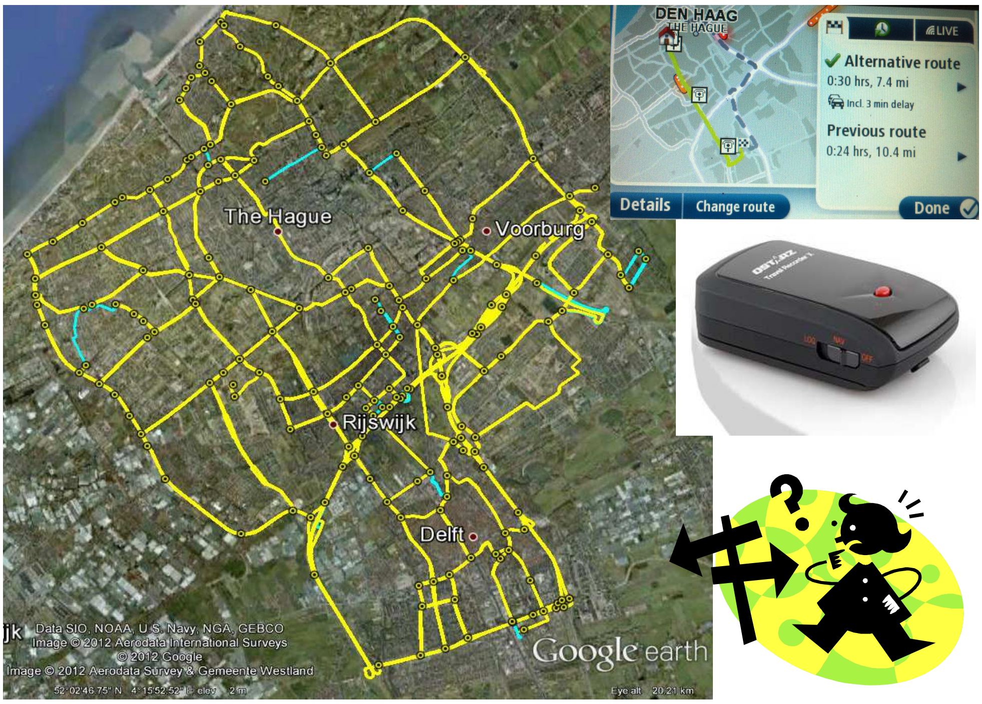

A revealed preference study on route choices in a congested network with real-time information

Giselle M. Ramos, Delft University of Technology
Emma Frejinger, KTH Royal Institute of Technology
Winnie Daamen, Delft University of Technology
Serge Hoogendoorn, Delft University of Technology

Travel Behaviour Research: Current Foundations, Future Prospects

13th International Conference on Travel Behaviour Research
Toronto 15-20, July 2012

A revealed preference study on route choices in a congested network with real-time information

Giselle de Moraes Ramos, MSc (corresponding author)
Department of Transport & Planning – CiTG - Delft University of Technology
Stevinweg 1, PO Box 5048, 2600 GA Delft – The Netherlands
phone +31 15 278 49 14
e-mail g.m.ramos@tudelft.nl

Emma Frejinger
Division of Transport and Location Analysis (TLA) – KTH Royal Institute of Technology
Teknikringen 10, 100 44 Stockholm – Sweden
phone +46 8 790 68 43
e-mail emma.frejinger@abe.kth.se

Winnie Daamen, PhD
Department of Transport & Planning – CiTG – Delft University of Technology
Stevinweg 1, PO Box 5048, 2600 GA Delft – The Netherlands
phone +31 15 278 59 27
e-mail w.daamen@tudelft.nl

Prof. dr. Serge Hoogendoorn
Department of Transport & Planning – CiTG – Delft University of Technology
Stevinweg 1, PO Box 5048, 2600 GA Delft – The Netherlands
phone +31 15 278 54 75
e-mail s.p.hoogendoorn@tudelft.nl

Abstract

The past decades have seen an increased interest in the role of information as a tool to alleviate congestion. However, because the relationship between travelers' behavior and information provision is not clear yet, the need for more experiments has been claimed in literature. From May 9th, 2011 to July 12th, 2011 a revealed route choice experiment was conducted in The Netherlands. With the aid of GPS devices and travel diaries, the experiment consisted of investigating the behavior of 32 commuters with similar origins and destinations in reaction to different sources and conditions of information provision. In addition, the real traffic condition during the period of the experiment is known, thus allowing us to know the traffic conditions on alternative routes.

This paper presents the setup of this unique revealed preference (RP) study of route choice behavior of car travelers driving in a congested network and a comprehensive descriptive analysis of the data set(s). To our knowledge a study on route choice behavior under provision of real time information in which GPS traces, travel diaries, interviews and traffic conditions in a real congested network is available has not yet been shown in the literature. The descriptive analyses presented in this paper focus on perception of route reliability, use of information and adaptive behavior. They are carried out by means of comparisons between GPS traces and traffic conditions in the network with travel diaries and interviews.

Descriptive analysis of the data set combining the different data sources suggest that travelers' perception of the routes' characteristics is biased in favor of the preferred routes, i.e., preferred routes are usually considered to be reliable when in reality they are among the most unreliable; travelers, commuters in particular, do not tend to use information to plan better departure times but instead use it to anticipate expectations regarding traffic conditions. Besides this, habit appears to have a very strong influence on travelers' behavior and even after experiencing long delays they are willing to stick to their preferred routes.

Keywords

Route choice behavior; Revealed preference experiment; GPS; Traffic information; reliability.

Preferred Citation

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

1. Introduction

Understanding and predicting travel behavior are part of the main challenges addressed by transportation researchers in order to develop reliable transportation models to help policy makers taking decisions. The literature has provided evidence that the route choice process is considered to be more complex and dynamic than other travel related decisions such as travel mode (Ben-Akiva et al., 1991; Polydoropoulou et al., 1994). This is due to factors such as the topology of the network that may lead travelers to consider a non-discrete set of alternatives (as the number of alternative paths may be infinite) (Cascetta, 2002) and the number of alternatives considered by each traveler depending on characteristics such as habits, previous experiences and the learning process (Bovy and Stern, 1990; Bogers, 2009).

Although each traveler makes its own route choice, this decision directly affects the level of congestion of the network and consequently all travelers in the congested part of the network at a given time. The growth in mobility and increased level of uncertainty regarding travel times and congestion patterns also increases the complexity of route choice decisions. This is because the uncertainty associated to travel times in the transportation network makes it very difficult to predict the duration of a trip, the best time to start a trip or even whether it is still feasible to leave home to engage in an activity in time without the aid of information.

The potential of information to influence travelers' behavior and consequently to steer them to less congested routes has led to an increased interest in the role of information to support travelers in their route choice tasks and to help alleviate congestion (Bogers, 2009; Arnott et al., 1991; Denant-Boèmont and Petiot, 2003; Avineri, 2006; Chorus et al., 2008). However, when information is provided travelers have to decide whether to comply and the complexity of the decision increases when travelers aim to adjust expectations based on the provided information (e.g. travel time, queue length). The quality of information is then crucial to travelers' confidence and compliance. Inconsistent information, i.e., not in accordance with the current traffic situation, may lead to an overreaction of the system if a large proportion of travelers responds or may become useless if travelers decide not to comply with it at all. Consequently, for a proper understanding of travelers' behavior, it is fundamental to take into account the relationship between behavior, in particular route choice behavior, and information (types and reliability).

The available sources of traffic information are quite extensive and vary from non-personalized public information, to semi-personalized public information and finally to personalized real time traffic information. Non-personalized traffic information usually refer to general traffic conditions in the network and information regarding major congested areas are reported irrespective of the interest of the traveler. This type of information is usually provided via radio or television. Semi-personalized public information, on the other hand, relate to major highways between a specific origin and destination pair of interest of the traveler. This is the type of information usually displayed in the Variable Message Signs (VMS) panels next/above roads or provided by websites specialized in traffic information provision, Finally, personalized real time traffic information provides the current traffic situation (travel times, delays, length of the queues) not only about the highways but also on local roads of interest for a specific origin and destination.

