3), 163-189. doi:10.1016/S1366-5545(00)00023-5

Guo, X., & Liu, H. X. (2011). Bounded rationality and irreversible network change. *Transportation Research Part B: Methodological, 45*(10), 1606-1618. doi:10.1016/j.trb.2011.05.026

Hartgen, D. T., & Fields, M. G. (2006). *Building roads to reduce traffic congestion in America's cities: How much and at what cost? [Appendix B: Detailed Methodology]*. Retrieved from http://reason.org/files/appendixb.pdf

Hayes, B. (2005). Coping with Selfishness [Review of the book *Selfish Routing and the Price of Anarchy*, by T. Roughgarden]. *American Scientist, 93*(6), 567-568. http://www.jstor.org/stable/27858690

Hektner, J., Schmidt, J., & Csikszentmihalyi, M. (2007). *Experience Sampling Method - Measuring the Quality of Everyday Life*. Thousand Oaks, California, USA: Sage Publications.

Henrich, J., Boyd, R., Bowles, S., Camerer, C., Fehr, E., Gintis, H., . . . Tracer, D. (2005). 'Economic man' in cross-cultural perspective: Behavioral experiments in 15 small-scale societies. *Behavioral and Brain Sciences, 28*(6), 795-815. doi:10.1017/S0140525X05000142

Hess, S., Rose, J. M., & Hensher, D. A. (2008). Asymmetric preference formation in willingness to pay estimates in discrete choice models. *Transportation Research Part E: Logistics and Transportation Review, 44*(5), 847-863. doi:10.1016/j.tre.2007.06.002

Hess, S., Rose, J. M., & Polak, J. (2010). Non-trading, lexicographic and inconsistent behaviour in stated choice data. *Transportation Research - Part D: Transport and Environment, 15*(7), 405-417. doi:10.1016/j.trd.2010.04.008

Hess, S., Stathopoulos, A., & Daly, A. (2012). Allowing for heterogeneous decision rules in discrete choice models: an approach and four case studies. *Transportation, 39*(3), 565-591. doi:10.1007/s11116-011-9365-6

Hoogendoorn-Lanser, S., Schaap, N. T. W., & Olde Kalter, M. J. (2015). The Netherlands Mobility Panel: An innovative design approach for web-based longitudinal travel data collection. *Transportation Research Procedia, 11*(2015), 311-329. doi:10.1016/j.trpro.2015.12.027

INRIX. (2018). INRIX 2017 Global Traffic Scorecard Infographic. Retrieved from http://inrix.com/resources/inrix-2017-global-traffic-scorecard/

Jager, W. (2003). Breaking 'bad habits': A dynamical perspective on habit formation and change. In L. Hendrickx, W. Jager, & L. Steg (Eds.), *Human Decision Making and Environmental Perception. Understanding and Assisting Human Decision Making in Real-life Settings* (pp. 149-160). Groningen: Rijksuniversiteit Groningen.

Jahn, O., Möhring, R. H., Schulz, A. S., & Stier-Moses, N. E. (2005). System-Optimal Routing of Traffic Flows with User Constraints in Networks with Congestion. *Operations Research, 43*(4), 600-616. doi:10.1287/opre.1040.0197

Jakobssen, C. (2003). *Household planning of car use: implementation of prospective car logs*. Paper presented at the 10th International Conference on Travel Behaviour Research, Lucerne, Switzerland, August 10-15, 2003.

Johnson, E. J., & Payne, J. W. (1985). Effort and Accuracy in Choice. *Management Science, 31*(4), 395-414. doi:10.1287/mnsc.31.4.395

Josefsson, M. (2004). *Sensitivity analysis of traffic equilibria.* (Master-Thesis), Chalmers University of Technology, Gothenburg.

Kahneman, D., & Tversky, A. (1979). Prospect theory: an analysis of decision under risk. *Econometrica, Journal of the econometric society, 47*(2), 263-292. doi:10.2307/1914185

Kattan, L., Nurul Habib, K. M., Tazul, I., & Shahid, N. (2011). Information provision and driver compliance to advanced traveller information system applications: case study on the interaction between variable message sign and other sources of traffic updates in Calgary, Canada. *Canadian Journal of Civil Engineering, 38*(12), 1335-1346. doi:10.1139/l11-093

Kestemont, B. (2011). Neoclassical Assumptions and Sustainable Development. A Review. *Etopia, Revue d'écologie Politique*(8), 151-183.

Khattak, A., Polydoropoulou, A., & Ben-Akiva, M. (1996). Modeling revealed and stated pretrip travel response to advanced traveler information systems. *Transportation Research Record: Journal of the Transportation Research Board, 1537*, 46-54. doi:10.3141/1537-07

Klein, I., Levy, N., & Ben-Elia, E. (2018). An agent-based model of the emergence of cooperation and a fair and stable system optimum using ATIS on a simple road network. *Transportation Research Part C, 2018*(86), 183-201. doi:10.1016/j.trc.2017.11.007

Knight, G. P., & Dubro, A. F. (1984). An individualized Regression and Clustering Assessment of the Social Values of Adults and Children. *Journal of Research in Personality, 18*(3), 372-382. doi:10.1016/0092-6566(84)90021-7

Korilis, Y. A., Lazar, A. A., & Orda, A. (1997). Achieving network optima using Stackelberg Routing Strategies. *IEEE/ACM Transactions on Networking (TON), 5*(1), 161-173. doi:10.1109/90.554730

Koutsoupias, E., & Papadimitriou, C. (1999). *Worst-case Equilibria.* Paper presented at the 16th annual Symposium on Theoretical Aspects of Computer Science (STACS).

Kouwenhoven, M., De Jong, G. C., Koster, P., Van den Berg, V. A. C., Verhoef, E. T., Bates, J., & Warffemius, P. M. J. (2014). New values of time and reliability in passenger transport in The Netherlands. *Research in Transportation Economics, 47*, 37-49. doi:10.1016/j.retrec.2014.09.017

Krichene, W., Reilly, J. D., Amin, S., & Bayen, A. M. (2014). Stackelberg Routing on Parallel Networks with Horizontal Queues. *IEEE Transactions on Automatic Control, 59*(3), 714-727. doi:10.1109/TAC.2013.2289709

Kroes, E. P., & Sheldon, R. J. (1988). Stated Preference Method: An Introduction. *Journal of Transport Economics and Policy, 22*(1), 11-25. http://www.jstor.org/stable/20052832

Kusumastuti, D., Hodgson, F., Thomopoulos, N., Hjalmarsson, A., Veenstra, S. A., Van Berkum, E., . . . Groenewolt, B. (2011). *Deliverable D3.3 "Impact of Incentives"*. Retrieved from www.sunset-project.eu/pdf/SUNSET_D3.3_Impact_of_Incentives.pdf

Lai, L. (2010). Maximizing without difficulty: A modified maximizing scale and its correlates. *Judgment and Decision Making, 5*(3), 164-175.

Larsson, T., & Patriksson, M. (1992). Simplicial Decomposition with Disaggregated Representation for the Traffic Assignment Problem. *Transportation Science, 26*(1), 4-17. doi:10.1287/trsc.26.1.4

Leong, W., & Hensher, D. A. (2012). Embedding Decision Heuristics in Discrete Choice Models: A Review. *Transport reviews: A transnational transdisciplinary Journal, 32*(3), 313-331. doi:10.1080/01441647.2012.671195

Levinson, D. (2003). The value of advanced traveler information systems for route choice. *Transport Research Part C: Emerging Technologies, 11*(1), 75-87. doi:10.1016/S0968-090X(02)00023-2

Levitt, S. D., & List, J. A. (2007). What do laboratory experiments measuring social preferences reveal about the real world? *Journal of economic perspectives, 21*(2), 153-174. http://www.jstor.org/stable/30033722

Levy, N., Klein, I., & Ben-Elia, E. (2017). Emergence of cooperation and a fair system optimum in road networks: A game-theoretic and agent-based modelling approach. *Research in Transportation Economics, In Press*. doi:10.1016/j.retrec.2017.09.010

Li, Z., & Hensher, D. A. (2013). Behavioural implications of preferences, risk attitudes and beliefs in modelling risky travel choice with travel time variability. *Transportation, 40*(3), 505-523. doi:10.1007/s11116-012-9445-2

Liebrand, W. B. G. (1984). The effect of social motives, communication and group size on behaviour in an N-person multi-stage mixed-motive game. *European Journal of Social Psychology, 14*(3), 239-264. doi:10.1002/ejsp.2420140302

Liebrand, W. B. G., & McClintock, C. G. (1988). The ring measure of social values: A computerized procedure for assessing individual differences in information processing and social value orientation. *European Journal of Personality, 2*(3), 217-230. doi:10.1002/per.2410020304

List, C. (2013). Social Choice Theory. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Winter 2013 ed.). Stanford, CA, USA: The Metaphysics Research Lab.

Loomes, G., & Sugden, R. (1982). Regret Theory: an alternative theory of rational choice under uncertainty. *The Economic Journal, 92*(368), 805-824. doi:10.2307/2232669

Lu, H., Fowkes, A., & Wardman, M. (2006). *The influence of SP design on incentive to bias in response*. Paper presented at the European Transport Conference, September 18th-20th, Strasbourg, France.

Lyons, G., Avineri, E., Farag, S., & Harman, R. (2007). *Strategic Review of Travel Information Research.* Technical Report. Department for Transport, London. Retrieved from http://eprints.uwe.ac.uk/10300

Mahmassani, H. S., & Chang, G. L. (1987). On boundedly rational user equilibrium in transportation systems. *Transportation Science, 21*(2), 89-99. doi:10.1287/trsc.21.2.89

Mahmassani, H. S., & Liu, Y. H. (1999). Dynamics of commuting decision behaviour under advanced traveller information systems. *Transportation Research Part C: Emerging Technologies, 7*(2-3), 91-107. doi:10.1016/S0968-090X(99)00014-5

Matsushima, H. (1997). Bounded Rationality in Economics: A game Theorist's View. *Japanese Economic Review, 48*(3), 293-306. doi:10.1111/1468-5876.00056

Messelodi, S., Modena, C. M., Zanin, M., De Natale, F. G. B., Granelli, F., Betterle, E., & Guarise, A. (2009). Intelligent Extended Floating Car Data Collection. *Expert Systems with Applications, 36*(3), pp. 4213-4227. doi:10.1016/j.eswa.2008.04.008

Ministry of Infrastructure and Environment. (2002). *User Research Dutch Motorways [Gebruikersonderzoek Nederlandse Autosnelwegen (in Dutch)]*. Rotterdam, The Netherlands: Adviesdienst Verkeer en Vervoer.

Ministry of Infrastructure and Environment. (2013). *Beter geinformeerd op weg - Routekaart 2013-2023 - Samenvatting (in Dutch)*. Retrieved from https://www.rijksoverheid.nl/documenten/rapporten/2013/11/04/beter-geinformeerd-op-weg-routekaart-2013-2023-samenvatting

Morgan, J., Orzen, H., & Sefton, M. (2008). Network architecture and traffic flows: Experiments on the Pigou-Knight-Downs and Braess Paradoxes. *Games and Economic Behaviour, 66*(1), 348-372. doi:10.1016/j.geb.2008.04.012

Murphy, R. O., & Ackermann, K. A. (2013). Explaining behavior in public goods games: How preferences and beliefs affect contribution levels. *SSRN Electronic Journal*. doi:10.2139/ssrn.2244895

Murphy, R. O., Ackermann, K. A., & Handgraaf, M. J. J. (2011). Measuring Social Value Orientation. *Judgment and Decision Making, 6*(8), 771-781. doi:10.2139/ssrn.1804189

Nash, J. (1951). Non-Cooperative Games. *Annals of Mathematics, 54*(2), 286-295. doi:10.2307/1969529

Nilsson, M., & Küller, R. (2000). Travel behaviour and environmental concern. *Transportation Research Part D: Transport and Environment, 5*(3), 211-234. doi:10.1016/S1361-9209(99)00034-6

Ostrom, E., & Walker, J. L. (2003). *Trust and reciprocity: Interdisciplinary lessons from experimental research.* New York, USA: Russell Sage Foundation.

Parvaneh, Z., Arentze, T., & Timmermans, H. J. P. (2011). A simulation model assessing impacts of advanced information and communication technologies on activity-travel patterns. *Procedia Social and Behavioral Sciences, 2011*(20), 236-243. doi:10.1016/j.sbspro.2011.08.029

Pichert, D., & Katsikopolous, K. V. (2007). Green Defaults: Information presentation and pro-environmental behaviour. *Journal of Environmental Psychology, 28*, 63-73. doi:10.1016/j.jenvp.2007.09.004

Platform Beter Benutten. (2014). Beter Benutten: Less congestion in 2014, shorter journey times in 2017. Retrieved from https://www.beterbenutten.nl/en

Platow, M. J. (1993). Observing social value orientations: a social interdependence approach. *New Zealand Journal of Psychology, 22*(2), 101-109.

