



TI 2010-110/3

Tinbergen Institute Discussion Paper

The Economics of Information in Transport

Piet Rietveld

VU University Amsterdam, and Tinbergen Institute.

Tinbergen Institute

The Tinbergen Institute is the institute for economic research of the Erasmus Universiteit Rotterdam, Universiteit van Amsterdam, and Vrije Universiteit Amsterdam.

Tinbergen Institute Amsterdam

Roetersstraat 31
1018 WB Amsterdam
The Netherlands
Tel.: +31(0)20 551 3500
Fax: +31(0)20 551 3555

Tinbergen Institute Rotterdam

Burg. Oudlaan 50
3062 PA Rotterdam
The Netherlands
Tel.: +31(0)10 408 8900
Fax: +31(0)10 408 9031

Most TI discussion papers can be downloaded at
<http://www.tinbergen.nl>.

The Economics of Information in Transport

Piet Rietveld

Introduction

Economic analyses of travel behavior are usually based on the assumption that travelers are well-informed about the options they have. In reality the situation may be rather different. Travelers may not know the complete set of alternatives available to them. Another possibility is that travelers are not well-informed about particular features of travel alternatives. Much of the literature focuses on uncertainty on travel times (Chorus, 2007). One possibility is that travelers have biased information on travel times of some alternatives. Another possibility is that the realizations of travel times with transport alternatives are variable due to factors such as incidents or variations in weather conditions. In that case travelers do not know beforehand what will be the actual travel times of the choices they are considering.

The various cases of incomplete information can be shown to have potentially important implications for the distinct domains of travel behavior such as whether or not to make a trip, modal choice, the timing of a trip or the choice of the route. Lack of information about choice alternatives naturally affects choice probabilities as also does biased information about travel times. An example of a systematic gap between perceived and actual travel times is provided by Exel and Rietveld (2009a) who find for a large sample of car travelers that perceptions of public transport travel time exceed objective values by on average 40-50%. Analysis of modal choice on the basis of actual behavior (revealed preference) under the assumption that perceived travel times of non-chosen alternatives are equal to objective values would then lead to biased estimates of the underlying utility function.

Variability in the availability and performance of travel alternatives also has important implications for travel behavior. People may dislike uncertainty and this would then affect their choices even when they are well informed on the mean values of the travel alternatives.¹ This leads to issues such as how information provision affects traveler behavior. Further, variability of realizations may induce efforts of information acquisition

where costs and benefits of information have to be traded-off. One of the issues is that effects have to be considered at the level of individual travelers and at the system level.

During the last decade large efforts have been made to increase the availability of information to travelers by means of advanced traveler information systems (ATIS). That ATIS will on average lead to a reduction of travel times is confirmed in a review of the time saving benefits of the introduction of ATIS on the functioning of road transport systems carried out by Levinson (2003). In a survey of some 10 model based studies, the median level of the decrease in overall travel time of all road users is about 7%, with some very high outcomes (up to 50%), implying that there is substantial variation among studies. Important factors that determine the outcome are the degree of congestion in the network as well as the structure of the network, the specification of incidents in the model and the share of the road users that are equipped with ATIS. From the studies surveyed it appears that as congestion levels increase also the potential gains of ATIS will increase, a point also made by Yang et al. (2003).²

In this chapter I will review some economic aspects of information in transport markets. Main questions addressed are: which factors explain search strategies adopted by travelers facing uncertainty on outcomes of their choices? How do information acquisition strategies determine the use of networks, and what is the resulting demand for information in transport markets? First, I will discuss information acquisition from an economics perspective by characterizing costs and benefits of information, leading to the formulation of optimal strategies to acquire information (section 2). This will be done in the context of search strategies leading to sequential information acquisition. In section 3, I discuss the broader consequences of information acquisition on the functioning of transport networks. In congested networks, when travelers change their behavior on the basis of information they obtain, this will have consequences not only for their own travel times, but also those of other travelers. This leads to interesting positive (and possibly negative) spillovers having important policy implications. Section 4 takes the further step of examining within the network model a traveler's choice whether to adopt an ATIS so that the demand function for information can be derived. Some specific themes are discussed in section 5. Section 6 concludes.