Understanding how travelers react to these different sources of information and whether provision of (more) information is beneficial to the network conditions requires further investigation. Travelers confronted with too much information may become oversaturated and may show some difficulties to process information leading to the development of simple heuristics to solve the situation. Besides this, travelers may overreact to the information and thereby cause additional fluctuations to the traffic in the network and as a result, instead of solving congestion, provision of information would possibly lead to even more congestion. Thus, travelers' behavior also has to be incorporated in traffic forecasts (Selten et al., 2007).

A number of experiments regarding travelers' reaction to information has been reported in the literature, but they are limited to either stated preferences (SP) surveys in which travelers are asked which route to choose given a specific context and type of information (De Palma and Picard, 2005; Zhang et al., 2010) or interactive route choice experiments in simulation environments in which, similar to a game, travelers make consecutive route choices and their behavior towards risk and different types and quality of information is investigated (Chen and Mahmassani, 1993, Chen et al., 1999; Koutsopoulos et al., 1994, Selten et al., 2007; Ben-Elia and Shiftan, 2010; Bogers, 2009). The interest in SP experiments, including travel simulators, has enormously increased because they are cheaper, allow more flexibility of scenarios and are efficient. This type of experiments, however, are subject to the usual drawbacks of using SP data, i.e. their external validity.

Several revealed preference (RP) datasets have also been used in the literature to analyze route choice. These are either surveys in which (i) travelers report their past route choices which, however, are often hardly related to an actual network in terms of alternatives and traffic conditions (Mahmassani et al., 1993; Rose et al., 2008), (ii) based on GPS data in which little or nothing is known about information access, trip purposes, etc. (Frejinger and Bierlaire, 2007; Bierlaire et al., 2010), comparisons between planned and observed routes using GPS (Papinski et al., 2009), route choice behavior of cyclist (Menghini et al., 2010) or (iii) combined field experiments with SP surveys to investigate behavioral responses and the willingness to pay for information (e.g., Zhang and Levinson, 2008), in which, however, little is known about the traffic condition in the network. Besides these limitations, most RP studies only use cross sectional data, i.e., one choice observation for each individual, because collecting RP data with repeated observations for the same group of people requires a strong commitment of the respondents and a longer data collection period (Axhausen et al., 2002). As a result, the type of RP data that has been usually collected are of limited use for the assessment of behavioral changes over time.

This paper presents the setup and a comprehensive descriptive analysis of the revealed preference route choice experiment conducted in The Netherlands from May 9th, 2011 to July 12th, 2011 with 32 commuters with similar origin and destination. The participants were subjected to different sources and conditions of information provision and GPS traces, travel diaries and interviews were used to investigate their behavior. Moreover, the traffic condition in the network during the period of the experiment is known. For the analysis presented in this paper we are considering the valid trips for which travel diaries were also filled in and this resulted in 897 valid GPS traces and travel diaries from which around 374 refer to trips made before provision of personalized traffic information and 523 otherwise.

The uniqueness of this research does not lie on the use of GPS traces to investigate route choice behavior under provision traffic information, but on the fact that on the top of that travel diaries were filled in for each trip and the traffic situation in the network during the period of the experiment is known. We acknowledge the limitations of our research with respect to the sample size of 32 participants. The 9 weeks duration of the experiment, however, makes it possible to investigate the effect of information over time and the consequent behavioral changes. To our knowledge such type of experiment combining GPS traces, travel diaries and in which the traffic situation in a real congested network is known has not been shown in the literature.

The next section introduces the setup of the experiment focusing on the characteristics of the experiment, GPS devices used and transportation network. Then, in Section 3, a descriptive analysis of the data set with respect to travelers' (i) perception of route reliability, (ii) use of traffic information and (iii) adaptive behavior are presented. Finally, conclusions and next steps are discussed in Section 4.

2. Route choice experimental design and set-up

The main objective of the conducted RP experiment is to investigate travelers' route choice behavior under information provision in order to assess (i) whether travelers actively look for information or are passive receptors of information, (ii) whether travelers comply with information and in particular under which conditions they comply the most and (iii) if and how provision of travel information influences travelers' behavior. Combining GPS traces and travel diaries allows investigating travelers' reaction to information and to compare the characteristics of the trip made with travelers' perceptions as well as their expectations about the next trip.

Participants were selected among staff and students of the Delft University of Technology (44% women and 56% men). The amount of participants was constrained by the amount of GPS devices available (40) and willingness of people to join a RP experiment of long duration. The age of the participants ranged from 23 to 60 years old among which 41% were between 35 and 45 years old. Their commute frequencies varied between 2 and 5 days/week, with the majority of travelers, 61%, commuting 5 days/week.

The preparations for the data collection consisted of equipping the participants with GPS devices and with a personalized tool of information provision to be used during their commute trips to and from work. In addition, participants were introduced to the travel diary that basically consisted of questions related to reaction to traffic information, perceptions about the trip made and expectations towards the next trip. At this occasion participants were also asked to fill the travel diary in after each trip.

In order to achieve the proposed objective it was necessary to properly design the experiment, which involved decisions with respect to its characteristics and motivation behind the chosen set-up, GPS devices and transportation network. These aspects are respectively discussed in sections 2.1, 2.2 and 2.3.

2.1 Characteristics of the experiment

The following aspects concerning the characteristics of the experiment are discussed in this section: (i) target group and origin-destination (OD) pair investigated, i.e., the group of travelers that would (in theory) benefit the most from information provision and whether to focus on general or specific OD pairs, (ii) subjective route choice set, i.e., routes known and considered feasible by the participants, (iii) types of information, i.e., sources and timing of information provision and (iv) characteristics of the travel diary, i.e., questions asked to investigate travelers' reaction to information, perceptions and expectations.

2.1.1 Target group and OD pair investigated

Commuters were chosen to be investigated because this category of travelers corresponds to the largest share of drivers during peak hours, thus in highly congested period. This is the type of situation in which provision of information would potentially help alleviate congestion the most. In addition, (in theory) travelers are already familiar with the characteristics of the alternative routes, thus better able to judge the added value of complying with the information or following own experience/ stick to intended routes.

According to the database of the Dutch institute of mobility research MON (Mobiliteitsonderzoek Nederland) of 2008 there were about 2 million car commuters in the Netherlands, of which 60% live within 19 km distance from work, 24% between 19 and 40 km and 16% over 40 km (Dutch MON database, 2008). In order to have a representative OD pair, thus making the chosen scenario correspond to the largest share of commuters driving in peak hours in the Netherlands (and thus the added value of providing traffic information), we have decided that the distance between the OD pair should be within 20 km. Drawback of this relatively short distance is that in the Netherlands many commuters use the bicycle, thus the limited amount of participants who joined our experiment. Besides this, because this this research is part of a program focusing on the Sustainability of the Randstad, the area investigated should be in the Randstad. The Randstad is the region in the Netherlands with the highest likelihood of occurrence of congestion (Randstad-Wikipedia).

In addition, as we are interested in investigating travelers' route choice behavior in relation to information provision, it was decided that the OD pair investigated should be connected by at least three comparable and distinct alternative routes. This is because we believe that in general travelers have a preferred route which is likely to be the one chosen the most when no information is provided. Thus, the potential of information to influence travelers to their least preferred routes (that, however, are as feasible as the most preferred route) would be made clearer with at least three routes. By comparable we mean that the alternative routes should have approximately the same length (otherwise the routes may not be seen as alternatives) and by distinct that they should have different characteristics, thus belonging to different classes/categories of roads, i.e. motorways, local roads, etc.

