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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

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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 non-selfish 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 level of selfishness in order to approach system-optimal conditions on the network level. Moreover, initial ideas and future research directions are provided for assessing the potential of travel information in order to improve network efficiency of existing road networks.

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1. 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 paper provides an in-depth literature review on route choice behaviour and the potential and limitations of travel information. 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, Molin, & van Wee, 2006a, 2006b; Lyons, Avineri, Farag, & Harman, 2007; Shiftan, Bekhor,

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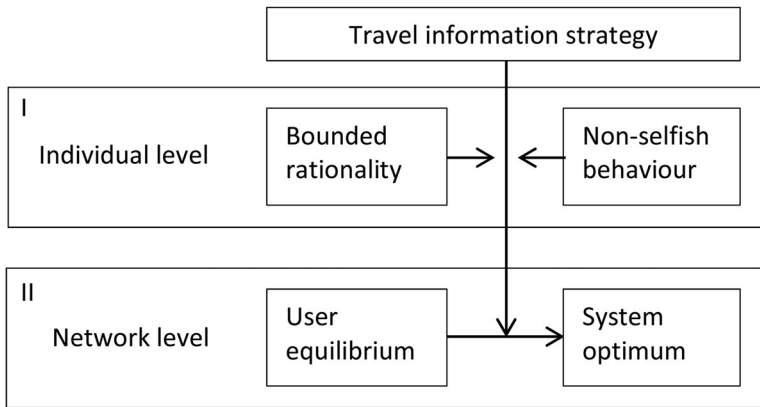


Figure 1. Conceptual framework.

& Albert, 2011; Tanaka, Uno, Shiomi, & Ahn, 2014), or making very simplified assumptions on individuals' choice behaviour (e.g. Ben-Akiva, de Palma, & Isam, 1991; Emmerink, Axhausen, Nijkamp, & Rietveld, 1995; Yang, 1998). Secondly, it highlights the role of bounded rationality as well as that of non-selfish behaviour in route choice behaviour and in response to information. Herewith, this review complements previous reviews that mostly focused on bounded rationality only (e.g. Szeto, Wang, & Han, 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 paper answers to that call.

From the above-mentioned, it is hypothesized that the conceptual model as presented in Figure 1 applies, that is, in order to understand the potential of specific travel information in terms of directing the transport system towards a system optimum on the network level, one needs to understand how bounded rationality and non-selfish behaviour interact at the individual level. After all, bounded rationality and non-selfish 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 essential in improving current travel demand management strategies.

This conceptual framework is followed throughout this review. First, general theories on choice behaviour will be introduced (Section 2) focusing on individual choice behaviour (Section 2.1) as well as interacting choice behaviour (Section 2.2). These general theories are subsequently applied within the field of transportation (Section 3), specifically regarding route choice behaviour (Section 3.1) and network equilibria (Section 3.2). This is followed by the introduction of travel information (Section 4) and its effects on individuals' choice behaviour (Section 4.1) and the network state (Section 4.2). Lastly, this review concludes on the lessons learnt from literature (Section 5).

2. General theories on choice behaviour

Classical economic theories developed in the eighteenth century and nineteenth 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 twentieth century, the perspective on economics shifted from the somewhat theoretical approach towards a more mathematical approach. Neoclassical theories largely build upon two behavioural assumptions, that is, individuals are rational in how they choose and selfish in what they choose (e.g. Kestemont, 2011).

2.1. 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, emphasizing the strength and legitimacy of their critiques. Now, the main line of criticism will be elaborated.

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-averse 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 similar choice situations in which the probabilities of all choice options are equally reduced, 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-averse 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 averse 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.

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. Thereby, this principle is partly motivated by self-interest, although the welfare of others is important as well. Ostrom (e.g. Ostrom & Walker, 2003; Poteete, Janssen, & Ostrom, 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 pay-off in order to obtain more fair outcomes (Fehr & Schmidt, 1999). Lastly, several researchers (e.g. Liebrand & McClintock, 1988) argue that individuals have a certain social value orientation (i.e. individualistic, competitive, cooperative or altruistic) that determines the extent to which an individual acts selfishly or selflessly.

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 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.

2.2. Perspective on interacting choice theory

Choice theory on the interacting network level is mainly studied by two theories; that is, 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 found 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).

Furthermore, these games often contain social dilemmas consisting of conflicts between self-interests and collective interests that highly challenge the functioning of a group or society. After all, if each individual acts in his own interest, everyone 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 pay-off 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 pay-off that each player reasonably can expect, resulting from their contribution to the overall cooperation.

From this, a system's efficiency depends clearly on the outcomes resulting from individual's choice behaviour. The degradation in 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.