Poteete, A. R., Janssen, M. A., & Ostrom, E. (2010). *Working Together: collective action, the commons, and multiple methods in practice*. Oxfordshire, UK: Princeton University Press.

Pritchard, R. D. (1969). Equity Theory: A review and Critique. *Organizational behavior and human performance, 4*(2), 176-2111. doi:10.1016/0030-5073(69)90005-1

Pruitt, D. G., & Kimmel, M. J. (1977). Twenty years of experimental gaming: Critique, synthesis, and suggestions for the future. *Annual Review of Psychology, 28*, 363-392. doi:10.1146/annurev.ps.28.020177.002051

Raffinetti, E., Siletti, E., & Vernizzi, A. (2015). On the Gini coefficient normalization when attributes with negative values are considered. *Statistical Methods & Applications, 24*(3), 507-521. doi:10.1007/s1026

Raiyn, J., & Toledo, T. (2014). Real-Time Short-Term Forecasting Bases on Information Management. *Journal of Transportation Technologies, 4*(1), 11-21. doi:10.4236/jtts.2014.41002

Rakotonarivo, O. S., Schaafsma, M., & Hockley, N. (2016). A systematic review of the reliability and validity of discrete choice experiments in valuing non-market environmental goods. *Journal of Environmental Management, 183*(1), 98-109. doi:10.1016/j.jenvman.2016.08.032

Ramjerdi, R. (2006). Equity Measures and their Performance in Transportation. *Transportation Research Record: Journal of the Transportation Research Board, 1983*, 67-74. doi:10.3141/1983-10

Ramos, G. (2015). *Dynamic route choice modelling of the effects of travel information using RP data.* (PhD-thesis), Delft University of Technology.

Ramos, G., Frejinger, E., Daamen, W., & Hoogendoorn, S. (2012). *A revealed preference study on route choices in a congested network with real-time information.* Paper presented at the 13th International Conference on Travel Behaviour Research, 15-20 July 2012, Toronto.

Rietveld, P. (2010). The economics of information in transport. In A. De Palma, R. Lindsey, E. Quinet, & R. Vickerman (Eds.), *A Handbook of Transport Economics* (pp. 586-603). Cheltenham, UK: Edward Elgar Publishing Limited.

Roughgarden, T. (2006). *Selfish Routing and the Price of Anarchy*. Cambridge, MA, USA: MIT Press.

Roughgarden, T., & Tardos, E. (2002). How bad is selfish routing? *Journal of the ACM, 49*(2), 236-259. doi:10.1145/506147.506153

Rousseeuw, P. J. (1987). Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. *Journal of Computational and Applied Mathematics, 20*(1987), 53-65. doi:10.1016/0377-0427(87)90125-7

Rubinstein, A. (1998). Modeling Bounded Rationality in games. *Modeling bounded rationality* (pp. 121). Cambridge, Massachusetts: MIT Press.

Saelensminde, K. (2006). Causes and consequences of lexicographic choices in stated choice studies. *Ecological Economics, 59*(3), 331-340. doi:10.1016/j.ecolecon.2005.11.001

Sahnoon, I., Shawky, M., & Al-Ghafli, A. (2018). Integrating Traffic Safety in Vehicle Routing Solution. In N. Stanton (Ed.), *International Conference on Applied Human Factors and Ergonomics: Advances in Human Aspects of Transportation. AHFE 2017* (Vol. 597, pp. 251-263). Springer , Cham.

Schaafsma, M., Brouwer, R., Liekens, I., & De Nocker, L. (2014). Temporal stability of preferences and willingness to pay for natural areas in choice experiments: A test–retest. *Resource and Energy Economics, 38*(2014), 243-260. doi:10.1016/j.reseneeco.2014.09.001

Schneider, S. (2010). *Homo economicus - or more like Homer Simpson*. Retrieved from Frankfurt am Main, Germany: https://www.dbresearch.com/PROD/DBR_INTERNET_EN-PROD/PROD0000000000259291.pdf

Schofer, J. L., Khattak, A., & Koppelman, F. S. (1993). Behavioral issues in the design and evaluation of advanced traveler information systems. *Transport Research Part C: Emerging Technologies*, *1*(2), 107-117. doi:10.1016/0968-090X(93)90008-4

Schwartz, S. H. (1977). Normative influences on altruism. In L. Berkowitz (Ed.), *Advances in Experimental Social Psychology* (Vol. 10, pp. 221-279). New York: Academic Press.

Sen, A. K. (1977). Rational Fools: A critique of the behavioural foundations of economic theory. *Philosophy and Public Affairs*, *6*(4), 317-344. http://www.jstor.org/stable/2264946

Sen, A. K. (1982). *Choice, Welfare and Measurement*: Oxford: Blackwell.

Senk, P. (2010). Route choice under the microscope: Process-oriented analysis of decision making. *Transportation Research Record: Journal of the Transportation Research Board*(2156), 56-63. doi:10.3141/2156-07

Serrano, R. (2009). Cooperative games: Core and Shapley value. In R. Meyers (Ed.), *Encyclopedia of Complexity and Systems Science*. New York: Springer.

Shapley, L. S. (1953). A value for n-person games. In A. W. Tucker & R. D. Luce (Eds.), *Contributions to the Theory of Games II* (pp. 307-317). Princeton, NJ, USA: Princeton University Press.

Shiftan, Y., Bekhor, S., & Albert, G. (2011). Route choice behaviour with pre-trip travel time information. *Intelligent Transport Systems, 5*(3), 183-189. doi:10.1049/iet-its.2010.0062

Simon, H. A. (1955). A behavioral model of rational choice. *The Quarterly Journal of Economics, 69*(1), 99-118. doi:10.2307/1884852

Simon, H. A. (1956). Rational Choice and the Structure of the Environment. *Psychological review, 63*(2), 129-138. doi:10.1037/h0042769

Site, P. D., & Filippi, F. (2012). Stochastic user equilibrium with reference-dependent route choice and endogenous reference points. *Procedia - Social and Behavioral Sciences, 54*(2012), 547-556. doi:10.1016/j.sbspro.2012.09.772

Slovic, P., Finucane, M. L., Peters, E., & MacGregor, D. G. (2007). The affect heuristic. *European Journal of Operational Research, 177*(3), 1333-1352. doi:10.1016/j.ejor.2005.04.006

SMART in Twente. (2016). Smartphone application 'SMART-Mobiliteit' (Version 2.2). www.smartintwente.nl

Spellucci, P. (1993). *DONLP2 Users Guide*. Retrieved from http://www.mathematik.tu-darmstadt.de/fbereiche/numerik/staff/spellucci/DONLP2/donlp2doc.pdf

Spiess, H. (1997). *Conical Volume-Delay Functions [including appendices]*. Retrieved from http://emme2.spiess.ch/archive/postscript/conic.pdf

Spitsmijden. (2013). Spitsmijden, het alternatief dat loont (in Dutch) [Peak hour avoidance, the alternative that rewards]. Retrieved from http://www.spitsmijden.nl/

Srinivasan, K. K., & Mahmassani, H. S. (2000). Modeling inertia and compliance mechanisms in route choice behavior under real-time information. *Transportation Research Record: Journal of the Transportation Research Board, 1725*(1), 45-53. doi:10.3141/1725-07

Stanovich, K. E., & West, R. F. (2000). Individual differences in reasoning: Implications for the rationality debate? *Behavioral and Brain Sciences, 23*(5), 645-665. doi:10.1017/S0140525X00003435

Statistics Netherlands (CBS). (2016). Tussen vier en zes onderweg voor werk of boodschappen (in Dutch). Retrieved from https://www.cbs.nl/nl-nl/nieuws/2016/41/tussen-vier-en-zes-onderweg-voor-werk-of-boodschappen

Sun, L., Karwan, M. H., & Kwon, C. (2015). Incorporating Driver Behaviors in Network Design Problems: Challenges and Opportunities. *Transport reviews: A transnational transdisciplinary Journal, 36*(4), 454-478. doi:10.1080/01441647.2015.1091047

Sunitiyoso, Y., Avineri, E., & Chatterjee, K. (2009). Role of minority influence on the difusion of compliance with a demand management measure. In R. Kitamura, T. Yoshii, & T. Yamamoto (Eds.), *The expanding sphere of travel behaviour research* (pp. 643-672). Bingley, UK: Emerald Group Publishing Limited.

Sunstein, C. R., & Thaler, R. H. (2003). Libertarian paternalism is not an oxymoron. *The University of Chicago Law Review, 70*(4), 1159-1202. http://www.jstor.org/stable/1600573

Szeto, W. Y., Wang, Y., & Han, K. (2015). Bounded rationality in Dynamic Traffic Assignment. In S. Rasouli & H. J. P. Timmermans (Eds.), *Bounded Rational Choice Behaviour: Applications in Transport* (pp. 163). Bingly, UK: Emerald Group Publishing Limited.

Takao, K., & Asakura, Y. (2005). Extraction of cognition results of travel routes from open-ended questionnaire texts. *Journal of the Eastern Asia Society for Transportation Studies, 6*, 1943-1955.

Tanaka, M., Uno, N., Shiomi, Y., & Ahn, Y. (2014). Experimental Study of Effects of Travel Time Distribution Information on Dynamic Route Choice Behavior. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations, 18*(2), 215-226. doi:10.1080/15472450.2013.806847

Tawfik, A. M. (2012). *Modeling driver heterogeneity in route choice behavior: perceptions, learning trends, latent classes, and personality traits.* (PhD-Thesis), Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA.

Tawfik, A. M., & Rakha, H. A. (2012). Network route-choice evolution in a real-world experiment: A necessary shift from network to driver oriented modeling. *Transportation Research Record; Journal of the Transportation Research Board, 2322*, 70-81. doi:10.3141/2322-08

Tawfik, A. M., Rakha, H. A., & Miller, S. D. (2010). *An experimental exploration of route choice: Identifying drivers choices and choice patterns, and capturing network evolution.* Paper presented at the 13th International IEEE Conference on Intelligent Transportation Systems (ITSC).

Te Brömmelstroet, M. (2014). Sometimes you want people to make the right choices for the right reasons: potential perversity and jeopardy of behavioural change compaigns in the mobility domain. *Journal of Transport Geography, 39*(2014), 141-144. doi:10.1016/j.jtrangeo.2014.07.001

Thaler, R. H., & Sunstein, C. R. (2008). *Nudge: Improving Decisions About Health, Wealth, and Happiness*. New Haven, CT, USA: Yale University Press.

Thomopoulos, N., Grant-Muller, S., & Tight, M. R. (2009). Incorporating equity considerations in transport infrastructure evaluation: Current practice and proposed methodology. *Evaluation and Program Planning, 32*(4), 351-359. doi:10.1016/j.evalprogplan.2009.06.013

Train, K. (2009). Chapter 7: Variations on a Theme *Discrete Choice Methods with Simulation* (Vol. 2nd Edition). New York, NY, USA: Cambridge University Press.

Tversky, A. (1972). Elimination by aspects: A theory of choice. *Psychological review, 79*(4), 281-299. doi:10.1037/h0032955

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and Biases. *Science, 185*(4157), 1124-1131. http://www.jstor.org/stable/1738360

Tversky, A., & Kahneman, D. (1991). Loss aversion in riskless choice: a reference-dependent model. *The Quarterly Journal of Economics, 106*(4), 1039-1061. doi:10.2307/2937956

Van de Kaa, E. J. (2008). *Extended Prospect Theory; Findings on choice behaviour from economics and the behavioural sciences and their relevance for travel behaviour.* (PhD-Thesis), Delft University of Technology.

Van de Kaa, E. J. (2010). Prospect Theory and Choice Behaviour Strategies: Review and Synthesis of Concepts from Social and Transport Sciences. *European Journal of Transport and Infrastructure Research, 10*(4), 299-329.

Van den Bosch, A., Van Arem, B., Mahmod, M., & Misener, J. (2011). *Reducing time delays on congested road networks using social navigation*. Paper presented at the IEEE Forum on Integrated and Sustainable Transportation Systems, Vienna, Austria, June 29th-July 1st, 2011.

Van den Broeke, A., Van der Horst, R., & Schotanus, L. (2004). *Reizigersinformatie van idee tot product - Het identificeren van kansrijke diensten.* Paper presented at the Colloquium Vervoersplanologisch Speurwerk, Zeist.

Van der Honing, R., Kwant, A., & Tempert, B. (2011). *Opstellen multi-modaal verkeersmodel Regio Twente [Set-up multi-modal transport model Twente Region (in Dutch)]*. Retrieved from https://dloket.enschede.nl/loket/sites/default/files/DOC/Rapportage_RVM_0.pdf

Van der Mede, P. H. J., & Van Berkum, E. C. (1993). *The impact of traffic information: Dynamics in route and departure time choice.* (PhD-thesis), Delft University of Technology.

Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. (2018). Compliance with social routing advice - evidence from SP and RP experiments. *Submitted to Transportation (under review).*

Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. G. (2016). From user equilibrium to system optimum: A literature review on the role of travel information, bounded rationality and non-selfish behaviour at the network and individual levels. *Transport Reviews: A Transnational Transdisciplinary Journal, 36*(4), 527-548. doi:10.1080/01441647.2015.1125399

Van Lange, P. A. M., Otten, W., De Bruin, E. M. N., & Joireman, J. A. (1997). Development of Prosocial, Individualistic, and Competitive Orientations: Theory and Preliminary Evidence. *Journal of Personality and Social Psychology, 73*(4), 733-746. doi:10.1037/0022-3514.73.4.733

Van Lange, P. A. M., Schippers, M., & Balliet, D. (2011). Who volunteers in psychology experiments? An empirical review of prosocial motivation in volunteering. *Personality and Individual Differences, 51*(3), 279-284. doi:10.1016/j.paid.2010.05.038

Van Lange, P. A. M., Van Vugt, M., Meertens, R. M., & Ruiter, R. A. C. (1998). A Social Dilemma Analysis of Commuting Preferences: The Roles of Social Value Orientation and Trust. *Journal of Applied Social Psychology, 28*(9), 796-820. doi:10.1111/j.1559-1816.1998.tb01732.x

Van Vugt, M., Van Lange, P. A. M., & Meertens, R. M. (1996). Commuting by car or public transportation? A social dilemma analysis of travel mode judgement. *European Journal of Social Psychology, 26*(3), 373-395. doi:10.1002/(SICI)1099-0992(199605)26:3<373::AID-EJSP760>3.0.CO;2-1

Verhoef, E. T., Nijkamp, P., & Rietveld, P. (1997). The Social Feasibility of Road Pricing: A Case Study for the Randstad Area. *Journal of Transport Economics and Policy, 31*(3), 255-276. http://www.jstor.org/stable/20053739

Verhoef, P. C., & Franses, P. H. (2003). Combining revealed and stated preferences to forecast customer behavior: three case studies. *International Journal of Market Research, 45*(4), 467-474. doi: 10.1177/147078530304500402

Verplanken, B., Aarts, H., & Van Knippenberg, A. (1997). Habit, information acquisition, and the process of making travel mode choices. *European Journal of Social Psychology, 27*(5), 539-560. doi: 10.1002/(SICI)1099-0992(199709/10)27:53.0.CO;2-A

Verplanken, B., Aarts, H., Van Knippenberg, A., & Van Knippenberg, C. (1994). Attitude versus general habit: antecedents of travel mode choice. *Journal of Applied Social Psychology, 24*(4), 285-300. doi:10.1111/j.1559-1816.1994.tb00583.x

Von Neumann, J., & Morgenstern, O. (1944). *Theory of Games and Economic Behavior*. Princeton, NJ, USA: Princeton University Press.

Vreeswijk, J., Rakha, H., Van Berkum, E., & Van Arem, B. (2015). Analysis of inertial choice behaviour based expected and experienced savings from a real-world route choice experiment. *International Journal of Transportation, 3*(3), 11-28. doi:10.14257/ijt.2015.3.3.02

Vreeswijk, J., Thomas, T., van Berkum, E., & van Arem, B. (2014). Drivers' perception of route alternatives as indicator for the indifference band. *Transportation Research Record: Journal of the Transportation Research Board*(2383), 10-17. doi:10.3141/2383-02

Vreeswijk, J. D. (2015). *The dynamics of user perception, decision making and route choice.* (PhD-thesis), University of Twente, Enschede, The Netherlands.

Wardman, M. (1988). A comparison of revealed preference and stated preference models of travel behaviour. *Journal of Transport Economics and Policy, 22*(1), 71-91. http://www.jstor.org/stable/20052836

Wardrop, J. G. (1952). Some theoretical aspects of road traffic research. *Proceedings of Institute of Civil Engineers, 1*(3), 325-378.

Waygood, E. O., & Avineri, E. (2010). *Visual Formats, Reference points, and Anchoring Effects on Perceptions of the Sustainability of Travel Choices.* Paper presented at the Anon. The 1st Workshop on Traffic Behavior, Modeling and Optimization (TBMO10), Madeira, Portugal.

Waze. (2018). Free Community-based GPS, Maps & Traffic Navigation App | Waze. Retrieved from https://www.waze.com/en/

Xu, Y., & Gonzalez, M. C. (2017). Collective benefits in traffic during mega events via the use of information technologies. . *Journal of the Royal Society Interface, 14*(129). doi:10.1098/rsif.2016.1041

Yamagishi, T. (1988). The Provision of a Sanctioning System in the United States and Japan. *Social Psychology Quarterly, 51*(3), 265-271. doi:10.2307/2786924

Yang, H. (1998). Multiple equilibrium behaviors and advanced traveler information systems with endogenous market penetration. *Transportation Research Part B: Methodological, 32*(3), 205-218. doi:10.1016/S0191-2615(97)00025-8

Yin, Y., & Yang, H. (2003). Simultaneous determination of the equilibrium market penetration and compliance rate of advanced traveler information systems. *Transportation research Part A: Policy and Practice, 37*(2), 165-181. doi:10.1016/S0965-8564(02)00011-3

Youn, H., Jeong, H., & Gastner, M. T. (2008). The Price of Anarchy in Transportation Networks: Efficiency and Optimality Control. *Physical Review Letters, 101*(12), 128-701.

Zajonc, R. B. (1980). Feeling and Thinking: Preferences Need No Inferences. *American Psychologist, 35*(2), 151-175. doi: 10.1037/0003-066X.35.2.151

Zeelenberg, M., Van Dijk, W. W., Manstead, A. S. R., & Van der Pligt, J. (2000). On bad decisions and disconfirmed expectancies: The psychology of regret and disappointment. *Cognition and emotion, 14*(4), 521-541. doi:10.1080/026999300402781

Zhang, L. (2011). Behavioral foundation of route choice and traffic assignment - Comparison of principles of user equilibrium traffic assignment under different behavioral assumptions. *Transportation Research Record: Journal of the Transportation Research Board, 2254*, 1-10. doi:10.3141/2254-01

Zhang, L., & Levinson, D. (2008). Determinants of route choice and value of traveller information - A field experiment. *Transportation Research Record: Journal of the Transportation Research Board,* 2086, 81-92. doi:10.3141/2086-10

Zhu, S., & Levinson, D. (2010). *Do people use the shortest path? An empirical test of Wardrop's first principle.* Paper presented at the 91st TRB Annual Meeting, January 22-26, 2012, Washington D.C., USA.

Zhu, W., & Timmermans, H. J. P. (2010). Modeling simplifying information processing strategies in conjoint experiments. *Transportation Research Part B: Methodological, 44*(6), 764-780. doi:10.1016/j.trb.2009.12.007

Çolak, S., Lima, A., & González, M. C. (2016). Understanding congested travel in urban areas. *Nature Communications, 7*, 1-8. doi:10.1038/ncomms10793

Appendix A - Clustering

This appendix provides the results of automatic k-means-clustering using various pre-set number of clusters; i.e. 4, 5 and 6 clusters (Table 17). Note that the results of the final clustering are included to facilitate comparisons. Cluster refinements were made by hand based on the cluster a certain pattern would belong to in the three different automatic clustering approaches. That is, patterns that belonged to the same cluster in each automatic clustering approach were bundled together (for instance, observations that belonged to cluster 2 in the 4-cluster approach, to cluster 3 in the 5-cluster approach and to cluster 6 in the 6-cluster approach). These bundles were then combined based on their similarities and behavioural interpretation as elaborated in the following paragraph.

First, patterns belonging to clusters 1, 1 and 1 (called bundle -111-) in the 4-, 5- and 6-cluster approach respectively contained no switches at all, and were therefore considered to form a distinct cluster (i.e. profile 1; Staying). Then, bundles -112-, -332-, -132- and -333- were combined as for these the non-preferred route alternative was only chosen once or twice at the beginning of the experiment (i.e. profile 2; Trying). Patterns in bundle -223- also had only one or two switches, except that these were made at the end of the experiment and were therefore regarded as a separate cluster (i.e. profile 3; Occasionally curious). Bundles -245-, -345-, -243- and -445- were combined because they had only a few switches both in the beginning and at the end of their patterns (i.e. profile 4; Confirmation seeking). Bundles -334- and -344- consisted of patterns containing switches at the beginning of the experiment, such as profile 2 except that they contained more switches, and were therefore combined in a separate cluster (i.e. profile 5; Exploring). Finally, bundles -456- and -455- were combined as they made many switches in which the 'centre of gravity' of switching was around run 6 (i.e. profile 6; Switching).

Hence, this exploratory clustering method resulted in six final clusters in which each cluster consisted of a substantial number of observed patterns, while distinctive patterns were separated into different clusters. Measures for cluster validation are presented in Table 18.

Although the correlation between the proximity matrix and the incidence matrix for the final clustering is lower than this correlation for the 4-cluster and 5-cluster approaches, its between-cluster sum-of-squares is higher and its within-cluster sum-of-squares is lower. Moreover, the final clustering has the highest silhouette coefficient. Note that none of the measures indicates bad clustering for any of the cluster approaches.

Table 17. Clustering results using 4, 5, and 6 pre-set clusters and the final clustering.

Cluster	Cluster centre			Cluster size (N)
	Average number of route switches [#]	Average number of times the preferred route was chosen [#]	Average switching moment [run t]	
4 clusters				
Cluster 1	0.4	10.6	0.7	92
Cluster 2	2.5	9.1	8.0	22
Cluster 3	3.3	8.3	4.7	52
Cluster 4	6.1	6.6	6.4	34
5 clusters				
Cluster 1	0.2	10.8	0.4	80
Cluster 2	1.8	9.8	8.5	12
Cluster 3	2.4	9.1	3.4	34
Cluster 4	3.7	8.0	6.0	42
Cluster 5	6.2	6.6	6.4	32
6 clusters				
Cluster 1	0	11	0	63
Cluster 2	1.6	9.7	2.6	39
Cluster 3	1.9	9.7	8.1	14
Cluster 4	3.3	7.9	4.4	25
Cluster 5	4	8	6.6	31
Cluster 6	6.4	6.5	6.4	28
Final clustering				
Cluster 1	0	11	0	63
Cluster 2	1.6	9.7	2.7	40
Cluster 3	1.8	9.8	8.5	12
Cluster 4	3.7	8.2	6.5	29
Cluster 5	3.3	7.9	4.3	24
Cluster 6	6.2	6.6	6.4	32

Table 18. Cluster validation measures.

	Correlation between proximity matrix and incidence matrix	Between-cluster sum-of-squares	Within-cluster sum-of-squares	Silhouette coefficient
4 clusters	-0.7096	2879	494	0.53
5 clusters	-0.6788	2999	374	0.50
6 clusters	-0.6373	3095	278	0.55
Final clustering	-0.6386	3067	307	0.56

Appendix B - Questionnaire ‘Route choice and travel information’

The survey was conducted in Dutch and translated into English for inclusion in this thesis. Note that four versions of this survey were distributed, each consisting one of the four information framing strategies; i.e. ‘recommend’-strategy (version 1), ‘nudge’-strategy (version 2), ‘social reinforcement’-strategy (version 3) and ‘educate’-strategy (version 4).

Welcome

At the Centre for Transport Studies at the University of Twente, we examine travel behaviour of car drivers and their route choice in response to travel information. As such, we hope to provide relevant, personalized information to travellers and use the existing road network more efficiently in the future.

Do you have a car at your disposal and do you sometimes use it to commute to work (or school/university)? In that case, we hope that you are willing to fill out our questionnaire. This will take about 15 minutes and your responses are completely anonymous.

Every respondent who completes this questionnaire has the chance to win 1 out of 3 bol.com vouchers at the value of €50,-.

Thank you in advance,

Mariska van Essen
Researcher at the Centre for Transport Studies, University of Twente

Version 1: Choice Situations – Explanation

First, we present three choice situations. In each choice situation, we ask you to choose between two route alternatives based on route advice that is presented to you in a message. This advice might pursue several societal goals, in this case:

- To reduce congestion in the road network;
- To stimulate overall traffic safety;
- To contribute to improved sustainability.

You receive the message with advice from your local government through an information service on your personal smartphone.

Version 2, 3 and 4: Choice Situations – Explanation

First, we present six choice situations. In each choice situation, we ask you to choose between two route alternatives based on route advice that is presented to you in a personalized information message. These messages provide information on travel times and pursue several societal goals, namely:

- To reduce congestion in the road network;
- To stimulate overall traffic safety;
- To contribute to improved sustainability.

You receive the information message from your local government through an information service on your personal smartphone.

Example of visualisation of choice situations

Each message was embedded in a picture of a smartphone screen in order to increase realism. We now provide one example of this visualization for each information strategy (Figure 19). For the sake of readability, the continuation of this appendix will only provide the content of the messages in each choice situation.