Another decision concerned whether to investigate route choice behavior in general, thus not focusing on a specific OD pair, or whether to investigate route choice behavior for a specific OD pair. Important factors influencing this decision were requirements concerning the existence of comparable alternative routes between the

OD pair, the level of familiarity with the routes from the point of view of the analyst, similarity of trip purposes, the availability of data regarding the traffic condition in the network, the choice set definition, the (possibility of) generalization of the results to bigger and/or more complex networks and the easiness to gather participants to join the experiment.

Advantages of choosing general OD pairs are that generalization of results is easier as different routes' characteristics and travel distances could be investigated and the process of selecting participants would be less restrictive. However, the need to get further data with respect to the traffic situation, the need to ensure similarity of trip purposes, the identification of the route choice set and existence of comparable alternative routes (that are "real" alternatives) are large disadvantages. This is because the level of complexity and workload associated to these tasks would be substantially higher depending on the amount of OD pairs. On the other hand, choosing a specific OD pair would lead to rather similar travel purposes besides the advantages of an easier definition of the choice set, of enabling a higher degree of familiarity of the analyst with the route choice set, thus allowing a better understanding of travelers' behavior under specific conditions, and moreover facilitates the collection of the extra data required (traffic conditions).

Given the abovementioned requirements and in order to facilitate the selection of participants, contact them whenever needed and logistical requirements (collect GPS and solve problems during the data collection), one of the locations was chosen to be Delft, where the great majority of this research is being conducted and the other location was chosen to be The Hague. This approach allows us to partially generalize the results, get familiar with the network and as the participants work in Delft, this approach also helps ensure similarity in trip purposes. The city centers of Delft and The Hague are situated approximately 16 km apart, however, depending on the exact home location of the participants, this distance varies (Figure 1). The reader has to have in mind that strictly speaking we investigate more than one OD pair as not all participants live in the same location (although all work in the Delft University of Technology). As a result, we have similar OD zones that result in the same set of (alternative) routes.

2.1.2 Subjective route choice set

At the beginning of the experiment the participants were asked about their known alternative routes from home (in The Hague) to work (in Delft) and based on that we derived a subjective route choice set covering the choice sets of all participants, i.e., routes known and considered feasible by the participants. We opted not to focus on the path itself, i.e., on the sequence of links, but on the existent main alternative routes because despite of the existence of a great number of paths to go from a specific origin to a specific destination we hypothesize that the route choice behavior is primarily based on the main alternative routes. From now on, when we refer to the set of main alternative routes that was defined based on the input of the participants, the term *main route(s)* will be used.

The choice set as communicated by the participants as well as the location of their homes is depicted in Figure 1. Blue dots indicate the locations of the homes of the participants and the Delft University of Technology - TU Delft - is indicated with the yellow drawing pin. It is possible to observe in this figure the existence of 5 main roads in the Delft area and 5 in The Hague area. Among these, the "A" routes (in red) are motorways, "N" (in blue) is a national road (in terms of speeds it is sort of a provincial highway) and the others, "L" (in yellow), are main local roads.

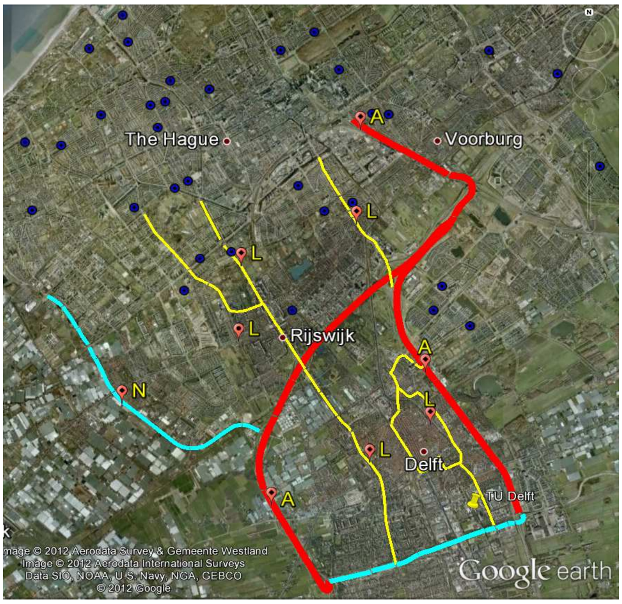

Figure 1: Subjective route choice set between Delft and The Hague and participants' homes

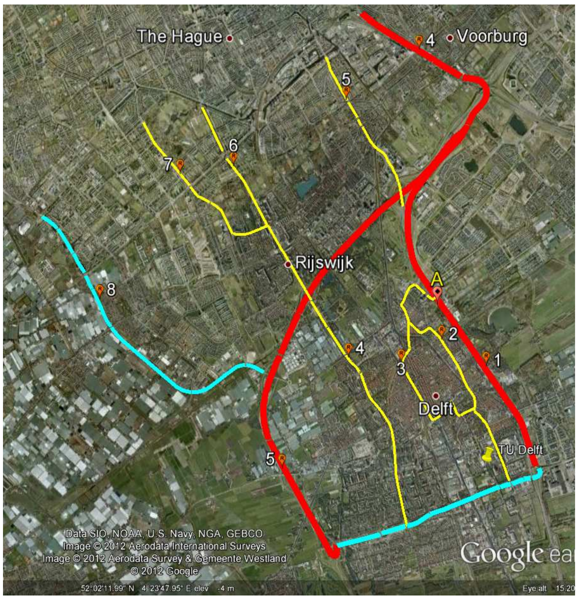

Figure 2: Coding of the *main routes* based on the subjective route choice set.

Travelers were also asked to rank their known *main routes* in terms of preference and indicate, among those, the fastest, the most reliable and the most unpredictable route. Notion of route reliability was introduced to the participants as routes in which the travel times are usually about the same magnitude and as such they would know what to expect in terms of travel times when choosing this route irrespective of how fast the route is. Some participants live just in the outskirts of Delft and some further in The Hague. As a result, for the participants living in Delft we have one subjective choice set (CS 1) composed from routes 1 to 5 (in Delft area) and for the other we have another subjective choice set (CS2) composed by one route in Delft (1 to 5) and one in The Hague (4 to 8). Thus, the routes belonging to CS 2 are in the range 14 to 58 (Figure 2). This way, for instance, choosing route 1 in Delft and 4 in The Hague, would result in *main route* 14; choosing route 1 in Delft and 5 in The Hague, would result in *main route* 15 and so on. The total amount of *main routes* in CS 2 is 17 as not all possible road combinations were considered to be "real" alternative routes.

2.1.3 Information provision

Travelers were split in two groups of information provision. Group 1 consisted of 20% of the travelers who did not receive any personalized information. As any traveler, however, they were allowed to check existent (public) sources of traffic information, such as existing websites, radio, VMS, etc. Indeed, depriving travelers to check public sources of information would not be in accordance to reality and would require change of habits of listening to the radio, watching television and consciously ignore existent VMS panels. Although information was available, as it was not personalized and required travelers to actively check these sources, we consider it as no info. Group 1 is denominated as *non-informed travelers*.

Group 2 consisted of the remaining 80% of the travelers who were subjected to two treatments regarding information provision: (i) no info treatment that corresponded to the initial three weeks of data collection and worked as a reference period and (ii) info treatment that lasted for the subsequent six weeks in which travelers received personalized real time traffic information via TomTom navigation devices of the type Via LIVE 120 – Europe, from now TomTom. Group 2 is denominated as *informed travelers*.

The separation of travelers into *informed* and *non-informed* travelers had two main objectives: (i) to investigate whether being part of an experiment would change the behavior of non-informed participants with time and (ii) whether behavioral changes could be observed by comparing *informed* and *non-informed* travelers. Nevertheless, as the experiment focused on *informed* travelers, there was a predominance of this type of travelers. Table 1 summarizes the number of participants under each condition of information provision.