3. Route choice behaviour

In general, route choice behaviour concerns the selection of routes between origins and destinations in a road network. In selecting their route, individuals usually like to obtain the highest benefits of their choice. Hence, they behave according the concept of the 'Homo Economicus', that is, rationally choosing a route alternative in their own interest. However, if many individuals like 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, individuals 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. One method, among others, that might reduce or even prevent congestion and increase throughput of the whole network is spreading these individuals more efficiently over the existing road network. In order to do so, individuals need to behave socially in choosing their routes by accepting possibly higher travel cost in favour of others. Thereby, route choice behaviour can be seen as a social phenomenon.

3.1. Perspective on individual route choice behaviour

The main perspective on how individuals choose their route is the theory of utility maximization (Ben-Akiva & Lerman, 1985), which builds upon the concept of 'Homo Economicus'. 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 are considered more important than others. Each route alternative in the choice set receives a certain utility based on the sum of the different attribute values and their weights. An individual 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, individuals 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 reference-dependency 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). Nonetheless, these decision rules still assume an optimizing strategy.

Johnson and Payne (1985) stated that an individual bases his decision strategy on an effort/accuracy framework. The individual makes a trade-off of both the perceived effort and perceived accuracy of the different decision rules. Maximization strategies such as introduced by the concept of the 'Homo Economicus' 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, individuals 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 individuals 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, Molin, & Van Wee, 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 these 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 an individual's route choice. Individuals might use different rules or strategies 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 individuals 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, 2013, p. 2).

In literature, not much attention has been addressed towards an individual's social choice behaviour in travel choices. Mainly, it is assumed that individuals choose in their self-interest (e.g. optimizing regret, gain or utility). However, empirical evidence shows that certain incentives can be quite motivational in order to change travel behaviour and nudge individuals towards socially desired choices (e.g. Bliemer, Dicke-Ogenia, & Ettema, 2009). Kusumastuti et al. (2011) identified four types of incentives with high potential, especially if they are bundled; that is, real-time travel information, feedback and self-monitoring, rewards and social networks.

Real-time travel information on, for example, incidents, road works or events can be used by individuals to adjust or update their route choices accordingly and hence change their travel behaviour. Feedback on and self-monitoring of personal behaviour help individuals to reflect on their past behaviour and increase awareness of the consequences of their travel. Based on these, individuals might set personal travel targets (e. g. reduce CO₂-emissions) and change their route choices to that purpose. Section 4 will further elaborate on these incentives and possible strategies to direct choice behaviour.

Within traffic management, there exist a large amount of programmes that are based on rewards feeding the self-interest of individuals, collectively referred to as 'Spitsmijden' (i.e. Peak Hour Avoidance) (Spitsmijden, 2013). In these, individuals 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, 40–70% of the participating individuals did change their travel behaviour (Donovan, 2013, p. 7). Opposed to 'Spitsmijden', road pricing programmes charge the use of roads during certain moments of the day, for example, peak hours, and are thereby based on punishments and loss aversion. Therefore, these programmes often lead to resistance. Nonetheless, applications in, for instance, Singapore, London and Stockholm show that these programmes induce travel behaviour changes as well (Lindsey & Anas, 2011).

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 pro-socially (Avineri, 2009b). However, it was found that an individual would be more prone to cooperate, if others in the social network are expected to cooperate as well (i.e. conditional cooperation) (Murphy & Ackermann, 2013). This is especially the case if the majority of individuals is expected to cooperate 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. Dugundji and Walker (2005) proposed and tested several methods in order to capture these social interdependencies within discrete choice modelling, which seem to be superior to the traditional approach.

Additionally, individuals might make route choices altruistically. However, the higher the perceived cost of acting socially, the less frequent this behaviour is performed (Fehr & Fishbacher, 2003). So, if there exist route alternatives that impose only a small increase in generalized cost to an individual, this individual 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, Möhring, Schulz, and Stier-Moses (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.

3.2. Perspective on interacting route choice behaviour and network equilibria

Selfish choice behaviour leads to less efficient use of the existing road network than when individuals cooperate and make social choices. Thereby, an individual'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 being cooperative. 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, individuals need some external steering in being cooperative, 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).

Due to day-to-day dynamics, the network equilibrium established in a real-world road network will not exactly be a user equilibrium, nor a system optimum. 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. For example, 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. Another example is 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, individuals might get used to the new route, and due to bounded rationality, they will not change back if 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). A third example is the reference-dependent stochastic user equilibrium that was introduced by Site and Filippi (2012). They define this equilibrium 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). Lastly, 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).