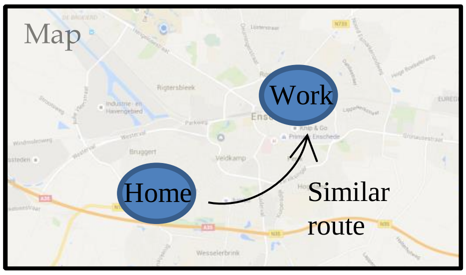
a) b) c) d)

Figure 19. Visualisations of a) 'recommend'-strategy, b) 'nudge'-strategy, c) ' social reinforcement'-strategy, and d) 'educate'-strategy.

Version 1: Choice situations[3]

Choice situation 1 - Congestion

Imagine that you are about to undertake a commute trip to work by car. In the following message the information service on your smartphone advises you to take another route than usual today:



"The route shown contributes to congestion alleviation within the road network in your region. Consequently, we advise you to take this route.

The advised route might result in a slightly longer travel time compared to your usual route."

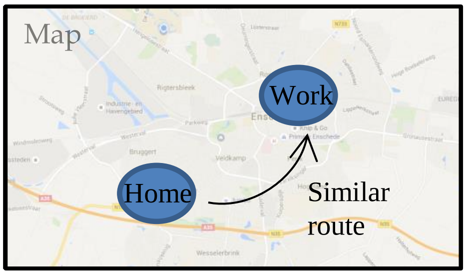
Which route would you choose?

- o The advised route
- o Your usual route

[3] All choice situations are randomly presented to respondents.

Choice situation 2 - Traffic safety

Imagine that you are about to undertake a commute trip to work by car. In the following message the information service on your smartphone advises you to take another route than usual today:



"The route shown contributes to overall traffic safety within the road network in your region by avoiding a high-risk location. Consequently, we advise you to take this route.*

The advised route might result in a slightly longer travel time compared to your usual route."

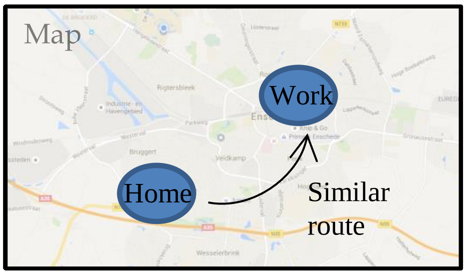
*a high-risk location could be a busy intersection, school area or city centre

Which route would you choose?

- o The advised route
- o Your usual route

Choice situation 3 - Sustainability

Imagine that you are about to undertake a commute trip to work by car. In the following message the information service on your smartphone advises you to take another route than usual today:



"The route shown contributes to a better environment in your region by lower emissions of harmful substances. Consequently, we advise you to take this route.

The advised route might result in a slightly longer travel time compared to your usual route."

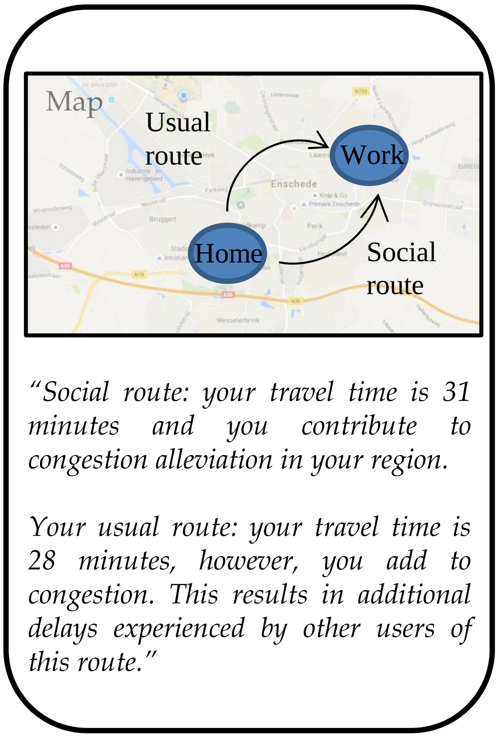
Which route would you choose?

- The advised route
- Your usual route

Version 2: Choice situations[4]

Choice situation 1 - Congestion

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



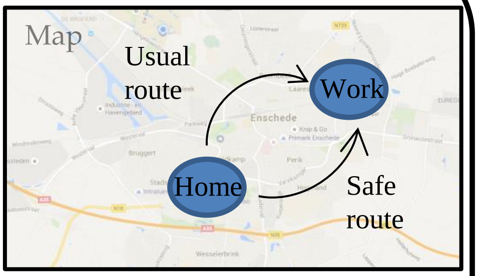
Which route would you choose?

- o The social route
- o Your usual route

[4] All choice situations are randomly presented to respondents.

Choice situation 2 - Traffic safety

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"Safe route: your travel time is 31 minutes and you contribute to overall safety in your region.

Your usual route: your travel time is 28 minutes, however, you pass a high-risk location. This results in additional traffic at this location, leading to a less safe traffic situation for users of this route."*

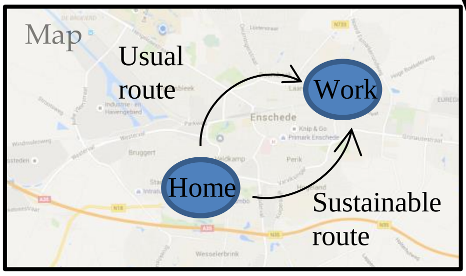
*a high-risk location could be a busy intersection, school area or city centre

Which route would you choose?

- ○ The safe route
- ○ Your usual route

Choice situation 3 - Sustainability

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"Sustainable route: your travel time is 31 minutes and you contribute to a better environment in your region.

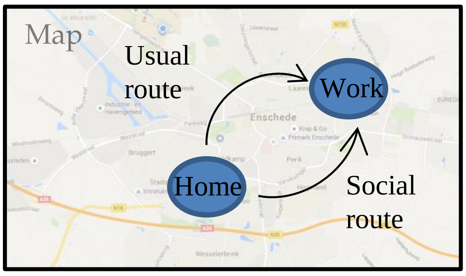
Your usual route: your travel time is 28 minutes, however, emissions of harmful substances are higher. As such, this route is worse for the environment."

Which route would you choose?

- The sustainable route
- Your usual route

Choice situation 4 - Congestion

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"Social route: your travel time is 35 minutes and you contribute to congestion alleviation in your region.

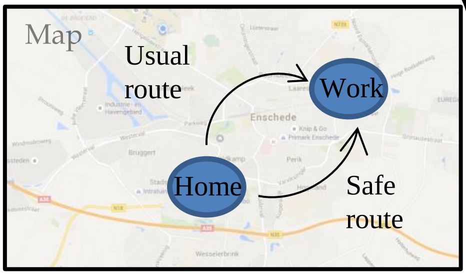
Your usual route: your travel time is 28 minutes, however, you add to congestion. This results in additional delays experienced by other users of this route."

Which route would you choose?

- The social route
- Your usual route

Choice situation 5 - Traffic safety

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"Safe route: your travel time is 35 minutes and you contribute to overall safety in your region.

Your usual route: your travel time is 28 minutes, however, you pass a high-risk location. This results in additional traffic at this location, leading to a less safe traffic situation for users of this route."*

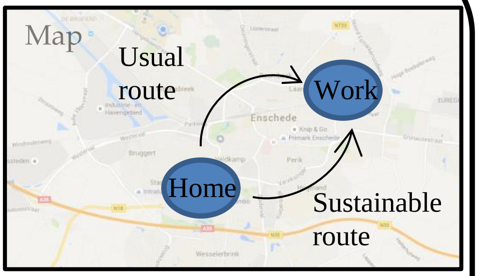
*a high-risk location could be a busy intersection, school area or city centre

Which route would you choose?

- ○ The safe route
- ○ Your usual route

Choice situation 6 - Sustainability

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"Sustainable route: your travel time is 35 minutes and you contribute to a better environment in your region.

Your usual route: your travel time is 28 minutes, however, emissions of harmful substances are higher. As such, this route is worse for the environment."

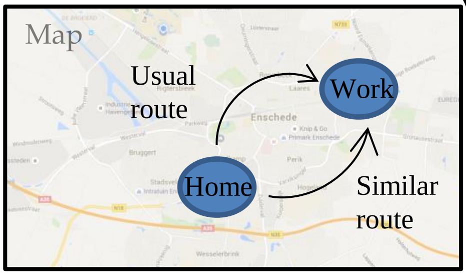
Which route would you choose?

- ○ The sustainable route
- ○ Your usual route

Version 3: Choice situations[5]

Choice situation 1 - Congestion

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"Your usual route takes 28 minutes. The similar alternative takes 31 minutes, however, when you take this route, you contribute to congestion alleviation in your region. For that reason, we ask you to take the similar alternative.

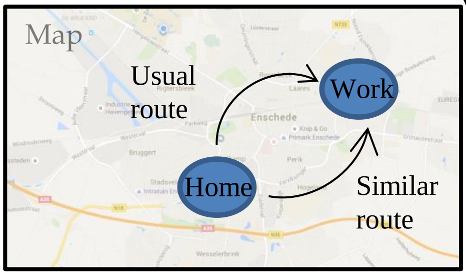
In other regions, we have asked travellers to choose a particular route alternative for the same reason. On average, 72% of travellers complied with our request. This had a big effect on the throughput in these regions. Do you take part to achieve this in your region as well?"*

Which route would you choose?
- The similar route
- Your usual route

[5] All choice situations are randomly presented to respondents.

Choice situation 2 - Traffic safety

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"Your usual route takes 28 minutes. The similar alternative takes 31 minutes, however, when you take this route, you avoid a high-risk location and as such you contribute to overall traffic. For that reason, we ask you to take the similar alternative.*

In other regions, we have asked travellers to choose a particular route alternative for the same reason. On average, 72% of travellers complied with our request. This had a big effect on the overall traffic safety in these regions. Do you take part to achieve this in your region as well?"*

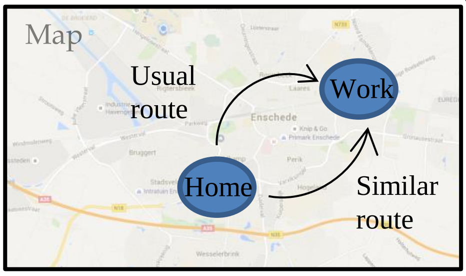
*a high-risk location could be a busy intersection, school area or city centre

Which route would you choose?

- The similar route
- Your usual route

Choice situation 3 - Sustainability

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"Your usual route takes 28 minutes. The similar alternative takes 31 minutes, however, when you take this route, emissions of harmful substances is lower. As such, you contribute to a better environment in your region. For that reason, we ask you to take the similar alternative.

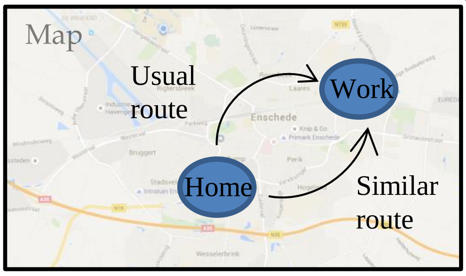
In other regions, we have asked travellers to choose a particular route alternative for the same reason. On average, 72% of travellers complied with our request. This had a big effect on the environment in these regions. Do you take part to achieve this in your region as well?"*

Which route would you choose?

- The similar route
- Your usual route

Choice situation 4 - Congestion

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"Your usual route takes 28 minutes. The similar alternative takes 35 minutes, however, when you take this route, you contribute to congestion alleviation in your region. For that reason, we ask you to take the similar alternative.

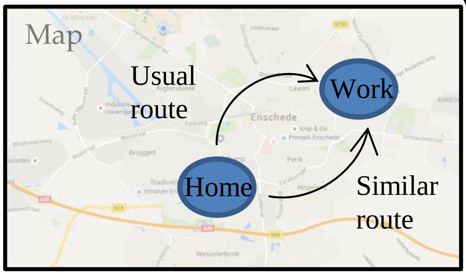
In other regions, we have asked travellers to choose a particular route alternative for the same reason. On average, 72% of travellers complied with our request. This had a big effect on the throughput in these regions. Do you take part to achieve this in your region as well?"*

Which route would you choose?

- ○ The similar route
- ○ Your usual route

Choice situation 5 - Traffic safety

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"Your usual route takes 28 minutes. The similar alternative takes 35 minutes, however, when you take this route, you avoid a high-risk location and as such you contribute to overall traffic. For that reason, we ask you to take the similar alternative.*

In other regions, we have asked travellers to choose a particular route alternative for the same reason. On average, 72% of travellers complied with our request. This had a big effect on the overall traffic safety in these regions. Do you take part to achieve this in your region as well?"*

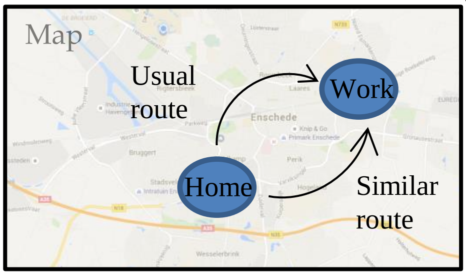
*a high-risk location could be a busy intersection, school area or city centre

Which route would you choose?