Table 1: Conditions of Information Provision

Period	**Treatment**	
	No info **(or public info sources)**	***Info*** **(free info sources +** ***TomTom*****)**
Initial 3 weeks	100% (32 participants)	0% (0 participants)
Last 6 weeks	20% (6 participants)	80% (26 participants)

Depending on the moment information was provided, different sources were available. For pre-route information, travelers could check radio, television, websites, TomTom, etc. For en-route information, radio, VMS and TomTom were available. This approach allows comparing the potential of different types and sources of information as well as how both prescriptive information (via TomTom) and descriptive information (via VMS) influence travelers.

The personalized real time traffic information provided via TomTom consists of a recommendation regarding the fastest route between origin and destination and the estimated arrival time and delay (in relation to free-flow travel time) considering the indicated departure time. In addition, it is also possible to plan the departure time based on the traffic situation and to compare the travel times on the actual recommended route with an alternative route (Figure 3). As a result, we consider that the participants were equipped with a proper tool of information provision which would potentially help them choose the best route (and departure time) between origin and destination.

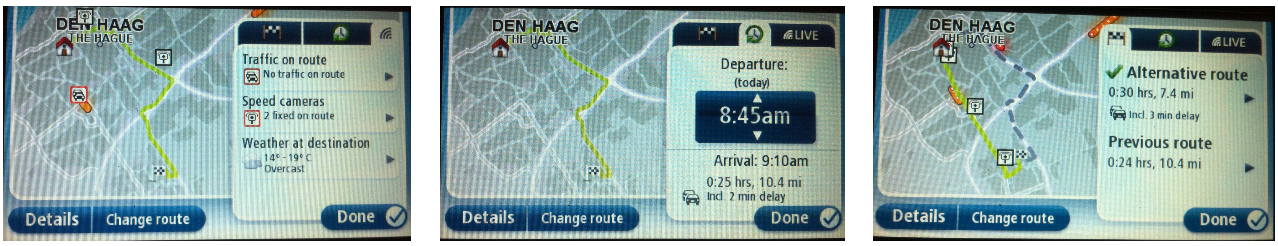

Figure 3: Example of the type of traffic information provided by *TomTom*.

Use of information was *not* imposed to the participants. Instead, at the beginning of the experiment, they were instructed to check traffic information whenever they wanted. In other words, they were instructed to make their trip related decisions, i.e.

route choice, departure time and use of information, the way they wanted to as in a regular trip. No change in behavior, besides using the GPS device and filling in the travel diaries, was imposed to the participants. None of the participants owned TomTom devices before the experiment, thus they were introduced to it during the experiment.

2.1.4 Travel diary and interviews

We consider the use of travel diaries the most appropriate way to get deeper insight into how travelers react to information, the type of information that appears to be more useful to travelers, what people actually recall from the information received and, moreover, whether travelers comply with information and under which conditions. In addition, it also helps investigating whether travelers have a good perception of what actually happened during the trip and whether and how expectations are updated based on past/recent experiences.

Therefore, besides carrying GPS devices during their commute trips, the participants were also asked to fill in a travel diary after each trip. The travel diary consisted of five sections related to (i) general information such as date of the trip, origin and destination; (ii) behavior towards pre-trip information, such as whether they checked pre-trip information, sources of information provision, whether they complied with it (and why not), whether the information favored the intended route and what they remembered from it, (iii) behavior towards en-route information containing questions similar to the ones related to pre-trip information; (iv) feedback about the trip just made, consisting of questions regarding the actual travel time, whether (in hindsight) the participants would have chosen the same route and departure time and whether (and what) additional traffic information was needed; and, finally, (v) expectations about the next trip with respect to their intended route choice and departure time, expected travel time and also flexibility regarding arrival time at the destination.

Besides the travel diaries, participants were interviewed in three occasions: at the beginning, in the middle (after 5 weeks of data collection) and at the end of the experiment. At the beginning of the experiment they were asked about (i) perceptions regarding fastest, most reliable and most unpredictable route, (ii) preferred routes to and from work (and why), (iii) usual departure times, (iv) frequency of use of pre-route and en-route information, (v) willingness to pay to use traffic information. In the middle of the experiment travelers were interviewed with respect on how they had reacted to the provided real time traffic information, i.e., (i) how often the route suggested by *TomTom* matched their expectations, (ii) how often they followed the suggested route, (iii) how satisfied they were with the information provided and (iv) how reliable they considered the information. Finally, at the end of the experiment, a combination of questions presented at the beginning and in the middle of the experiment were asked again.

2.2 Characteristics of the GPS devices

We used GPS devices from the brand Qstarz, type BT-Q1000XT. These are small devices of approximately 8 cm long, with capacity of recording up to 40 days based on logging each waypoint every 5 seconds for 12 hours/day and a battery duration up to 42 hours of consecutive use. Based on previous pilot experiments, it was found that on average this GPS has a horizontal precision of around 1m and makes use, on average, of 8 satellites. Thus, accurate enough to investigate route choice behavior. The routes observed during the experiment could be matched to the network without ambiguity. The data collected with the GPS comprise the most relevant attributes to investigate route choice behavior: route chosen, departure and arrival times, trip duration, distance and speed.

The GPS was set to log every 5 seconds and the logging of the data to automatically start when movement was detected. Therefore, participants did not need to handle the GPS, just keep it in the car.

2.3 The Network

As we were dealing with an RP experiment in which the data was being collected during the commute trips of the participants, for obvious reasons feedback information about the alternative routes and traffic situation was not provided at the end of the trip. However, in order to investigate travelers' perception it is important to know the traffic situation during the experiment, thus the need to know the traffic conditions.

The road network investigated consists of 520 unidirectional links and 200 nodes (Figure 4). Links travel times have been retrieved from the TomTom database and consist of travel time on each link at 1 minute interval during the whole study period. As we are focusing on commuters driving in the morning and afternoon peak hours, the time periods investigated are from 07:00h to 10:00h and from 16:00h to 19:00. From now on, when referring to this data, the term *network data* will be used. In Figure 4, links in yellow correspond to the ones for which *network data* is available and links in blue otherwise. For the blue links, we consider free flow travel time.

A limitation of our *network data* is that the travel times of each link are provided for 1 minute interval. However, the travel times in some links are shorter than 1 minute: in our case, the shortest travel time is 10 seconds. As a result, our *network data* was defined for time intervals of 10 seconds. Both the morning and peak hours were divided in intervals of 10 seconds which resulted in 1080 time intervals, meaning that although time is continuous, we have discrete intervals. Moreover, the travel times of each link within each interval are deterministically given. Thus, within each 1 minute interval, and for each link, the travel times from TomTom were replicated 6 times.

As we have discrete time intervals, in order to calculate the travel times of each *main route* we have to add up the travel times of each link belonging to a specific *main route*. By defining time intervals of 10 seconds we ensure progression in time when calculating the travel times of each *main route*. In other words, a traveler departing at time interval t_0 from link l_1, would arrive at link l_2 at time interval t_1, where t_1.= t_0 + travel time to go from l_1 to l_2 and $t_1 > t_0$.

In addition to the *network data*, historical travel times for each *main route* and for the same period of the experiment, but for the year of 2010, was also retrieved from the database of TomTom. Historical data was retrieved from the TomTom database to be used as a source of comparison with the *network data*. This is because TomTom has an algorithm that processes the *network data* and the outcomes of this algorithm are the predicted travel times that are then reported to the travelers. This algorithm, however, is not available to us. In order to address this problem, we compare the travel times of each main route resultant from the *network data* with the historical data by means of a linear regression (Figure 5). A correction factor of 0.6871 was then determined and we assume that for the purposes of our analysis dividing the travel times of each *main route* based on the *network data* by the correction factor would lead to a good estimate of the travel times.