These 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 comply with the established traffic flows within one equilibrium.

4. Travel information

In earlier years, travel information was obtained using newspapers, television or radio. However, information came with substantial delay and contained only information on the most congested routes (Dicke-Ogenia, 2012). 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. These information sources are called Advanced Traveller Information Systems (ATIS), which is a generic term to describe all systems that acquire, analyse, and present travel information to individuals. With ATIS, travel information can be provided for the whole network without considerable delay to each individual at any time and at any location (Dicke-Ogenia, 2012).

4.1. 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 distribution of travel information, different information strategies can be used. These information 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). Individuals 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); that is, 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, & Shifan, 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, individuals 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 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 rule an individual uses. Maximizers benefit from information, in that it helps them to choose the alternative with

maximum pay-off (Chorus et al., 2006b). Thereby, they address high value to travel information and are prone to search for and comply with travel information. With respect to risk, De Palma, Lindsey, and Picard (2012) found that individuals with very high or very low levels of risk aversion do not value information and stay uninformed. After all, they take respectively the risky route alternative or the safest route alternative every day, even when this alternative might be less beneficial. Individuals 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 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 individuals. However, regret-averse individuals benefit from travel information as well as it enables them to choose route alternatives that result in less regret.

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 instance, incidents or road works (Chorus et al., 2006a; Fujii, Gärling, & Kitamura, 2001).

Information strategies might be designed in such a manner that they nudge individuals 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 an individual searches for a 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 the awareness on these options and nudges individuals 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 individuals (e.g. by introducing an eco-friendly routing option within route navigation systems and trip planners), enabling them to make non-selfish 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, individuals using the eco-friendly route alternative are not necessarily acting non-selfishly. Additionally, choice outcomes are very sensitive to the set value of individuals' reference points and travel information might be used to influence these (Avineri, 2006). Lastly, Sunitiyoso, Avineri, and Chatterjee (2009) found 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.

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

In general, it is believed that travel information reduces traffic congestion and improves network efficiency. After all, travel information removes perception errors and knowledge limitations among individuals and thereby improves their decision-making (e.g. Bonsall, 1992). However, at the aggregated 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. Thereby, they demonstrate that informing (part of the) individuals is only beneficial in specific situations. Furthermore, they identified several adverse effects of travel information, such as oversaturation, over-reaction and concentration. It is believed that modern state-of-the-art personalized information can overcome these effects (e.g. Adler & Blue, 1998; Bottom et al., 1999).

Many studies assume that informed or equipped individuals automatically make rational choices in compliance with the received information. However, individuals do not always use or comply with the received information. Individuals need to accept the information, which depends highly on the information characteristics, 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 individuals might accept the provided information and deliberately do not comply with it, as they assume that other individuals 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 the individuals noticed the information signs, of which 92% actually read and understood the message. Thirty-three per cent of them complied with the information. This is only 18% of all individuals within the study. In a survey by Kattan, Nurul Habib, Tazul, and Shahid (2011), 21.4% of the individuals 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 individuals within a 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 individuals 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 have been achieved.

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 individuals 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.

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

With respect to non-selfish choice behaviour, the effects of travel information on the network level might differ. Social choices with respect to travel time are likely to direct the network state towards the travel time-based system optimum. However, Ahn and Rakha (2008) demonstrated that a user equilibrium as well as a system optimum based on travel time do not necessarily minimize emissions and fuel consumption. In other words, social choices based on eco-routing are likely to direct the network state towards another system optimum, that is, an eco-friendly system optimum. The findings of Ahn and Rakha (2008) show smaller emission and fuel savings of this eco-friendly system optimum compared to a travel time system optimum than compared to the user equilibrium. This indicates that the system optimum based on travel time and emissions might be close to each other. However, their findings are based on simulations on a single origin-destination pair. According to the author's best knowledge, empirical findings on the effects of travel information on the network level resulting from non-selfish behaviour do not yet exist.

5. Discussion and conclusions

This literature review is built 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.

Obviously, the notion of bounded rationality in route choice behaviour in general as well as under travel information is vastly explored within literature both on the individual level and on the network level, while non-selfish choice behaviour has not received much attention yet. Nonetheless, an individual's degree of rationality and degree of selfishness 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 degree of selfish 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 non-selfishly 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 level of selfishness, some individuals 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 non-selfish choice behaviour is needed (e.g. information strategies nudging individuals towards the desired choice 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 information to those individuals who are actually open to this kind of non-selfish 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 an individual is social-oriented and possibly interested to behave eco-friendly, he should receive travel information that stimulates him to make that social eco-friendly choice. Questions that arise are how to identify who these individuals exactly are and how many of them actually need to be directed to those social route alternatives in order to establish desired network conditions. Moreover, to what routes exactly should these non-selfish travellers be directed in order to anticipate on the choices that selfish travellers will make in response (i.e. what assignment strategy should be pursued). 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 individuals might not be aware of the fact that certain received information is not beneficial for themselves or they are not 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 selfishness, in order to assign each specific individual to that route alternative that is intended for him under system-optimal network conditions.