- The similar route
- Your usual route

Choice situation 6 - Sustainability

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"Your usual route takes 28 minutes. The similar alternative takes 35 minutes, however, when you take this route, emissions of harmful substances is lower. As such, you contribute to a better environment in your region. For that reason, we ask you to take the similar alternative.

In other regions, we have asked travellers to choose a particular route alternative for the same reason. On average, 72% of travellers complied with our request. This had a big effect on the environment in these regions. Do you take part to achieve this in your region as well?"*

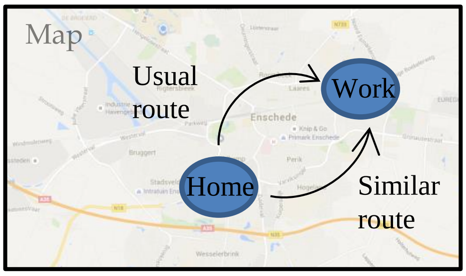
Which route would you choose?

- o The similar route
- o Your usual route

Version 4: Choice situations[6]

Choice situation 1 - Congestion

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"When everybody chooses the fastest route alternative (your usual route), this could lead to delays and congestion on this route. Consequently, everyone ends up with additional travel time. When part of the travellers take a short detour using a similar alternative (social route), the remaining travellers on this route could drive on faster. As a result, we expect to reduce congestion and improve throughput significantly. You can contribute by complying with our advice:"

	Your usual route (fastest route)	**Similar route (social route)**
Estimated travel time	28 minutes	31 minutes

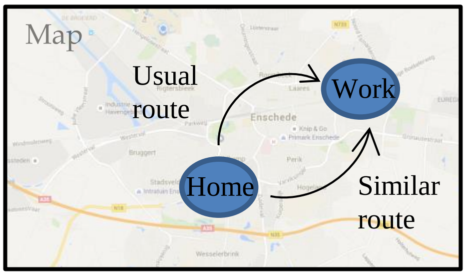
"We advise you to take the similar route today. This is the social alternative."

Which route would you choose?
- o The similar route
- o Your usual route

[6] All choice situations are randomly presented to respondents.

Choice situation 2 - Traffic safety

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"When everybody chooses the fastest route alternative (your usual route), this could lead to crowdiness on this route. As a result, there might arise a high-risk situation at a certain location on this route. When part of the travellers take a short detour using a similar alternative (social route) to avoid this location, the remaining travellers on this route could drive on safer. As a result, we expect to improve overall traffic safety significantly. You can contribute by complying with our advice:"*

	Your usual route (fastest route)	**Similar route (social route)**
Estimated travel time	28 minutes	31 minutes

"We advise you to take the similar route today. This is the social alternative."

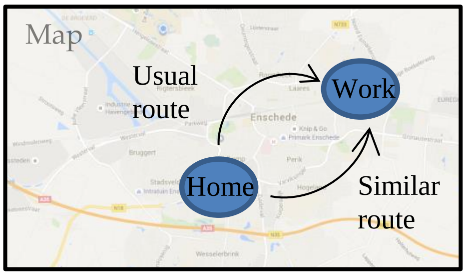
*this could be at a busy intersection, school area or city centre

Which route would you choose?

- o The similar route
- o Your usual route

Choice situation 3 - Sustainability

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"When everybody chooses the fastest route alternative (your usual route), this could lead to delays and congestion on this route. Consequently, travellers need to break an accelerate more. This entails an increase in the emission of harmful substances. When part of the travellers take a short detour using a similar alternative (social route) it becomes less crowded on this route and the remaining travellers will have lower emissions as well. As a result, we expect to improve the environment significantly. You can contribute by complying with our advice:"

	Your usual route (fastest route)	**Similar route (social route)**
Estimated travel time	28 minutes	31 minutes

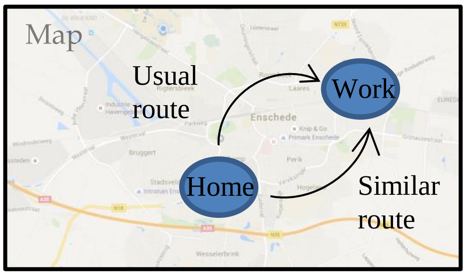
"We advise you to take the similar route today. This is the social alternative."

Which route would you choose?

- o The similar route
- o Your usual route

Choice situation 4 - Congestion

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"When everybody chooses the fastest route alternative (your usual route), this could lead to delays and congestion on this route. Consequently, everyone ends up with additional travel time. When part of the travellers take a short detour using a similar alternative (social route), the remaining travellers on this route could drive on faster. As a result, we expect to reduce congestion and improve throughput significantly. You can contribute by complying with our advice:"

	Your usual route (fastest route)	**Similar route (social route)**
Estimated travel time	28 minutes	35 minutes

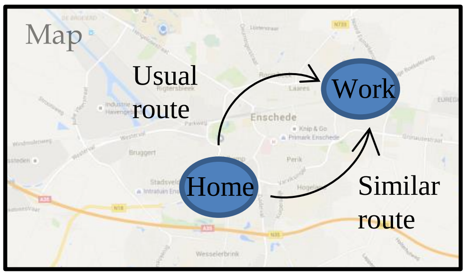
"We advise you to take the similar route today. This is the social alternative."

Which route would you choose?

- o The similar route
- o Your usual route

Choice situation 5 - Traffic safety

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"When everybody chooses the fastest route alternative (your usual route), this could lead to crowdiness on this route. As a result, there might arise a high-risk situation at a certain location on this route. When part of the travellers take a short detour using a similar alternative (social route) to avoid this location, the remaining travellers on this route could drive on safer. As a result, we expect to improve overall traffic safety significantly. You can contribute by complying with our advice:"*

	Your usual route (fastest route)	**Similar route (social route)**
Estimated travel time	28 minutes	35 minutes

"We advise you to take the similar route today. This is the social alternative."

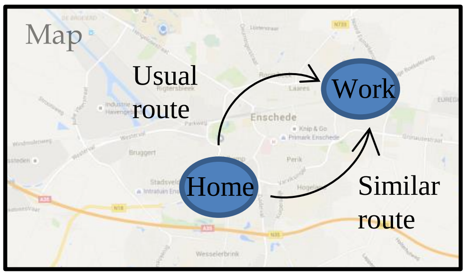
*this could be at a busy intersection, school area or city centre

Which route would you choose?

- o The similar route
- o Your usual route

Choice situation 6 - Sustainability

Imagine that you are about to undertake a commute trip to work by car. Your usual route takes 28 minutes. You receive the following message concerning your usual route and some similar alternative by the information service on your smartphone:



"When everybody chooses the fastest route alternative (your usual route), this could lead to delays and congestion on this route. Consequently, travellers need to break an accelerate more. This entails an increase in the emission of harmful substances. When part of the travellers take a short detour using a similar alternative (social route) it becomes less crowded on this route and the remaining travellers will have lower emissions as well. As a result, we expect to improve the environment significantly. You can contribute by complying with our advice:"

	Your usual route (fastest route)	**Similar route (social route)**
Estimated travel time	28 minutes	35 minutes

"We advise you to take the similar route today. This is the social alternative."

Which route would you choose?

- The similar route
- Your usual route

Decision-making strategy – Explanation

People could use several approaches when making their choices. For that reason, we now provide you with several statements. The first set of statements relate to your decision-making strategy in general. These are followed by a set of statements about your route choice for your commute specifically.

General statements[7]

Choose the applicable answer for each statement:

1. Whenever I am faced with a choice, I try to imagine what all the possibilities are, even ones that are not present at the moment.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

2. My decisions are well thought through.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

3. I am uncomfortable making decisions before I know all of my options.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

4. Before making a choice, I consider many alternatives thoroughly.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

5. No matter what I do, I have the highest standards for myself.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

[7] Statements retrieved from the Context-Free Maximizing Tendency Scale by Lai (2010).

Statements about route choice for commute[8]

Choose the applicable answer for each statement:

When I go to work by car…

1. … I want to spend effort to find out which route alternative is the best.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

2. … I think about which route alternative I want to use.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

3. … there is no doubt in my mind about which route alternative I will take.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

4. … I want to know in detail which pros and cons various route alternatives have.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

5. … I think it is useless to spend time and energy to find out which route alternative is most suitable.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

6. … I want to prepare the journey well before.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

[8] Statements retrieved from the Decision Involvement Scale by Verplanken et al. (1994).

7. … I don't need to deliberate about which route to take, because I already know.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

8. … I use the first route alternative that comes to mind.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

Personal preference – Explanation

The next part contains 6 questions about your personal preference to divide resources, in this case money (€), but it could as well relate to for example travel time.

You and some other (anonymous) person play a game in which you both could earn money. Your choices influence both the amount you receive and the amount the (anonymous) other receives.

You are presented with several game situations. For each situation, we would like to know which outcomes you would pursue. There are no wrong answers in this assignment; it is all about your personal preference. However, you can only provide one answer for each situation.

Personal preference – Game situations[9]

Choose the applicable answer for each situation:

Situation 1

You receive (€):	85	85	85	85	85	85	85	85	85
Other receives (€):	85	76	68	59	50	41	33	24	15
What outcome do you pursue?	□	□	□	□	□	□	□	□	□

Situation 2

You receive (€):	85	87	89	91	93	94	96	98	100
Other receives (€):	15	19	24	28	33	37	41	46	50
What outcome do you pursue?	□	□	□	□	□	□	□	□	□

Situation 3

You receive (€):	50	54	59	63	68	72	76	81	85
Other receives (€):	100	98	96	94	93	91	89	87	85
What outcome do you pursue?	□	□	□	□	□	□	□	□	□

[9] Social Value Orientation Slider Measure by Murphy et al. (2011).

Situation 4

You receive (€): Other receives (€):	50 100	54 89	59 79	63 68	68 58	72 47	76 36	81 26	85 15
What outcome do you pursue?	□	□	□	□	□	□	□	□	□

Situation 5

You receive (€): Other receives (€):	100 50	94 56	88 63	81 69	75 75	69 81	63 88	56 94	50 100
What outcome do you pursue?	□	□	□	□	□	□	□	□	□

Situation 6

You receive (€): Other receives (€):	100 50	98 54	96 59	94 63	93 68	91 72	89 76	87 81	85 85
What outcome do you pursue?	□	□	□	□	□	□	□	□	□

Travel behaviour - General

Now, we would like to know more about your general travel behaviour.

Which mode of transportation do you use in general?

- o I mostly take the car.
- o I regularly take the car and every now and then I use public transport or take the bike.
- o I sometimes take the car, but often I use public transport or take the bike.
- o I mostly use public transport or take the bike.
- o Other, namely…

To what extent are the following statements applicable to you?

1. I am quite familiar with the local road network.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

2. I visit many different locations in an average week.

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

3. When I travel to work, I regularly use travel information (e.g. route planner, navigation system, traffic reports, etc.).

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

4. I have many social contacts (family, friends, acquaintances that you keep in contact with).

Not applicable at all	Hardly applicable	Somewhat applicable	Reasonably applicable	Highly applicable
O	O	O	O	O

Travel behaviour – Specific trip

Now, think about your trip to work (or school/university). The following questions are being asked in relation to this trip.

1. When you travel by car to work, what is your travel time on average?
   - o 10 minutes or less
   - o 11-20 minutes
   - o 21-30 minutes
   - o 31-40 minutes
   - o 41 minutes or more
   - o Not applicable/ I never go to work by car

2. Most people have several routes to work they could choose from. Which of the following aspects are most important to your route choice when travelling to work by car? Rank those with respect to their importance. Please, select 1 to 3 answers.

A) Travel time	B) Travel time variability
C) Travel distance	D) Heavy traffic
E) Environmental sustainability	F) Variation and alternation of routes
G) Maximum speed limit	H) The number of intersections and traffic lights
I) Fuel costs	J) The number of unsafe and/or complex locations (e.g. neighbourhoods, school areas or city centres)

Ranking (1 being the most important):

1. ………………

2. ………………

3. ………………

3. Please, indicate which statement concerning your route choice is most applicable when you travel to work by car[10].
   - □ I always use the same route (go to question 3.1).
   - □ I mostly use the same route, but every now and then I take another route* (go to question 3.2).
   - □ I switch regularly between routes* (go to question 3.2).
   - □ Not applicable/ I never go to work by car.

*Routes do not have to be different from start to end; they may partially overlap.

3.1. You indicated to always use the same route. Do other (realistic) route alternatives exist?
   - □ Yes, other (realistic) route alternatives exist.
   - □ No, this is the only (realistic) route alternative.

3.2. You indicated to use multiple route alternatives. How many route alternatives do you use?

I use ………….. different routes.

4. When you travel to work, how many minutes would you be willing to add to your current travel time to contribute to:

To alleviate congestion within the road network?	…………. minutes
To improve general traffic safety within the road network?	…………. minutes
To reduce overall emissions and pollution and to improve environmental sustainability?	…………. minutes

General

This is the last part of the questionnaire, which contains a few personal questions.