Figure 4: Transportation network studied

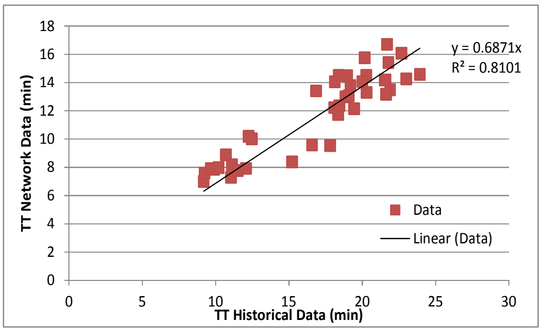

Figure 5: Historical versus network travel times

3. Results and discussion

This section presents a comprehensive descriptive analysis of the data set by comparing the valid GPS traces and *network data* with the *travel diaries* and *interviews*. At occasions the GPS lost signal before arriving at the destination, data started to be logged after the trip had started (or both), or the participant did not do the regular commute trip. Therefore, by valid trips we refer to trips in which both the origin and destination of the GPS trace is within 1.5 km of home and work. The resultant data set after data treatment consists of 897 valid GPS traces and *travel diaries* from which 374 refer to initial 3 weeks of data collection under *no info* treatment and 523 to the subsequent 6 weeks under the *info* treatment. The reader should have in mind that when dealing with the *travel diaries* and GPS traces our sample consists of 897 trips and when dealing with the *interviews*, our sample consists of 32 interviews for each of the three occasions participants were interviewed.

The analysis presented in the following sections concerns three main aspects: travelers' perception of route reliability (Section 3.1), use of information (Section 3.2) and adaptive behavior (Section 3.3).

3.1 Travelers' perception of route reliability

The literature has largely discussed the importance of route reliability for route choice decisions. In particular it is often argued that travelers value travel time reliability higher than travel time savings (Small et al., 2005; Liu et al., 2004; Ramos et al., 2011). This aspect is now investigated in a real congested network.

Although traffic data was not available for some links in our network, all links belonging to the *main routes* are part of the *network data*. The travel times of each *main route* were defined as the sum of travel times of all links belonging to it divided by the correction factor (0.6871) and were defined for both directions, i.e., to and from work. We considered departure times at every 5 minutes during the morning (7:00h – 10:00) and afternoon (16:00h – 19:00h) peak hours.

Participants reported that among the routes belonging to CS1, route 1 is the most preferred and the others are equally less preferred. Among the routes belonging to CS2, route 14 is the most preferred and routes 46, 54 and 58 the least preferred. In addition, the routes reported as preferred were usually also considered to be reliable and the least preferred to be unreliable. Figures 6 and 7 depict the standard deviation and average travel times for CS 1 (based on the *network data*) in the morning and afternoon peak hours; Figures 8 and 9 refer to CS 2. The standard deviation of travel times has been normalized in relation to the average travel time of each route.

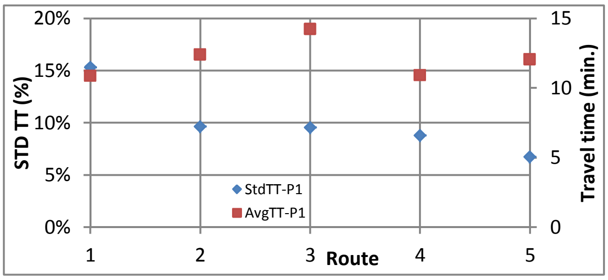

Figure 6: StdTT and AvgTT of *main routes* in CS 1 in the morning peak

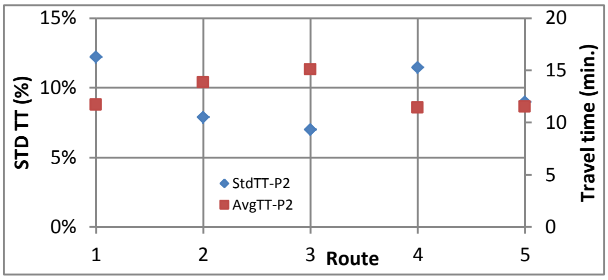

Figure 7: StdTT and AvgTT of *main routes* in CS 1 in the afternoon peak

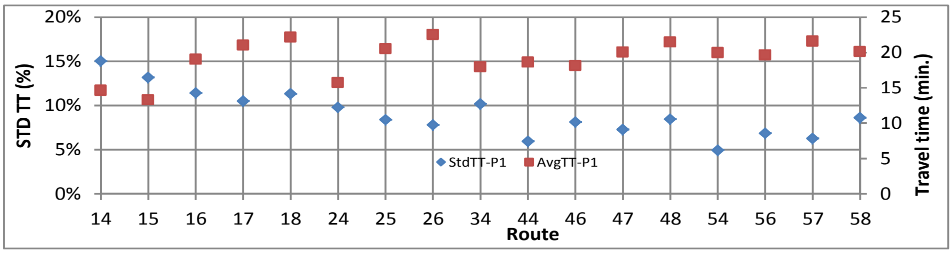

Figure 8: StdTT and AvgTT of *main routes* in CS 2 in the morning peak

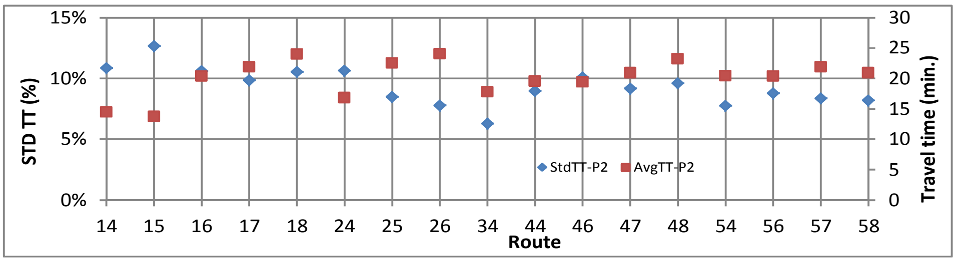

Figure 9: StdTT and AvgTT of *main routes* in CS 2 in the afternoon peak

It is possible to observe in Figures 6 to 9 that the routes considered to be reliable (and actually chosen the most by the participants) are actually among the most unreliable although fastest routes. This is contrary to what has been reported in the literature. Among the 32 participants joining the experiment, 30 were assertive about route reliability (and 2 did not consider any route reliable) and 21 were assertive about route unpredictability (and 11 did not consider any route unpredictable) (Table 2). The 1st column in Table 2 refers to the aspect investigated, the 2nd column to situations in which morning peak is considered, the 3rd to situations in which the afternoon peak is considered and the 4th to situation neither related to morning nor to the afternoon peak. For questions related to the most preferred route, participants gave their opinion concerning morning and afternoon peaks and for the other situations, it was a generic answer.

Table 2: Relationship between preferred route and (perceived) reliability

Aspect investigated		MorningPeak	AfternoonPeak	N/A
1.	Preferred route is ACTUALLY the most RELIABLE route	2	3	-
2.	Preferred route is ACTUALLY the most UNRELIABLE route	18	17	
3.	Preferred route in the morning is the same as in the evening	-	-	25
4.	Consider Preferred route reliable	17	17	
	Consider the preferred route to be reliable (but actually it is among the MOST UNPREDICTABLE)	8	8	
5.	Consider the least preferred to be unreliable			8
	Consider the least preferred route to be unreliable (but actually it is among the MOST RELIABLE)			4
6.	Route considered reliable and actually is AMONG the most reliable			8
	Route considered unreliable is AMONG the most unreliable			9
	Route considered reliable is AMONG the most reliable AND route considered unreliable is actulally AMONG the most unreliable			2
7.	Route considered Reliable is AMONG the Fastest			16
	Route considered Reliable is AMONG the Fastest & Unpredictable			9
	Route considered Unpredictable is AMONG the Slowest			14
	Route considered Unpredictable is AMONG the Slowest & Reliable			5

From Table 2 it is possible to observe two main aspects: (i) travelers are biased in favor of their preferred routes and (ii) the terms fastest & reliable and slowest & unpredictable appear to be confounded. This is aligned with findings reported in the literature regarding perception of route reliability for habitual and non-habitual routes, i.e., higher travel times in habitual routes are treated as exceptions while slow/normal travel times reinforce the preference for the habitual route; the opposite holds for non-habitual routes (Bogers, 2009). Nevertheless, these findings are somehow contrary to what has been reported in the literature regarding the importance of route reliability and outcomes of our data sample lead us to argue that the importance of route reliability may be overestimated. When investigating travelers' behavior in a real setting it seems that what matters is to arrive at the destination the fastest possible, which suggests that travelers behave as risk prone when making route choice decisions.