Potential successful system-beneficial information strategies could, for example, build upon an individual'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 route was chosen);
- Feeling for equity (e.g. by telling them: Today we ask you to take the possible longer route alternative, tomorrow we will ask someone else);
- Believe or expectations about choices of others (e.g. by telling them: 75% of travellers followed the advice and choose 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 individuals, 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 individuals with different degrees of rationality and non-selfishness, 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, none of them takes individuals' degree of non-selfishness into account. This review emphasizes the importance of all these aspects in the route choice decision-making process together. Especially when information strategies specifically aim at the system's benefit, individuals' 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 individuals' 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 paper stress the importance of anticipation on individuals' non-selfish choice behaviour as well as bounded rationality when applying travel information strategies 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.

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References

- 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
- Allais, M. (1953). Le comportement de l'homme rationnel devant le risque, critique des postulats et axiomes de l'école américaine. *Econometrica, Journal of the Econometric Society*, 21, 503–546. doi:10.2307/1907921
- 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: 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 30–April 2, 2009, Harrogate, UK.
- 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: Emerald.
- 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:10.1016/j.tra.2012.10.003
- 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:10.1016/j.jtrangeo.2014.04.005
- 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., & Lerman, S. (1985). *Discrete choice analysis: Theory and application to travel demand*. Cambridge, MA: MIT Press.
- 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-Elia, E., & Avineri, E. (2015). Response to travel information: A behavioural review. *Transport Reviews: A Transnational Transdisciplinary Journal*, 35, 352–377.
- 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., 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
- 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.
- 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: 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
- 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

- 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, DC.
- 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: Edward Elgar.
- 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
- 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: John Wiley & Sons. Retrieved from <http://dii.uchile.cl/~jcorrea/papers/Chapters/CS2010.pdf>
- Daganzo, C. F., & Sheffi, Y. (1977). On stochastic models of traffic assignment. *Transportation Science*, 11(3), 253–274.
- Danczyk, A., & Liu, H. (2010). *Unexpected causes, unexpected effects: Empirical observations of twin cities traffic behavior after the I-35W bridge collapse and reopening*. TRB 89th Annual Meeting Compendium of Papers CD-ROM, Transportation Research Board, Washington, DC.
- 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.
- Donovan, S. (2013). *Introducing Spitsmijden – experiments with peak avoidance incentives in the Netherlands*. Retrieved from <http://www.vtpi.org/spitsmijden.pdf>
- 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.
- Ellsberg, D. (1961). Risk, ambiguity, and the savage axioms. *Quarterly Journal of Economics*, 75, 643–669.
- 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), 369–383. doi:10.1016/j.trc.2006.10.001
- 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., & 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 and 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: 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: Princeton University Press.
- Godbout, J. (2000). *The world of the gift*. Montreal, QC: McGill-Queen's Press.
- 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
- 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
- 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*, 53(4), 600–616. doi:10.1287/opre.1040.0197
- Johnson, E. J., & Payne, J. W. (1985). Effort and accuracy in choice. *Management Science*, 31(4), 395–414.
- Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, Journal of the Econometric Society*, 47(2), 263–292.
- 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.