1. What is your age?
   - o 16 - 24 years
   - o 25 - 34 years
   - o 35 - 44 years
   - o 45 - 54 years
   - o 55 - 64 years
   - o 65 years or older

[10] In the online questionnaire, respondents are automatically directed to the referred question within their answer without noticing it.

2. What is your gender?
   - Male
   - Female

3. What is the highest level of education you completed?
   - None/elementary education
   - High school
   - Vocational education
   - University of applied science
   - University
   - Other

4. Do you have any further remarks and/or suggestions?

…………………………………………………………………………………………….

Thank you

This is the end of the questionnaire. Thank you for your participation!

If you like to have a chance to win 1 out of 3 bol.com vouchers at the value of €50,-, please enter your e-mail address:
…………………………………………………………………………………………….

Your e-mail address will be saved separately from your answers and will only be used to contact you if you are the winner of one of the vouchers.

Future research
Based on the findings from this questionnaire, a personalized travel information strategy will be developed. This strategy will be implemented in an already existing smartphone application, called 'SMART Mobiliteit'. This application registers your trips and provides insights into your mobility. You can participate in challenges through which you can earn points. These points can be exchanged for gifts at local companies within the Twente Region. Additional information can be found on www.smartintwente.nl.

Are you interested in participating in an experiment in which this personalized travel information strategy is being tested? In that case, we will contact you once (without obligation) through the provided email address.

- Yes, I am interested in participating in the experiment and you may contact me about this once.
- No, I am not interested in participating in the experiment.

Summary

Traffic congestion is one of the main problems of today's society. It arises when many travellers want to use the same low-cost route at the same time. Such selfish route choice behaviour leads to a so-called user equilibrium; a network state in which all travellers use the shortest available route and therefore travel times on all used routes are equal. However, the existing road network is not used to its fullest potential. A more efficient network state, the so-called system optimum, arises when travellers take into account the additional travel time they impose on others. As such, the total travel time within the road network will be minimised. However, travel times on used routes are no longer equal. As a consequence, some travellers need to act non-selfish and take a detour to the benefit of others (i.e. the network as a whole). An important question in this regard is how to motivate those travellers to take this detour.

Conventional steering approaches, such as road pricing or personalized incentives (e.g. discounts or rewards), either lead to resistance or are costly, and their social desirability is questioned. Meanwhile, advances in information & communication technology (ICT) enable real-time traffic management using personalized information strategies. Moreover, it is generally assumed that individuals are rational in how they choose and selfish in what they choose. However, studies on choice behaviour in several research fields found evidence that individuals suffer from cognitive limitations and perception errors, or have biases and emotions influencing their decision-making, i.e. they are boundedly rational. As such, they do not necessarily choose the shortest travel time alternative. Studies on social choice behaviour found evidence that individuals do not exclusively behave in selfish ways, but do care about others welfare as well. As a result, the application of information-based demand measures using social routing advice is receiving increasingly attention. After all, travellers might be willing to take a detour if they are being asked or advised to do so depending on their social orientation, or they might be (subconsciously) nudged towards this detour depending on the degree of rationality in their decision-making. However, firm evidence that empirically supports these expectations regarding the potential of social routing advice does not exist.

After all, response towards advice that might not directly benefit travellers themselves is not completely understood yet, while impacts on network performance remain unclear.

The main objective of this thesis is *'to empirically determine the potential to use current state-of-the-art, personalized travel information and social routing advice to make more efficient use of the existing road network'.* Although stimulating favourable departure time changes or motivating car drivers to switch to other modes of transportation would have a positive effect on road network efficiency as well, only car drivers' route choice optimization is considered. Moreover, the main focus is on travel time optimization, although optimization regarding sustainability and traffic safety are shortly addressed as well. This thesis deals with both the individual perspective and the network perspective. As such, it complements existing studies that consider only one of both perspectives and either ignore the effects at the network level or make very simplified assumptions on individuals' choice behaviour. Moreover, a reasonable number of studies within the transport field consider the notion of bounded rationality, whereas social choice behaviour has not received much attention yet. In order to complement existing literature, this thesis considers both bounded rationality and social choice behaviour.

Chapter 2 provides an in-depth literature review of papers that have studied – or are highly relevant to – the potential and limitations of travel information as a travel demand management measure. This chapter puts forward the idea that in order to understand the potential of specific travel information in terms of directing the transport system towards a system optimum at the network level, one needs to understand how both bounded rationality and social orientation interact at the individual level. In line with this, it stresses the importance of anticipation on individuals' social orientation as well as bounded rationality when applying information-based demand measures and advocates for tailor-made personalised information messages.

Chapter 3 provides empirical insights into the effect of conventional travel information (i.e. travel information that aims at travellers' personal benefit) on day-to-day route choice behaviour in a real-world context. To that end, a field experiment was conducted, consisting of two parts. In the first part, participants had to make five consecutive trips, while choosing between two route alternatives. In the second part, they received pre-trip travel time information for both route alternatives in addition. Findings show that the provision of travel time information leads to a decline in switching propensity and a higher probability that the shortest route is chosen, specifically on those origin-destination (OD) pairs for which alternatives with distinct travel times exist. This is even the case for travellers who reveal switch-prone behaviour on OD-pairs with similar travel time routes.

Chapter 4 examines travellers' compliance with travel information and social routing advice based on a stated choice experiment and a revealed choice experiment (which also collected stated intentions). It introduces four social routing information strategies that build upon behavioural principles that are identified in existing literature; i.e. a 'Recommend'-strategy, 'Nudge'-strategy, 'Social Reinforcement'-strategy and 'Educate'-strategy. The 'Recommend'-strategy has low information content and capitalizes on aspects of bounded rationality such as limited mental resources and decision time *('In order to alleviate congestion, please use this route today'*). The 'Nudge'-strategy has moderate information content and capitalizes on aspects of bounded rationality such as the theory of default settings and loss aversion (*'The social route takes 31 minutes and you will contribute to congestion alleviation, whereas your usual route takes 28 minutes while adding to congestion'*). The

'Social Reinforcement'-strategy has moderate information content and focusses on existing social norms while putting sacrifices into perspective ('*Your usual route takes 28 minutes. The similar alternative takes 31 minutes and contributes to congestion alleviation. X% of travellers took the similar alternative. Do you too?*'). Finally, the 'Educate'-strategy has high information content and focusses on creating awareness and changing attitudes towards social behaviour (this strategy consisted of three elements: 1) explain importance of social behaviour, 2) provide a map with both the usual and social alternative and inform on estimated travel times for both alternatives, 3) provide route advice to take the social route).

In the stated choice experiment, respondents were asked to picture a hypothetical commute trip and were provided with an information message regarding this trip. They were asked to choose between two route alternatives: their (hypothetical) usual route and some 'similar route' with a slightly higher travel time. Each respondent received the information message in line with one of the aforementioned strategies. In the revealed choice experiment, participants were asked to install the smartphone application 'SMART Mobility' on their personal smartphone, which automatically collected trip-data, i.e. origin, destination, departure time, arrival time, route and mode (-chain) for each trip. On working days, this application sent a tailored information message containing route advice for the morning commute to its users. After a commute trip was made, users received two questions about the main reason for choosing a particular route and the role that the information message played in that decision.

Both experiments show that travellers are sometimes willing to choose the social detour over their usual route when they are being asked or advised to do so. Nonetheless, in daily-life travellers comply less with the advice than stated, i.e. compliance rates of 31% (revealed choice) and 57% (stated choice) are found. Results from the stated choice experiment indicate a significant difference in compliance behaviour across different information frames, societal goals, sizes of travel time sacrifices and personality. More specifically, travellers are most likely to choose the social route when small travel time sacrifices are involved, when information messages are aiming at alleviating congestion, and when these messages are framed according to the 'Nudge'-strategy, 'Social Reinforcement'-strategy or 'Educate'-strategy. Moreover, travellers are most likely to comply with the received advice when they are cooperatively oriented and when they make their choices in a non-habitual manner. Nonetheless, above findings are less evident from the results based on revealed choices. That is, the main motivation for revealed compliance seems to be an intrinsic motivation to contribute to improved throughput. The main motivation for revealed non-compliance with social routing advice relates to perceived traffic conditions; i.e. the social route is believed to be crowded as well or the usual route is not busy at all. One reason for this combination of empirical findings might be that context-related aspects, such as familiarity with routes or trust in the information system, are present in the revealed choice experiment, while absent in the stated choice experiment. Finally, we observed a relation between behavioural intention as stated before the revealed choice experiment and compliance frequency throughout the revealed choice experiment; participants who stated an inclination to choose the social route, chose this route on average in 56% of the cases during the field experiment, whereas participants who stated an inclination to choose their usual route, chose the social route in only 17% of the cases during the field experiment.

Chapter 5 explores the impacts of social routing advice on road network performance and equity among trips in a large-scale road network based on observed compliance behaviour (from the experiments in Chapter 4). Hence, it links individual behaviour with network effects. As such, it shows the potential of information-based demand measures using social routing in improving road network efficiency. Traffic is assigned to the road network (representing part of the Twente Region in The Netherlands) using several shares of social trips (i.e. trips that comply with social routing advice) and selfish trips (i.e. non-complying trips). Results show that if all travellers comply with the social routing advice, 3.6% of total travel time at current traffic conditions could be potentially saved in our research area during the morning peak; this corresponds to regional economic benefits of about €2,600,000,- each year. However, an information-based demand measure using social routing is expected to direct only 10% of trips towards social routes (taking into account market penetration, compliance behaviour and detour alternation among travellers). As such, potential travel time savings could only be achieved to some extent. Moreover, individual benefits will be marginal; the majority of travellers experience a travel time gain of less than two minutes. Observed network impacts show that structural congestion and unstable flows would be reduced, especially on major city roads. However, trips seem to be redirected through minor local roads, increasing cut-through traffic. Observed equity impacts indicate that a pure system optimum would be most beneficial to all travellers; average and maximum travel time losses are lowest, while average travel time gains are highest (i.e. when compared to travel times experienced in the user equilibrium) and travel time sacrifices (i.e. travel time difference compared to the travel time on the shortest travel time route) are smallest. In fact, it seems that the lower the share of social trips, the more social travellers need to compensate for the selfish behaviour of others by taking longer detours and sacrificing more travel time. Finally, only 12% of travellers need to take a detour in order to achieve a system optimum. This is close to the expected share of social trips in response to social routing advice. However, all those social travellers need to be concentrated on only a few specific OD-pairs; i.e. on these OD-pairs a large share of travellers need to take a detour, while on other OD-pairs none of the travellers needs to do so. It seems highly unlikely that on these specific OD-pairs the share of social travellers would be large enough.

In conclusion, this thesis demonstrated in a real-world daily-life context that travel information and social routing advice do have potential to improve road network efficiency, although a perfect system optimum seems out of reach. Several design considerations can be derived from the findings presented. The most important consideration is to provide social routing information tailored to the user (depending on his decision-making strategy and social orientation) as well as the choice context (depending on (perceived) traffic conditions). Our findings motivate future research into social routing, especially from the behavioural point of view. One future challenge is to upscale the experiments to a large-scale living lab integrating research in real-life communities and settings in which participants are not aware of taking part in an experiment. As such, a larger sample size over a longer time span, consisting of authentic choice behaviour, can be obtained.

Samenvatting

Files vormen een belangrijk probleem in de huidige samenleving. Ze ontstaan wanneer vele reizigers tegelijkertijd dezelfde snelle routes willen gebruiken. Zulk egoïstisch routekeuzegedrag resulteert in een zogeheten *gebruikersevenwicht*; een netwerkstaat waarin alle reizigers de snelste route gebruiken waardoor alle reistijden op de gebruikte routes gelijk zijn. Echter, het bestaande wegennetwerk wordt op deze manier niet efficiënt benut. Een efficiëntere netwerkstaat, het zogeheten *systeem optimum*, ontstaat wanneer reizigers rekening houden met de extra reistijd die zij andere reizigers toebrengen door dezelfde weg te gebruiken. Op die manier wordt de totale reistijd in het gehele wegennet geminimaliseerd. Reistijden op de gebruikte routes zijn dan echter niet meer gelijk. Om deze netwerkstaat te bereiken, moeten sommige reizigers zich dus sociaal gedragen door een kleine omweg te nemen, opdat andere reizigers sneller door kunnen rijden. Maar hoe motiveren we deze reizigers om een dergelijke omweg te nemen?