Information acquisition, a search theoretic perspective³

Consider a traveler who lacks information on some travel alternatives. This may be a case of a person who has changed residence and job, and who is considering the best route for his commute, but also the choice between various holiday destinations can be studied by this approach. In the present section we focus on individual choices and ignore feed-backs on the overall functioning of transport systems (this will be the subject of section 3).

Another difference between this and next section is that in section 3 the performance of travel alternatives is inherently uncertain, whereas these uncertainties are ignored here.

There are essentially three strategies available to deal with the lack of information:

1. *Search* for information on the uncertain alternatives and then select the best alternative on which information is available.
2. *Trial and error*: Experience one or more of the uncertain alternatives by selecting them. This provides information on the best alternative to be chosen amongst those tested, in subsequent choice situations.
3. *Skip* uncertain alternatives: choose an alternative in the choice set that is certain.

The *information search* option involves both costs and benefits. Among the costs are the time and cognitive effort needed to get the information. In addition, information may cost money. The *trial and error* option just means that travelers obtain information by trying alternatives;⁴ after the search phase they will then adopt the best performing alternative they happened to find. As we will see, the main difference between information search and trial and error lies on the cost side. In the case of search, travelers incur costs in terms of pre-trip efforts, in the case of trial and error the costs relate to the loss in utility from choosing an alternative at random instead of choosing the best known alternative. The *skip* option means that uncertain options are not chosen or explored and that an alternative is chosen that is not plagued by uncertainty, for example 'staying at home'. This option is important because it allows for elastic demand for transport. The extent of elasticity depends on how broadly the choice set is defined: it may include travel alternatives in terms of route, mode, timing or destination. In that case the lack of information does not lead to a skipped trip, but when an outside alternative such as staying at home is part of the choice set, the information context becomes an important determinant of elastic demand. A traveler who lacks information and incurs high information acquisition costs is likely to forego activities.

Costs and benefits of information search

What factors influence the choice between the three alternatives to deal with uncertainty, and in particular the attractiveness of the information search option? Nelson (1970) sketches a search context where the consumer (traveler) is uncertain about the exact features of alternatives, but he has information on the probability distribution of the utility of the choice options. The consumer then sequentially searches for information about alternatives. Information search involves costs and benefits. When considering a pre-trip context, the costs of information search consist of the time spent on it, the search efforts including the cognitive efforts (Grotenhuis et al., 2007), and the price:

$$MC^s = MC^s(\text{pre-trip search time, efforts, price}).$$

Note, that search efforts are determined among other factors by the user friendliness of the ATIS or alternative information search channels. Having described the costs of information acquisition we now consider the benefits. As the consumer inspects more alternatives the utility of the best alternative on which information is available will gradually increase. The optimal stopping rule is to continue searching until the marginal cost of information search is equal to the marginal expected return for an additional search (MR) (see Nelson, 1970). The latter is equal to the difference between the expected present value of the utility of the best alternative in a given number of searches (j) minus the expected value of this utility with one search less ($j-1$):

$$MR_j = E(B_j) - E(B_{j-1}) ,$$

where $E(B_j)$ is the expected present value of the best of j randomly chosen options.⁵ In order to be able to determine $E(B_j)$, information is needed on the probability density of all possible alternatives. Expected values of the best alternative can be computed by means of order statistics approaches⁶ (Mood et al., 1974).