3.2 Use of information

Travelers were interviewed in 3 occasions during the experiment: at the beginning, in the middle and at the end of the experiment. Outcomes of these *interviews* regarding the use of traffic information show that (i) as time evolves travelers' tend to seek travel information more often (ii) en-route information appears to be more interesting than pre-trip information and (iii) equipping travelers with an appropriate tool of traffic information provision increases the likelihood information is used (Table 3). These results also suggest that although informed travelers are more willing to look for information while driving (or just before starting the trip), they do not tend to use it as a tool to plan departure times. In other words, although informed travelers have been equipped with an appropriate tool of information provision to help better plan departure times, they do not seem to be using it for this purpose. Travelers seem to be more interested to know the best route given they have to depart "*now*". As reported by the participants, information was usually checked when just inside of the car and not beforehand while still at home or in the office.

Based on the *interviews* we also observed that around 77% of the informed travelers reported that only less than 30% of the times the route suggested by the *TomTom* was different from their intended route. For this group of travelers, 95% reported to have followed the information provided over 70% of the times. One informed traveler, however, reported that the route suggested by *TomTom* differed from the expectations over 70% of the times and as a result compliance rates reduced to less than 30% of the times. These results raises questions concerning how travelers react in case the traffic information is not aligned to expectations, which is definitely a point to be further investigated. If travelers comply with information only when it is aligned with their expectations, the potential of information to influence travelers' route choice behavior may be considerably lower than expected. Regarding satisfaction with the information, over 75% of the informed travelers reported to be satisfied or very satisfied with the *TomTom* information and around 80% of them consider it to be reliable over 70% of the times. So, the fact that information was not usually checked is apparently not related to lack of confidence in the information.

These, however, are travelers' perceptions regarding the use of information. Based on the *travel diaries* we further investigated what actually happened during the commute trips. Table 4 depicts how often travelers seek travel information after each trip. By comparing Tables 3 and 4 it is possible to observe that travelers' perception regarding the use of en-route information is similar to the actual use. However, the actual use of pre-trip information is substantially lower than the perceived use. This reinforces our argument that travelers are more interested in trying to find an alternative solution in case the preferred route is too congested rather than finding out what the best alternative route is. The fact that the travelers are very familiar with the network and aware of the regularity of traffic jams might also play an important role.

Table 3: Percentage of travelers seeking information based on *interviews**

Period	Overall		Informed Travelers		Non-Informed Travelers	
	Seek Pre-Trip Info	Seek En-Route Info	Seek Pre-Trip Info	Seek En-Route Info	Seek Pre-Trip Info	Seek En-Route Info
1. At the beginning of the experiment	19%	38%	-	-	-	-
2. Middle of the experiment (5 weeks)	41%	72%	38%	81%	50%	33%
3. At the end of the experiment	50%	66%	54%	73%	33%	33%

* Results refer to participants' perception of "usually" checking travel information. Definition of "usually" was not presented.

Table 4: Percentage of travelers seeking information based on the *travel diaries*

Treatment	Number of Trips			Overal		Informed Travelers		Non-Informed Travelers	
	Overall	Informed Travelers	Non-Informed Travelers	Seek Pre-Trip Info	Seek En-Route Info	Seek Pre-Trip Info	Seek En-Route Info	Seek Pre-Trip Info	Seek En-Route Info
No Info treatment	374	316	58	16%	34%	16%	37%	3%	14%
Info treatment	523	464	59	41%	67%	38%	64%	14%	44%

In terms of sources of information provision, radio appears to be the preferred source of public information even when compared to VMS. This may be due to the fact that, as reported by some travelers, it is not so straightforward to understand the messages provided by the VMS. It is clear, however, that when personalized traffic information is available, it turns out to be the main used source of traffic information (Table 5).

Table 5: Percentage of use of each source of information based on the *travel diaries**

Treatment	Considered sources of Pre-Trip info					Considered sources of En-Route info			
	Internet	Radio	TV	Tom Tom	Other	Tom Tom	Radio	VMS	Other
No Info treatment	31%	63%	3%	0%	7%	0%	58%	54%	9%
Info treatment	1%	28%	0%	82%	0%	88%	11%	29%	88%

*The total percentage is higher than 100% because more than one source of information could be checked.

Regarding compliance with information, an interesting fact observed is that although en-route information is checked more often, travelers are more willing to comply with pre-trip information (Table 6). This may be influenced by (i) the fact that changing routes while en-route would imply taking local roads and thus the resultant time-saving would not be so great, (ii) habit, so being aware of a delay was already "good" and travelers prefer then to stick to their own routes or (iii) information matches intended route and as a result although travelers are actually also "following" the information, it may be perceived as unnecessary/not needed. From Table 6 it is also possible to observe that informed travelers are more willing to comply with information than non-informed travelers which reinforces the benefit of provision of personalized traffic information.

Table 6: Travelers' compliance rate with all sources of information based on the *travel diaries**

Treatment	Number of Trips			Overal		Informed Travelers		Non-Informed Travelers	
	Overall	Informed Travelers	Non-Informed Travelers	Comply with Pre-Trip Info	Comply with En-Route Info	Comply with Pre-Trip Info	Comply with En-Route Info	Comply with Pre-Trip Info	Comply with En-Route Info
No Info treatment	374	316	58	64%	50%	67%	49%	50%	2%
Info treatment	523	464	59	82%	75%	84%	75%	50%	24%

***** The percentages are calculated based on the number of trips in which information was actually checked

3.3 Adaptive behavior

As argued in section 3.2 travelers appear to be more likely to use information to decide what route to choose rather than to plan the best departure time. In other words, travelers are more likely to change routes than departure time which is contrary to what has been reported on the literature. Questions regarding change in departure time due to provision of information were part of the *travel diary* and Table 7 shows the outcomes.

During the whole experiment, only in 6 out 897 trips there were changes in departure time due to information provision. Although this is not aligned to what has been reported in the literature, in the context of commute trips this seems to be very plausible. This is because travelers might already have a pre-defined schedule and changes would be perceived as beneficial only in case of extreme accidents, such as road blocks due to accidents and thunder storms. For the usual regular congestion travelers might have already incorporated the "expected" delay as part of their routines. Nevertheless, this implies that in order to change the departure time behavior of commuters, either the penalty associated to a late arrival or the benefit for on time/earlier arrival should be higher. This, however, does not seem to be the case for regular commute trips. For instance only in 12% of the trips punctuality or early arrival was considered to be mandatory, while in 49% of the cases 10-20 minutes delay would still make it possible to fulfill the daily obligations, in 35% of the cases 30 min. – 1 hour delay would still make it possible to fulfill the daily obligations and in 4% of the cases canceling the trip would be possible.

Table 7: Percentage of changes in departure time due to information based on the *travel diaries*

Treatment	Number of Trips			Changed DT		
	Overall	Informed Travelers	Non-Informed Travelers	Overall	Informed Travelers	Non-Informed Travelers
No Info treatment	374	316	58	1.3%	1.3%	2%
Info treatment	523	464	59	0.2%	0.0%	2%

Although the likelihood to change routes is also low, it is higher than for changes in departure time (Table 8). Moreover, when incurring delays longer than expected travelers are more willing to stick to the same route as chosen than trying a different one. This reinforces the argument that bad experiences in habitual routes are treated as exceptions.