Conventionele sturingsmethoden, zoals rekeningrijden of het toepassen van persoonlijke drijfveren (bijvoorbeeld kortingen of beloningen), roepen weerstand op of kosten veel geld. De sociale wenselijkheid van deze sturingsmethoden is dan ook een punt van discussie. Ondertussen bieden ontwikkelingen in de informatie- en communicatietechnologie (ICT) de mogelijkheid tot real-time verkeersmanagement door middel van persoonlijke informatievoorziening. Daarnaast versterkt bestaande kennis van keuzegedrag het geloof dat reisinformatie en routeadvies reizigers naar de gewenste routes zou kunnen sturen. Over het algemeen wordt aangenomen dat mensen rationeel en egoïstisch zijn in het maken van hun keuzes. Meerdere studies hebben echter ontdekt dat het cognitief vermogen van mensen beperkt is, dat zij perceptiefouten maken en dat hun keuzes worden beïnvloed door vooroordelen en emoties; met andere woorden, ze zijn beperkt rationeel. Daardoor kiezen zij niet noodzakelijkerwijs de route met de kortste reistijd. Andere studies hebben ontdekt dat mensen zich niet altijd egoïstisch gedragen, maar zich ook het welzijn van anderen aantrekken. Deze bevindingen suggereren dat reizigers, afhankelijk van de mate van rationaliteit in hun keuzeproces en hun maatschappelijke betrokkenheid, mogelijk bereid zijn de sociale omweg te nemen als dit hun gevraagd of geadviseerd wordt of ze zouden onbewust richting deze omweg geduwd kunnen worden. Dit alles heeft ertoe geleid dat er steeds meer aandacht is voor sturingsmaatregelen gebaseerd op reisinformatie en sociaal route advies. Er bestaat echter geen gedegen empirisch bewijs die de verwachtingen met betrekking tot de potentie van sociaal route advies bevestigen. Zo weet men nog weinig van de reactie van reizigers op advies dat niet direct voordelig is voor de reiziger zelf en het effect op de toestand van het wegennet is nog onduidelijk.

Het hoofddoel van dit proefschrift is *'om de potentie van moderne, gepersonaliseerde reisinformatie en sociaal route advies voor een efficiënter gebruik van het bestaande wegennet empirisch vast te stellen'*. Hoewel het optimaliseren van vertrektijdkeuze en vervoerswijzekeuze ook een positief effect zou hebben op de efficiëntie van het wegennet, wordt er in dit proefschrift alleen gekeken naar het optimaliseren van routekeuzes. Daarbij ligt de focus op reistijdoptimalisatie, hoewel optimalisatie op basis van duurzaamheid en verkeersveiligheid ook kort worden aangestipt. Dit proefschrift vult bestaand onderzoek aan door het probleem te bekijken vanuit het perspectief van zowel de reiziger als het netwerk en door niet alleen aandacht te besteden aan beperkte rationaliteit, maar ook aan sociaal keuzegedrag.

Hoofdstuk 2 evalueert bestaande literatuur in relatie tot de mogelijkheden en beperkingen van reisinformatie als een sturingsmaatregel. Op basis hiervan wordt gesteld dat men eerst moet begrijpen hoe op het individuele niveau beperkte rationaliteit en maatschappelijke betrokkenheid van invloed zijn op het effect van reisinformatie. Hierna kan de potentie tot het verbeteren van efficiëntie op het netwerkniveau pas worden begrepen. Daarnaast wordt het belang om te anticiperen op de beperkte rationaliteit en maatschappelijke betrokkenheid van reizigers wanneer reisinformatie als een sturingsmaatregel wordt gebruikt, benadrukt en wordt er gepleit voor op maat gemaakte informatieberichten.

Hoofdstuk 3 geeft empirische inzichten in het effect van conventionele reisinformatie (i.e. reisinformatie gericht op het persoonlijk belang van reizigers) op routekeuzegedrag. Daartoe is een tweedelig veldexperiment uitgevoerd. In deel één van het experiment maakten deelnemers vijf aaneengesloten ritten, waarbij ze konden kiezen uit twee routes. Daarnaast ontvingen deelnemers in deel twee van het experiment voorafgaand aan iedere rit reistijdinformatie over beide routes. De bevindingen laten zien dat het geven van reistijdinformatie leidt tot een afname in het afwisselen van routes en een toename in het gebruik van de snelste route. Dit is met name het geval op herkomst- en bestemmingsparen (HB-paren) waarbij er een duidelijk verschil zit tussen de reistijden van beide routes. Dit is zelfs het geval voor reizigers die veel wisselen op HB-paren bestaande uit routes met vergelijkbare reistijden.

Hoofdstuk 4 geeft empirische inzichten in het effect van sociale reisinformatie en routeadvies op routekeuzegedrag, waarbij specifiek wordt gekeken naar het opvolggedrag van reizigers. Dit wordt gedaan middels een stated choice experiment (i.e. vermelde keuze in een vragenlijst) en een revealed choice experiment (i.e. getoonde keuze in dagelijks leven) waarin ook stated intentions (i.e. vermelde intenties voorafgaand aan experiment) verzameld worden. Het hoofdstuk introduceert vier sociale routeinformatiestrategieën die gebaseerd zijn op gedragsprincipes uit bestaande literatuur; i.e. de aanbevelingsstrategie, de duwstrategie, de sociale versterkingsstrategie en de educatiestrategie. De aanbevelingsstrategie bevat weinig informatie en profiteert van aspecten gerelateerd aan beperkte rationaliteit, zoals beperkte aanwezige mentale middelen en de beperkte tijd om een keuze te maken (*'Gebruik vandaag* *deze route om files te verminderen'*). De duwstrategie bevat al wat meer informatie en profiteert van eventuele beperkte rationaliteit door het gebruik van standaard instellingen en door in te spelen op reizigers' afkeer van verlies ('*De sociale route duurt 31 minuten en u draagt bij aan het verminderen van files. Uw gebruikelijke route duurt 28 minuten, maar u verergert filevorming*'). De sociale versterkingsstrategie bevat ook wat meer informatie en focust zich op bestaande sociale normen waarbij het reistijdoffer in perspectief wordt geplaatst ('*Uw gebruikelijke route duurt 28 minuten. Een vergelijkbaar alternatief duurt 31 minuten en draagt bij aan het verminderen van files. X% van de reizigers koos het vergelijkbare alternatief. U ook?*'). Tot slot, de educatiestrategie bevat veel informatie en focust op het creëren van bewustwording en het veranderen van de houding ten opzichte van sociaal keuzegedrag. Deze strategie bestaat uit drie elementen: 1) uitleg van het belang van sociaal keuzegedrag, 2) een kaart met de gebruikelijke route en het sociale alternatief inclusief geschatte reistijden voor beide routes, 3) het advies om de sociale omweg te kiezen.

In het stated choice experiment werden respondenten gevraagd om een hypothetische woon-werkrit in gedachten te nemen waarvoor zij informatieberichten te zien kregen. Vervolgens werd er gevraagd om te kiezen tussen twee routes: hun (hypothetische) gebruikelijke route en een 'vergelijkbare route' met een iets langere reistijd. Iedere respondent ontving de informatieberichten in lijn met één van de eerdergenoemde informatiestrategieën. In het revealed choice experiment werden deelnemers gevraagd om de smartphone-app 'SMART Mobiliteit' op hun persoonlijke smartphone te installeren. Deze app verzamelt automatisch ritinformatie, zoals herkomst, bestemming, vertrektijd, aankomsttijd, route en vervoerswijze voor iedere gemaakte rit. Gedurende het experiment zond deze app een op maat gemaakt informatiebericht met routeadvies voor de woon-werkrit naar zijn gebruikers. Zodra de bestemming was bereikt, ontvingen gebruikers twee vragen over hun motivatie voor de keuze van een bepaalde route en de rol die het informatiebericht hierin heeft gespeeld.

Beide experimenten laten zien dat reizigers soms de sociale omweg willen nemen in plaats van hun gebruikelijke route wanneer dit geadviseerd wordt. Echter volgen reizigers het advies minder vaak op in hun dagelijks leven dan gesteld in de vragenlijst (i.e. opvolgratios van 31% (getoonde keuze) en 57% (vermelde keuze) zijn gevonden). Resultaten van het stated choice experiment laten een significant verschil in opvolggedrag zien met betrekking tot verschillende informatiestrategieën, verschillende maatschappelijke doelen, de grootte van het reistijdoffer en persoonlijkheid. Om precies te zijn, reizigers zijn eerder geneigd te kiezen voor de sociale route wanneer slechts kleine reistijdoffers benodigd zijn, wanneer informatieberichten zich richten op het verminderen van files en wanneer informatieberichten gestuurd worden volgens de duwstrategie, de sociale versterkingsstrategie of de educatiestrategie. Verder is het het meest waarschijnlijk dat reizigers het sociale routeadvies opvolgen wanneer zij coöperatief georiënteerd zijn en wanneer zij geen gewoontegedrag vertonen. Bovenstaande bevindingen zijn echter minder duidelijk aanwezig in de resultaten van het revealed choice experiment. De belangrijkste motivatie voor getoond opvolggedrag is een intrinsieke motivatie om bij te dragen aan het verbeteren van de doorstroming, terwijl de belangrijkste motivatie voor het negeren van sociaal routeadvies betrekking heeft op de ervaren verkeerssituatie; i.e. men gelooft dat het erg druk is op de sociale route of vindt dat de gebruikelijke route helemaal niet druk is. Een reden voor deze combinatie van bevindingen is het feit dat context-gerelateerde aspecten, zoals bekendheid met het wegennet of vertrouwen in het informatiesysteem, in het stated choice experiment geen rol spelen en alleen van belang zijn in het revealed choice experiment. Tot slot lijkt er een relatie te bestaan tussen de stated intentions voorafgaand aan het revealed choice experiment en de opvolgfrequentie gedurende dit experiment; deelnemers die aangaven de sociale route te zullen kiezen, kozen deze route daadwerkelijk in 56% van de gevallen, terwijl deelnemers die aangaven hun gebruikelijke route te zullen kiezen, de sociale route in slechts 17% van de gevallen kozen.

Hoofdstuk 5 onderzoekt de effecten van sociaal routeadvies op de verkeerssituatie in het wegennet en de verdeling van reistijdoffers over reizigers op basis van het waargenomen opvolggedrag uit hoofdstuk 4. Op die manier wordt een directe link gelegd tussen individueel gedrag en netwerkeffecten en wordt de potentie van sturingsmaatregelen gebaseerd op sociaal routeadvies duidelijk. Verkeer wordt toegedeeld aan een realistisch wegennet – het model van een gedeelte van de regio Twente wordt hiervoor gebruikt – waarbij verschillende verhoudingen van sociale en egoïstische ritten (i.e. ritten die sociaal routeadvies respectievelijk wel en niet opvolgen) worden toegepast. Resultaten laten zien dat wanneer alle reizigers het sociale advies opvolgen, 3.6% van de totale reistijd in de huidige verkeerssituatie verminderd kan worden tijdens de ochtendspits; dit komt overeen met een regionale besparing van ongeveer €2.600.000,- per jaar. Een sturingsmaatregel op basis van sociaal routeadvies zal naar alle waarschijnlijkheid slechts 10% van de ritten richting sociale routes kunnen sturen (rekening houdend met het marktaandeel gebruikers, opvolggedrag en het afwisselen van reizigers die gevraagd wordt een omweg te nemen). Hierdoor kunnen potentiële reistijdbesparingen slechts tot op zekere hoogte worden bereikt. Daarnaast zijn individuele reistijdwinsten marginaal; de meeste reizigers ervaren een reistijdwinst van minder dan twee minuten. Waargenomen netwerkeffecten laten zien dat structurele filevorming en onstabiele verkeersstromen worden verminderd, met name op hoofdwegen in de steden. Ritten worden echter omgeleid via kleinere lokale wegen, waardoor sluipverkeer toeneemt. Waargenomen reistijdverdelingen laten zien dat een puur systeem optimum het meest voordelig is voor iedereen; gemiddelde en maximale reistijdverliezen zijn het laagst, terwijl gemiddelde reistijdwinsten het hoogst zijn (i.e. in vergelijking met reistijden in het gebruikersevenwicht), en reistijdoffers (i.e. reistijdverschil vergeleken met de reistijd van de kortste route op dat moment) zijn het kleinst. In feite lijkt het erop dat hoe lager het aandeel sociale ritten, hoe meer sociale reizigers moeten compenseren voor het egoïstische gedrag van anderen door langere omwegen te nemen en meer reistijd op te offeren. Tot slot blijkt dat slechts 12% van alle reizigers een omweg moet nemen om een systeem optimum te bereiken. Dit zit dicht bij het verwachte aandeel sociale ritten in reactie op sociaal route advies. Echter, alle sociale reizigers moeten in dat geval geconcentreerd zijn op slechts een paar specifieke HB-paren; dat wil zeggen dat op deze HB-paren een groot deel van de reizigers een omweg moet nemen, terwijl op de overige HB-paren geen enkele reiziger dit hoeft te doen. Het is onwaarschijnlijk dat het aandeel sociale reizigers op specifiek deze HB-paren groot genoeg zal zijn.