Costs and benefits of trial and error

Next we consider the strategy of trial and error: just experience an arbitrary chosen travel alternative and observe its utility. The marginal returns of additional alternatives tried is again equal to the marginal returns MR defined above. As already indicated above, the difference between information search and trial and error is on the cost side. In the case

of search, travelers experience costs in terms of pre-trip efforts, whereas in the case of trial and error the costs relate to the loss in utility from not choosing the best known alternative, but rather trying another alternative in the hope that this one may be even better. Hence the expected marginal costs incurred by trying an additional alternative j , MC_j^t , are equal to:

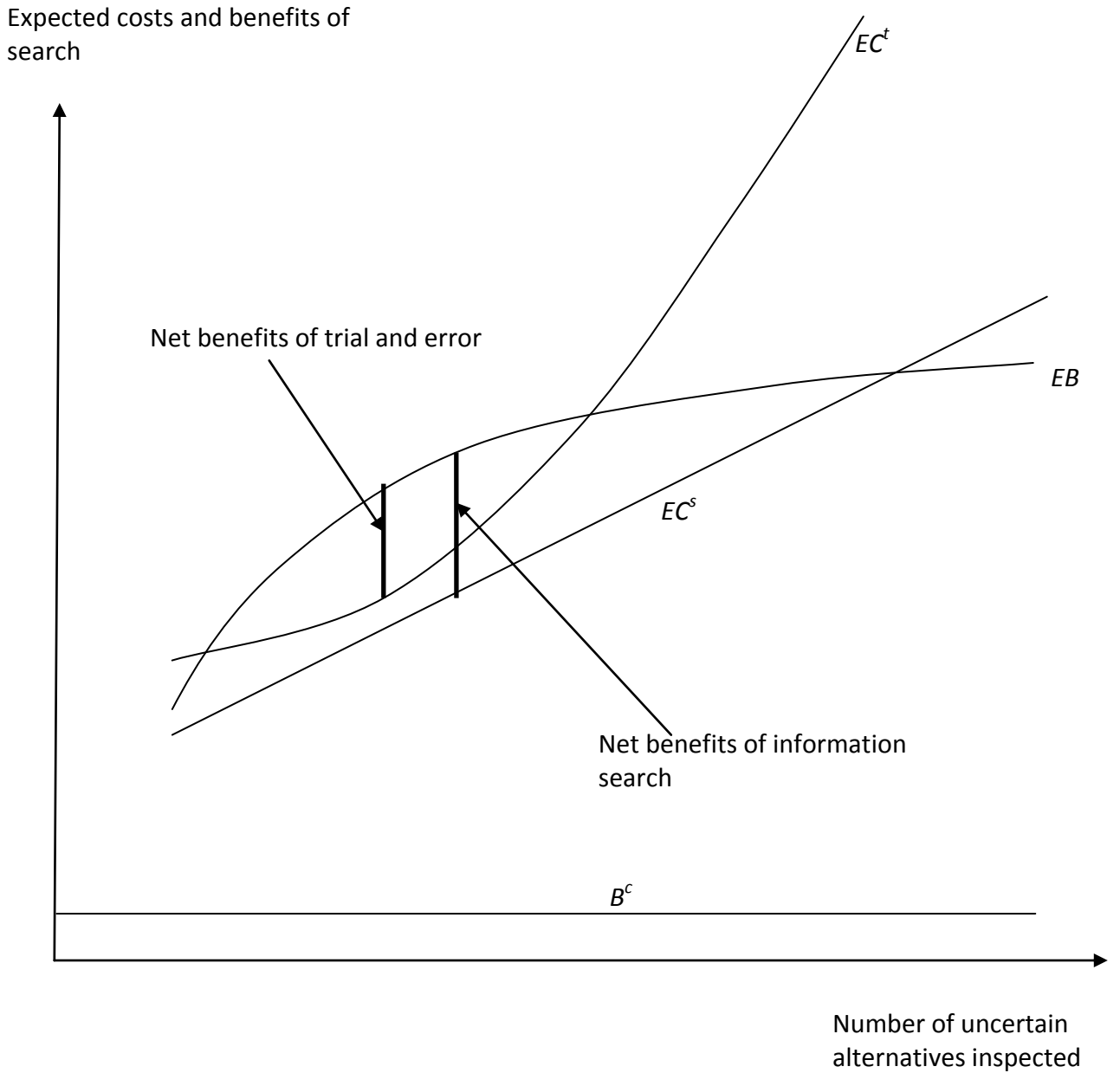
$$MC_j^t = E(B_{j-1}) - u ,$$

where u is the expected benefit, being equal to the mean of the utility density function. Since we assume the distribution of utilities of alternatives to be known, also its mean value u is known. Note also that as the number of tested alternatives increases, $E(B_j)$ increases, so that the marginal costs of testing a new travel alternative increase: with each additional trial the gap between $E(B_j)$ and u becomes wider.