Table 8: Relationship between delay and willingness to choose the same route again based on the *travel diaries*

How long the delay was	Would have chosen the same route in hindsight	Would NOT have chosen the same route in hindsight
Longer than expected	11%	4%
NOT longer than expected	85%	1%

Regarding awareness of the route choice set, outcome of the GPS traces show that the general route choice set provided by the participants is quite comprehensive: only 2 extra roads (in The Hague) had not been mentioned by any of the participants and were actually chosen during the *no info* treatment. In addition, at times travelers diverted from the *main routes* to local ones. The individual reported choice set, however, appeared to be smaller than what was actually chosen for 12 out 32 participants, i.e., at least one route different from the reported was chosen in the *no info* treatment. This is most likely due to the fact that the non-reported routes were rarely used. Overall, *main route* 1 was the route chosen the most in Delft (73%) and *main route* 14 in The Hague (42%). These are the main highways between Delft and The Hague and also the fastest and most straightforward routes (as discussed before, however, these are the most unreliable routes).

Route choice behavior in the *info* and *no info* treatments also remained quite similar and travelers tended to stick to their preferred routes. Figure 10 shows travelers' exploration rates having the preferred routes as basis, i.e., if a route different from the preferred one was chosen, it was considered as if exploring a different route. Only few travelers showed an explorative behavior while most of them, even the ones belonging to the *no info* treatment, stick to the preferred routes: around 75% of the times the chosen route was the same as the preferred route either to or from work.

The fact that travelers do not seem willing to comply with information and tend to stick to their preferred routes instead of changing routes when facing longer delays may explain higher percentages of planned routes equal to chosen routes. Over 70% of the times the planned route was the same as the actually chosen route. Figure 11 illustrates the routes chosen before and after information provision, making clear that the pattern of route choices remained (almost) the same.

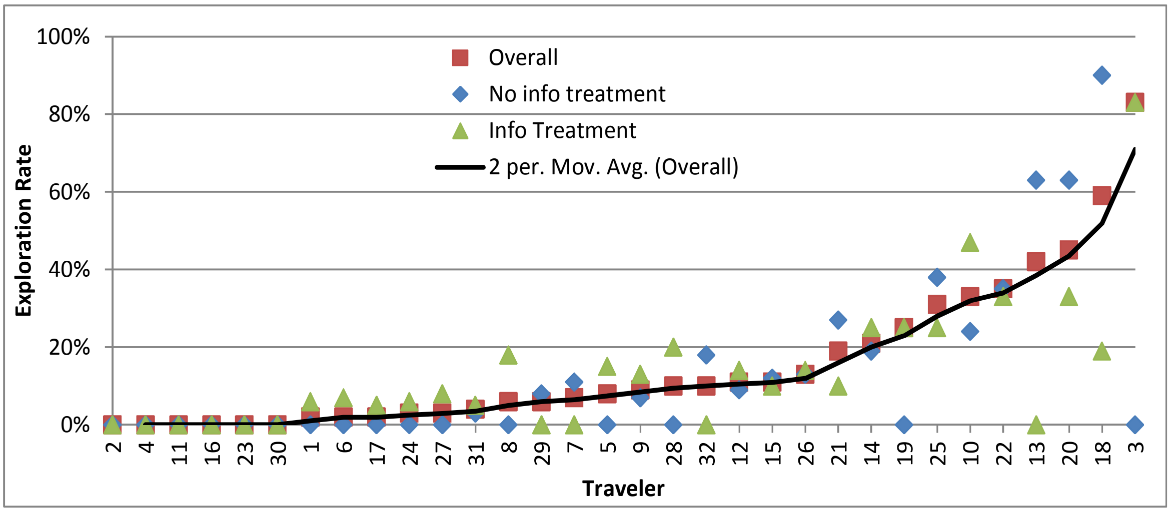

Figure 10: Exploration rates during the experiment based on the GPS traces

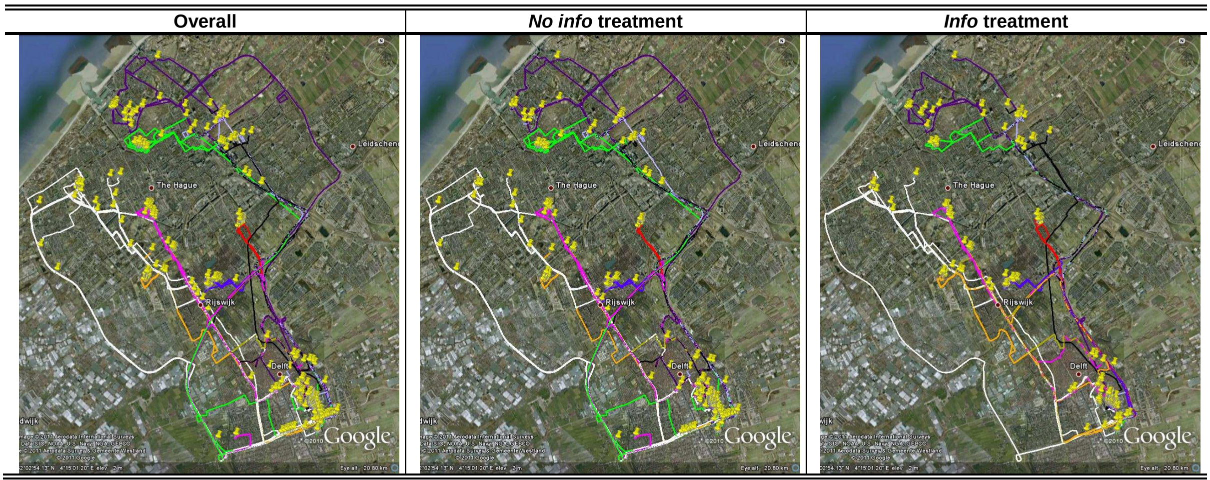

Figure 11: Route choices before and after information provision

4. Conclusions and next steps

This paper presents the setup and some findings of an RP route choice experiment conducted in the Netherlands between May 9th, 2011 and July 12th, 2011 in which the route choices of 32 participants were tracked with the aid of GPS devices. It resulted in 897 observed trips with correspondent *travel diaries* from which 374 refer to trips made before provision of personalized traffic information and 523 otherwise. The added value of this research lies not only in the use of GPS traces to investigate travelers' actual behavior, but on the investigation of the relationship between travelers behavior and information provision throughout *travel diaries* and *interviews* (at the beginning, middle and end of the experiment). Moreover, the traffic situation on the network during the period of the experiment is known.

Descriptive analysis of our data set suggest that travelers' perception of routes' characteristics is biased in favor of the preferred routes, i.e., preferred routes are usually considered to be reliable when in reality they are among the most unreliable. Despite the importance of travel time reliability in the route choice context as discussed in the literature, outcomes of this RP experiment suggest that travelers are actually interested in arriving at their destination as fast as possible. Thus behaving as risk-prone. The fact that in general the preferred route is considered to be reliable, however, is aligned to findings in the literature that higher travel times are usually treated as exceptions.

Another important aspect that diverges from the literature concerns change in departure time due to information provision: outcomes of this RP experiment suggest that travelers do not tend to use information to plan/change departure times; they actually seem to be interested to know what route to choose considering they want to depart "now". Although the likelihood to change routes or departure time appears to be low, it is a bit higher in case of route choices. This may be related to the fact we are dealing with commuters and as such they might already have a pre-defined schedule or incorporated the "expected" delay as part of their routines. Nevertheless, this implies that in order to change the departure time behavior of commuters, either the penalty associated to a late arrival or the benefit for on time/earlier arrival should be higher. Given the observed differences into travelers' stated and revealed preferences, this seems to be an interesting topic for future research as this raises questions concerning stated preference surveys in which travelers are asked what they would do given a specific situation.