Samenvattend laat dit proefschrift zien dat reisinformatie en sociaal routeadvies in het dagelijks leven potentie hebben tot het verbeteren van netwerkefficiëntie, hoewel een perfect systeem optimum buiten bereik lijkt. Verschillende ontwerpoverwegingen voor effectieve sturingsmaatregelen kunnen uit de gepresenteerde bevindingen afgeleid worden. De belangrijkste is om sociaal routeadvies op maat aan te bieden, afhankelijk van zowel de gebruiker (met betrekking tot de mate van beperkte rationaliteit en maatschappelijke betrokkenheid) als de context (met betrekking tot de (ervaren) verkeerssituatie). De bevindingen geven aanleiding tot diepgaander onderzoek naar sociaal routekeuzegedrag in de toekomst. Eén van de uitdagingen is het opschalen van de experimenten naar een 'living lab' waarin onderzoek plaatsvindt in bestaande gemeenschappen en deelnemers zich niet bewust zijn van deelname aan een experiment. Op die manier kan een grotere steekproef over een langer tijdsbestek behaald worden waarbij authentiek gedrag wordt geobserveerd.

About the author

Mariska van Essen was born on the 30th of August 1990 in Apeldoorn, the Netherlands. She obtained her VWO diploma at the Christelijk Lyceum Sprengeloo in Apeldoorn. In 2008 she moved to Enschede to study Civil Engineering at the University of Twente. After earning her Bachelor's degree, she started specializing in the field of transportation engineering and management. She worked on her Master's thesis about the development and evaluation of a day-to-day route choice model at the Virginia Tech Transportation Institute (VTTI) in Blacksburg, Virginia, which is the second largest university-level transportation institute in the USA. Simultaneously, she performed a field experiment on route choice behaviour in response to travel information by actually supervising a vast number of experiments at VTTI. Her thesis was awarded the *Master Thesis Price 2015 of the Civil Engineering and Management Master Programme* and the *Master Thesis Award 2015 of the faculty of Engineering Technology*, both at the University of Twente. Besides her study, she was secretary of the board of the local student sailing association.

A curiosity for travel behaviour and keen interest in transport modelling, analyses and simulations led her to pursue a PhD at the Centre for Transport Studies (CTS) at the University of Twente. There she conducted research on the potential of travel information and social routing advice in order to influence route choice behaviour and therewith approach system optimal network conditions. At the same time, she became chair of the PhD-council of the TRAIL (Transport, Infrastructure and Logistics) Research School.

In her spare time, she likes to enjoy the beautiful nature and historical cities around the Netherlands and across borders, especially by foot, bike or sailing vessel. While travelling, camping trips and road trips are favourite. Additionally, she likes to participate in several sports and activities from time to time.

Author's publications

Journal publications

Van Essen, M., Thomas, T., Chorus, C., & Van Berkum, E. (2018). Travelers' compliance with social routing advice: Impacts on road network performance and equity. *Submitted to IEEE Transactions on Intelligent Transportation Systems (under review).*

Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. (2018). Compliance with social routing advice - evidence from SP and RP experiments. *Submitted to Transportation (under review).*

Van Essen, M., Thomas, T., Chorus, C., & Van Berkum, E. (2018). The effect of travel time information on day-to-day route choice behavior: Evidence from a real-world experiment. *Submitted to Transportmetrica B:Transport Dynamics (under review).*

Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. G. (2016). From user equilibrium to system optimum: A literature review on the role of travel information, bounded rationality and non-selfish behaviour at the network and individual levels. *Transport Reviews: A Transnational Transdisciplinary Journal*, 36(4), 527-548. doi:10.1080/01441647.2015.1125399

Conference proceedings (peer reviewed)

Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. (2018). Compliance with Social Routing Advice – Evidence from SP and RP experiments. *Proceedings of the 97th Annual Meeting of the Transportation Research Board*, January 7-11, 2018, Washington DC, USA.

Van Essen, M., Thomas, T., Chorus, C., & Van Berkum, E. (2016). Role of Travel Time Information on Day-to-Day Route Choice Behavior Based on Real-World Experiments. *Proceedings of the 95th Annual Meeting of the Transportation Research Board*, January 10-14, 2016, Washington DC, USA.

Conference proceedings (non-peer reviewed)

Van Essen, M., Rakha, H., Vreeswijk, J., Wismans, L., & Van Berkum, E. (2015). Day-to-day route choice modeling incorporating inertial behavior. *Proceedings of the 14th International Conference on Travel Behaviour Research (IATBR)*, July 19-23, 2015, Windsor, UK.

Technical journal publications (non-peer reviewed)

Van Essen, M. (2017). Taking the detour - Richting een efficiënter gebruik van het wegennet [Taking the detour - Towards a more efficient use of the road network (in Dutch)]. *Conceptueel*, Edition 26-2, pp. 24-27.

Presentations (non-peer reviewed)

Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. (2017). Taking the detour – Travellers' compliance with social routing advice. *Poster presented at the CTIT Symposium 'IoT is ready. What about us?'*, November 14th, 2017, Enschede, The Netherlands.

Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. (2017). Taking the detour – Travellers' compliance with social routing advice. *Poster presented at the 'Your research @CTIT'-Event 2017*, October 3rd, 2017, Enschede, The Netherlands.

Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. (2017). Taking the detour – Travellers' compliance with system-beneficial route advice. *Presented at the TRAIL congress 2017*, November 9th, 2017, Utrecht, The Netherlands.

Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. (2017). Taking the detour – Travellers' compliance with system-beneficial route advice in a real-world context. *Presented at the 6th Symposium of the European Association for Research in Transportation (hEART 2017),* September 12-14, Haifa, Israel.

Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. (2017). Taking the detour – Travelers' compliance with system-beneficial travel information. *Presented at the International Choice Modelling Conference 2017 (ICMC2017),* April 3-5, 2017, Cape Town, South Africa.

Van Essen, M., Thomas, T., Van Berkum, E., & Chorus, C. (2016). Taking the detour – The effect of various system-beneficial information strategies on individuals' route choice behaviour. *Presented at the TRAIL congress 2016,* November 8th, 2015, Utrecht, The Netherlands.

Van Essen, M., & Huang, B. (2016). Empower travel behavior change. *Poster presented at the CTIT Symposium 'Citizenship in a digital society',* November 1st, 2016, Enschede, The Netherlands.

Van Essen, M., & Huang, B. (2016). Empower travel behavior change. *Poster presented at the 'Your research @CTIT'-Event 2016,* October 17th, 2016, Enschede, The Netherlands.

Van Essen, M., Thomas, T., Chorus, C., & Van Berkum, E. (2015). The role of travel time information on day-to-day route choice behavior based on real-world experiments. *Presented at the TRAIL-Beta congress 2015,* November 17th, 2015, Utrecht, The Netherlands.

Van Essen, M., Thomas, T., Chorus, C. & Van Berkum, E. (2015). Towards a system optimal Road network state using personalized travel information. *Poster presented at the 'Your research @CTIT'-Event 2015*, May 7th, 2015, Enschede, The Netherlands.

Other

Van Essen, M. (2014). *One route or the other? Development and evaluation of a day-to-day route choice model incorporating the principles of inertial behavior and quantification of the indifference band based on a real-world experiment.* (Master thesis), University of Twente, The Netherlands.

Van Essen, M., Vreeswijk, J., Thomas, T., Van Berkum, E., & Van Arem, B. (2013). Experimental design for an experience-based survey on route choice behavior. *Working paper.*

TRAIL Thesis Series

The following list contains the most recent dissertations in the TRAIL Thesis Series. For a complete overview of more than 200 titles see the TRAIL website: www.rsTRAIL.nl.

The TRAIL Thesis Series is a series of the Netherlands TRAIL Research School on transport, infrastructure and logistics.

Essen, van M.A., *The Potential of Social Routing Advice*, T2018/7, October 2018, TRAIL Thesis Series, the Netherlands

Su, Zhou, *Maintenance Optimization for Railway Infrastructure Networks*, T2018/6, September 2018, TRAIL Thesis Series, the Netherlands

Cai, J., *Residual Ultimate Strength of Seamless Metallic Pipelines with Structural Damage,* T2018/5, September 2018, TRAIL Thesis Series, the Netherlands

Ghaemi, N., *Short-turning Trains during Full Blockages in Railway Disruption Management,* T2018/4, July 2018, TRAIL Thesis Series, the Netherlands

Gun, van der J.P.T., *Multimodal Transportation Simulation for Emergencies using the Link Transmission Model,* T2018/3, May 2018, TRAIL Thesis Series, the Netherlands

Van Riessen, B., *Optimal Transportation Plans and Portfolios for Synchromodal Container Networks,* T2018/2, March 2018, TRAIL Thesis Series, the Netherlands

Saeedi, H., *Network-Level Analysis of the Market and Performance of Intermodal Freight Transport,* T2018/1, March 2018, TRAIL Thesis Series, the Netherlands

Ypsilantis, P., *The Design, Planning and Execution of Sustainable Intermodal Port-hinterland Transport Networks,* T2017/14, December 2017, TRAIL Thesis Series, the Netherlands

Han, Y, *Fast Model Predictive Control Approaches for Road Traffic Control,* T2017/13, December 2017, TRAIL Thesis Series, the Netherlands

Wang, P., *Train Trajectory Optimization Methods for Energy-Efficient Railway Operations,* T2017/12, December 2017, TRAIL Thesis Series, the Netherlands

Weg, G.S. van de, *Efficient Algorithms for Network-wide Road Traffic Control,* T2017/11, October 2017, TRAIL Thesis Series, the Netherlands

He, D., *Energy Saving for Belt Conveyors by Speed Control,* T2017/10, July 2017, TRAIL Thesis Series, the Netherlands

Bešinović, N., *Integrated Capacity Assessment and Timetabling Models for Dense Railway Networks,* T2017/9, July 2017, TRAIL Thesis Series, the Netherlands

Chen, G., *Surface Wear Reduction of Bulk Solids Handling Equipment Using Bionic Design,* T2017/8, June 2017, TRAIL Thesis Series, the Netherlands

Kurapati, S., *Situation Awareness for Socio Technical Systems: A simulation gaming study in intermodal transport operations*, T2017/7, June 2017, TRAIL Thesis Series, the Netherlands

Jamshidnejad, A., *Efficient Predictive Model-Based and Fuzzy Control for Green Urban Mobility*, T2017/6, June 2017, TRAIL Thesis Series, the Netherlands

Araghi, Y., *Consumer Heterogeneity, Transport and the Environment*, T2017/5, May 2017, TRAIL Thesis Series, the Netherlands

Kasraian Moghaddam, D., *Transport Networks, Land Use and Travel Behaviour: A long term investigation*, T2017/4, May 2017, TRAIL Thesis Series, the Netherlands

Smits, E.-S., *Strategic Network Modelling for Passenger Transport Pricing*, T2017/3, May 2017, TRAIL Thesis Series, the Netherlands

Tasseron, G., *Bottom-Up Information Provision in Urban Parking: An in-depth analysis of impacts on parking dynamics*, T2017/2, March 2017, TRAIL Thesis Series, the Netherlands

Halim, R.A., *Strategic Modeling of Global Container Transport Networks: Exploring the future of port-hinterland and maritime container transport networks*, T2017/1, March 2017, TRAIL Thesis Series, the Netherlands

Olde Keizer, M.C.A., *Condition-Based Maintenance for Complex Systems: Coordinating maintenance and logistics planning for the process industries*, T2016/26, December 2016, TRAIL Thesis Series, the Netherlands

Zheng, H., *Coordination of Waterborn AGVs*, T2016/25, December 2016, TRAIL Thesis Series, the Netherlands

Yuan, K., *Capacity Drop on Freeways: Traffic dynamics, theory and Modeling*, T2016/24, December 2016, TRAIL Thesis Series, the Netherlands

Li, S., *Coordinated Planning of Inland Vessels for Large Seaports*, T2016/23, December 2016, TRAIL Thesis Series, the Netherlands

Berg, M. van den, *The Influence of Herding on Departure Choice in Case of Evacuation: Design and analysis of a serious gaming experimental set-up*, T2016/22, December 2016, TRAIL Thesis Series, the Netherlands

Luo, R., *Multi-Agent Control of urban Transportation Networks and of Hybrid Systems with Limited Information Sharing*, T2016/21, November 2016, TRAIL Thesis Series, the Netherlands

Campanella, M., *Microscopic Modelling of Walking Behavior*, T2016/20, November 2016, TRAIL Thesis Series, the Netherlands

Horst, M. van der, *Coordination in Hinterland Chains: An institutional analysis of port-related transport*, T2016/19, November 2016, TRAIL Thesis Series, the Netherlands

TRAIL

Summary

Traffic congestion is one of the main problems of today's society. This thesis deals with the problem of improving road network efficiency by the provision of social routing advice. Stated choice and revealed choice experiments provide insights into compliance behaviour, while network simulation indicates the resulting impacts. Results show that travellers are sometimes willing to comply with the received advice. As such, network efficiency improves, although individual benefits are marginal.

About the Author

Mariska van Essen carried out her PhD research from 2014 to 2018 at the Centre for Transport Studies, University of Twente. Her research focus is travel behaviour in response to social routing advice.

TRAIL Research School ISBN 978-90-5584-237-7

Erasmus University Rotterdam
Radboud University Nijmegen
University of Groningen, faculty of economics and business
TU Delft, Delft University of Technology
University of Twente.
TU/e Technische Universiteit Eindhoven University of Technology