- 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.
- Korilis, Y. A., Lazar, A. A., & Orda, A. (1997). Achieving network optima using Stackelberg routing strategies. *IEEE/ACM Transactions on Networking*, 5(1), 161–173. doi:10.1109/90.554730
- Koutsoupias, E., & Papadimitriou, C. (1999). *Worst-case equilibria*. Paper presented at the Proceedings of the 16th annual Symposium on Theoretical Aspects of Computer Science (STACS).
- 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
- 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
- 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.
- 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., & 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 Social Psychology*, 2, 217–230.
- Lindsey, R., & Anas, A. (2011). Reducing urban road transportation externalities: Road pricing in theory and in practice. *Review of Environmental Economics and Policy*, 5(1), 66–88.
- List, C. (2013). Social choice theory. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Winter 2013 ed.). Stanford, CA: The Metaphysics Research Lab. Retrieved from: <http://plato.stanford.edu/archives/win2013/entries/social-choice/>.
- Loomes, G., & Sugden, R. (1982). Regret theory: An alternative theory of rational choice under uncertainty. *The Economic Journal*, 92(368), 805–824.
- Lyons, G., Avineri, E., Farag, S., & Harman, R. (2007). *Strategic review of travel information research*. Technical Report. London: Department for Transport/Bristol: University of the West of England. 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.
- 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.
- Ministry of Infrastructure and Environment. (2002). *Gebruikersonderzoek Nederlandse Autosnelwegen* [in Dutch]. [User research Dutch motorways]. Rotterdam: Adviesdienst Verkeer en Vervoer.
- Murphy, R. O., & Ackermann, K. A. (2013). *Explaining behavior in public goods games: How preferences and beliefs affect contribution levels*. Manuscript under review.
- Nash, J. (1951). Non-cooperative games. *Annals of Mathematics*, 54(2), 286–295.
- Ostrom, E., & Walker, J. L. (2003). *Trust and reciprocity: Interdisciplinary lessons from experimental research*. New York: Russell Sage Foundation.
- Poteete, A. R., Janssen, M. A., & Ostrom, E. (2010). *Working together: Collective action, the commons, and multiple methods in practice*. Oxfordshire: Princeton University Press.
- Raijn, J., & Toledo, T. (2014). Real-time short-term forecasting bases on information management. *Journal of Transportation Technologies*, 4(4), 11–21.

- Ramos, G. (2015). *Dynamic route choice modelling of the effects of travel information using RP data* (PhD-thesis), Delft University of Technology.
- 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: Edward Elgar.
- Roughgarden, T. (2006). *Selfish routing and the price of anarchy*. Cambridge, MA: 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
- Rubinstein, A. (1998). *Modeling bounded rationality in games modeling bounded rationality*. Cambridge, MA: MIT Press, p. 121.
- Saelensminde, K. (2006). Causes and consequences of lexicographic choices in stated choice studies. *Ecological Economics*, 59(3), 331–340.
- 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/PROD000000000259291.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
- Sen, A. K. (1977). Rational Fools: A critique of the behavioural foundations of economic theory. *Philosophy and Public Affairs*, 6(4), 317–344.
- Sen, A. K. (1982). *Choice, welfare and measurement*. Oxford: Blackwell.
- Serrano, R. (2009). Cooperative games: Core and Shapley value. In R. Meyers (Ed.), *Encyclopedia of complexity and systems science*. New York: Springer. Retrieved from: <http://www.econ.brown.edu/faculty/serrano/pdfs/2008ECSS.pdf>
- 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: 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.
- Simon, H. A. (1955). A behavioral model of rational choice. *The Quarterly Journal of Economics*, 69(1), 99–118.
- Simon, H. A. (1956). Rational choice and the structure of the environment. *Psychological Review*, 63(2), 129–138.
- 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.
- Slovic, P., Finucane, M. L., Peters, E., & MacGregor, D. G. (2007). The affect heuristic. *European Journal of Operational Research*, 177(3), 1333–1352.
- 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
- Sun, L., Karwan, M. H., & Kwon, C. (2015). Incorporating driver behaviors in network design problems: Challenges and opportunities. *Transport Reviews: A Transnational Transdisciplinary Journal*. Advance online publication. doi:10.1080/01441647.2015.1091047.
- Sunitiyoso, Y., Avineri, E., & Chatterjee, K. (2009). Role of minority influence on the diffusion 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: Emerald Group.
- 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* (p. 163). Bingley: Emerald Group.
- 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., 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).
- Thaler, R. H., & Sunstein, C. R. (2008). *Nudge: Improving decisions about health, wealth, and happiness*. New Haven, CT: Yale University Press.
- Tversky, A. (1972). Elimination by aspects: A theory of choice. *Psychological Review*, 79(4), 281–299.
- Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and Biases. *Science*, 185(4157), 1124–1131.
- Tversky, A., & Kahneman, D. (1991). Loss aversion in riskless choice: A reference-dependent model. *The Quarterly Journal of Economics*, 106(4), 1039–1061.
- 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 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 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.
- 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.
- Von Neumann, J., & Morgenstern, O. (1944). *Theory of games and economic behavior*. Princeton, NJ: Princeton University Press.
- Vreeswijk, J., Thomas, T., van Berkum, E., & van Arem, B. (2013). 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
- Wardrop, J. G. (1952). Some theoretical aspects of road traffic research. *Proceedings of Institute of Civil Engineers*, 1(3), 325–378.
- Yang, H. (1998). Multiple equilibrium behaviors and advanced traveler information systems with endogenous market penetration. *Transportation Research - Part B: Methodological*, 32(3), 205–218.
- 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.
- 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.
- 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.
- 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, 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