Regarding the role of information, it was observed that equipping travelers with proper devices to provide personalized real time traffic information substantially increases the likelihood they will use it to assist their travel related decisions. In addition, although en-route information appears to be checked more often, travelers are more willing to comply with pre-trip information. This may be influenced by (i) the fact that changing routes while en-route would imply taking local roads and thus the resultant time-saving would not be so high, (ii) habit, so being aware of a delay was already "good" and travelers prefer then to stick to their own routes or (iii) information matches intended route and as a result although travelers are actually also "following" the information, it may be perceived as unnecessary/not needed. In addition, as the information provided was most of the times aligned with travelers intentions, no substantial change in their route choice patterns was identified. Thus, it clearly remains to be investigated how travelers would react in case the information was not aligned to their expectations.

We are aware of the limitations of our data set which consisted of investigating the behavior of 32 commuter only. Nevertheless, based on the data sample of our RP experiment we could observe important aspects of travel behavior that diverge from what has been reported in the literature. While on the one hand our sample has limitations, findings reported by the literature are often based on SP experiments. More RP experiments are definitely mandatory before definitive conclusions can be made. Our RP experiment is one of the first attempts to investigate travelers' behavior in a real setting and we hope this encourages more research in this direction.

Research already in progress concerns estimation of a route choice model based on the RP data and transportation network of this experiment. Based on a model estimation we intend to discuss findings discussed in this paper such as that travelers appear to be risk prone when making route choice decisions.

Acknowledgements

This research was funded by the NWO, Dutch Organization of Science, under the program TRISTAM: "Traveler Response and Information Service Technology: Analysis and Modeling". We thank *TomTom®* for cooperating with our research and making available the *TomTom* Via LIVE 120 – Europe devices used by the participants during the experiment.

References

Arnott, R., A. de Palma and R. Lindsey (1991). Does Providing Information to Drivers Reduce Traffic Congestion? *Transportation Research Part A*, Vol. 25, no.5, pp: 309–318.

Avineri, E (2006). The Effect of Reference Point on Stochastic Equilibrium. *Transportation Science*, Vol. 40, no. 4, pp: 409-420.

Axhausen, K.W., A. Zimmermann, S. Schönfelder, G. Rindsfüserand, T. Haupt (2002). Observing the rhythms of daily life: a six-week travel diary. *Transportation*, Vol. 29, no. 2, pp: 95–124.

Ben-Akiva, M., A. de Palma and I. Kayasi (1991). Dynamic network models and driver information system. *Transportation Research Part A*, Vol. 25, pp: 251 – 266.

Ben-Elia, E. and Y. Shiftan. Which road do I take? A learning-based model of route-choice behavior with real-time information (2010). *Transportation Research Part A*, Vol. 44, pp: 249-264.

Bierlaire, M., J. Chen and J. Newman (2010). *Modeling route choice behavior from smartphone GPS data*. Report TRANSP-OR 101016, 2010, Ecole Polytechnique Fédérale de Lausanne.

Bogers, E. A. I (2009). *Traffic Information and Learning in a Day-to-day Route Choice.* TRAIL Thesis Series, T2009/5, The Netherlands.

Bovy P. and E. Stern (1990). Route Choice: Wayfinding in Transport Networks. *Kluwer Academic Publishers*, Dordrecht, the Netherlands.

Cascetta E (2002). Modelli per i sistemi di trasporto, teoria e applicazioni. *Utet Università*, pp: 206-215.

Chen, P., Mahmassani, H.S. (1993). A dynamic interactive simulator for the study of commuter behavior under real time traffic information supply strategies. *Transportation Research Record*, Vol. 1413, pp: 12–21.

Chen, P. S.-T., K. K. Srinivasan and H. S. Mahmassani (1999). Effect of information quality on compliance behavior of commuters under real-time traffic information. *Transportation Research Record*, Vol. 1676, pp: 53-60.

Chorus, C. G., T. A. Arentze and H. J. P. Timmermans (2008). A comparison of regret-minimization and utility maximization in the context of travel mode-choices. *Presented at the 87th annual meeting of the Transportation Research Board.* Washington, DC.

Denant-Boèmont, L. and R. Petiot (2003). Information value and sequential decision-making in a transport setting: an experimental study. *Transportation Research Part B*, Vol. 37, pp: 365-386.

De Palma, A. and N. Picard (2005). Route choice decision under travel time uncertainty. *Transportation Research Part A*, Vol. 39, pp: 295-324.

Frejinger, E. and M. Bierlaire (2007). Capturing correlation with subnetworks in route choice models, *Transportation Research Part B*, Vol. 41, pp: 363-378.

Koutsopoulos, H. N., T. Lotan, Q. Yang (1994). A driving simulator and its application for modeling route choice in the presence of information. *Transportation Research Part C*, Vol. 2 (2), pp: 91–107.

Liu, H. X., W. Recker and A. Chen (2004). Uncovering the contribution of travel time reliability to dynamic route choice using real-time loop data. *Transportation Research Part A*, Vol. 38, pp: 435–453.

Mahmassani, H.S., T. Joseph and R.C. Jou (1993). Survey approach for study of urban commuter choice dynamics. *Transportation Research Record*, Vol. 1412, pp: 80–89.

Menghini, G., N. Carrasco, N. Schüssler, K.W. Axhausen (2010). Route choice of cyclists in Zurich *Transportation Research Part A*, Vol. 44, no. 9, pp: 754-765

Papinski, D., D. M. Scott, S.T. Doherty. (2009). Exploring the route choice decision-making process: A comparison of planned and observed routes obtained using person-based GPS. *Transportation Research Part F,* Vol. 12, pp: 347-358.

Polydoropoulou, A., M. Ben-Akiva and I. Kayasi (1994). Influence of traffic information on drivers' route choice behaviour. *Transportation Research Record*, Vol. 1453, pp: 56-65.

Ramos, G. M., W. Daamen and S. Hoogendoorn (2011). Comparison of Expected Utility Theory, Prospect Theory, and Regret Theory for prediction of route choice behavior. *Transportation Research Record,* Vol. 2230, pp: 19-28.

Rose, J., Bliemer, M., Hensher and D. Collins (2008). Designing efficient stated choice experiments in the presence of reference alternatives. *Transportation Research Part B*, Vol. 42, pp: 395–406.

Small, K. A., C. Winston and J. Yan (2005). Uncovering the distribution of motorists' preferences for travel time and reliability. *Econometrica*, Vol. 73(4), pp: 1367–1382.

Selten, R., T. Chmura, T. Pitz, S. Kube and M. Schreckenberg (2007). Commuters route choice behaviour. *Games and Economic Behavior*, Vol. 58, pp: 394-406.

Zhang, L., D. Levinson (2008). Determinants of route choice and value of traveler information. *Transportation Research Record*, Vol. 2086, pp: 81–92.

Zhang, J., Z. Wang, Harry Timmermans and Akimasa Fujiwara (2010). Integrating the concepts of Relative Utility and Prospect Theory curvature to represent context dependence in travel choice behavior. *12th World Conference on Transport Research*, Lisbon, Portugal.

Web sources:

Dutch MON database (2008). *http://www.rijkswaterstaat.nl/wegen/innovatie_en_onderzoek/betere_doorstroming/mobiliteitsonderzoek_nederland/* (page visited on August 20th, 2010)

Randstad – Wikipedia: *http://en.wikipedia.org/wiki/Randstad* (page visited on July 14th, 2011)

TomTom - *http://www.tomtom.com.br* (page visited on July 14th, 2011)

Qstarz - *http://www.qstarz.com* (page visited on July 14th, 2011)