In both cases of information search and experience, the optimal number of cases to be considered can be determined once the parameters in terms of time preference, standard deviation etc, are known. One of the relevant results is that *ceteris paribus* for both strategies, as the frequency of choice increases, the number of alternatives to be inspected increases (Nelson, 1970). Thus, a daily decision like the route choice in the commuting trip is worth a larger number of alternatives to be explored than a trip that is only made once.⁷ However, it may well be that trips that are rarely made also involve larger potential costs and benefits. For example, a long distance holiday trip may involve large resources in terms of time and money, leading to high marginal benefits of additional information search.

Reference alternative: skipping uncertain alternatives

The third choice strategy is to ignore the uncertain alternatives and just stick to the best alternative among the certain ones, including the alternative of not making the trip.



EB : Expected benefits given a set of alternatives inspected
 EC^t : Expected costs of trial and error
 EC^s : Expected costs of search
 B^c : Benefits of choosing best certain alternative

Figure 1 Choice of information acquisition strategy

Comparison of strategies

The choice between the three strategies can be made by comparing the optimal level of the net benefits of the information search strategy (based on the optimal number of alternatives inspected), the optimal outcome of the trial and error strategy, obtained in a similar way, and that of the skip strategy. Figure 1 illustrates the choice of information search strategy when there are many alternatives, for example, the joint time and route choice in an urban commuting trip. The expected benefits curve EB is applicable for both information acquisition strategies: search and trial and error. The EB curve is increasing, but at a decreasing rate: as information is available on more and more alternatives the probability that an additional alternative is found that implies a substantial improvement is becoming smaller and smaller. The trial and error expected cost curve is convex as can be explained by the MC_j^t formula given above: with an increasing number of alternatives already tried, the loss of not using the best known alternative (found in the preceding search) is increasing. In this figure we assume that information search costs by means of ATIS are characterized by a fixed cost to get access to an information system and a variable cost related to getting information on each alternative. This figure has been drawn such that ATIS is the optimal strategy: maximum net benefits are obtained for the information search strategy. Note further that with the given cost structures the optimal number of alternatives inspected in the search strategy is larger than in the trial and error strategy. In this example the search strategy dominates the strategy of skipping uncertain alternatives.

Comparative statics can be applied to Figure 1 to analyze the effects of changes in cost parameters. From a technological viewpoint it is clear that the introduction of ATIS has reduced the slope of the information search cost curve. This has two effects: it leads to an increase of the optimal number of alternatives to be inspected, and it increases the probability that information search is indeed the optimal strategy. It brings travelers in their final choice of a travel alternative closer to the best possible one. And it reduces the probability that trips are skipped due to uncertainty problems.

Since the search approach implies that travelers trade off the marginal costs and benefits of further search, they will usually stop searching before the whole choice set has been explored. Hence there is no guarantee that travelers will choose the best alternative. This result coincides with that of bounded rationality and satisficing approaches (Chorus, 2007). The common element of the two is the role played by the cost of information.

Note, however, that the background of both approaches is different, since search theory remains entirely within the domain of economics, which is not the case with the other approaches.

A special case occurs when the information acquisition takes place in the context of a trip that is only made once. In such a case the information obtained cannot be used another time, an example being a holiday trip to a certain destination. Then the benefits related to the trip are large, and also variations between alternatives will probably be large. An uninformed trial and error based choice will then by definition lead to a choice with the average utility level within the choice set. In this context marginal costs of information search will probably be low compared with the benefits to be obtained, so that search will be the best strategy. The opposite occurs with a trip where the marginal gains of information are relatively small. For example, it may take a few minutes to get the exact time table of a metro service. There will be a tendency that when frequency is high (say 8 trains per hour), the benefits of search leading to shorter waiting time at platforms do not outweigh the search effort on departure times, and travelers tend to go to such metro stops without consulting time tables implying that they arrive randomly at the platforms (Danas, 1980, Tirachini et al., 2008). Fosgerau (2009) gives a thorough analysis of the decision whether or not to plan (search for information) or use the trial and error strategy. In addition to service frequency another relevant factor would be the reliability of a service: when the service is very unreliable, this is another reason to ignore officially published timetables. These examples show that although the choice contexts can be very different (time of departure versus destination choice), the same trade-offs between costs and benefits of information search strategies apply.

Who benefits from search?

Of particular interest is the question which types of travelers will be most inclined to make use of ATIS as an information acquisition strategy. Chorus (2007) indicates that in terms of socio-economic features, well educated, high income travelers and professionals are among the most intensive users of ATIS. This is indeed a plausible result in the context of Figure 1. The slopes of the EB , EC^t , and EC^s curves are proportional to the value of time (VOT), implying that the optimal number of searches does not vary with income. But there are two reasons why the search alternative is more likely to be preferred when income increases. First, the fixed part of the EC^s curve will be less than proportional to the value of time, thus leading to a higher probability that with a high VOT, search will have the largest

positive gap between the EB and EC curves in Figure 1. Second, it improves its performance compared with the outside alternative (B^c does not change).

In Figure 2 we present another dimension of the benefits of being informed. We focus on a heterogeneous group of travelers who consider a potential trip to be made only once. The inverse demand curve in Figure 2 indicates the variety in the willingness to pay for this trip in terms of generalized costs. Let the actual generalized costs be c . Travelers base their decision on their perception of generalized costs. There are clear indications in the literature that travelers have biased and in general inflated estimates of the costs of travel alternatives they don't often choose (see for example Exel and Rietveld (2009b) for car user perceptions of public transport travel times). Consider travelers that overestimate the generalized costs by an amount of d . Travelers with willingness to pay between c and $c+d$ then will not make the trip even though they would experience positive net benefits. Applying the rule of half then leads to a welfare loss related to the biased perception as indicated in Figure 2.

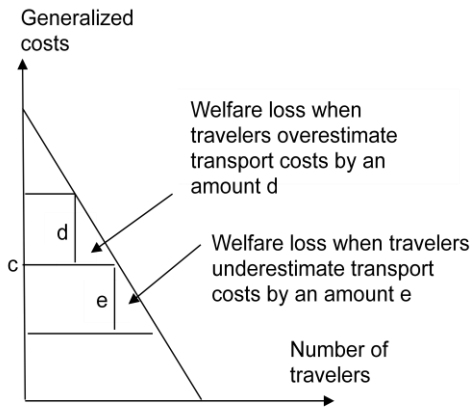


Figure 2 Welfare losses due to overestimation or underestimation of transport costs

Underestimation of costs can be treated in a similar way. Suppose travelers underestimate the generalized costs by an amount e (see Figure 2). Those travelers with willingness to pay between $c-e$ and c who make the trip would regret what they did because they end up with negative net benefits. We conclude that provision of information is beneficial for

passengers who have a willingness to pay that is close to the generalized costs, and that have incomplete or biased knowledge on these costs.

On the other hand, passengers with a willingness to pay for the trip that is either much higher or much lower than the actual costs will not benefit from information since their decision will not be affected by it. These findings will be further explored and refined in section 3.

Extensions of base sequential search model

Transport alternatives have some special features compared with other goods and services delivered that have important implications for information acquisition strategies. These are:

Dependence. Alternative routes are often overlapping for parts of the total routes. This means that information acquisition for one trip will also yield useful information –though incomplete- for alternative routes. This aspect was ignored in the analysis above.⁸ Note that it holds for both information acquisition strategies. It means that the choice of additional alternatives to be inspected will be guided by information in related alternatives, implying that fewer alternatives need to be inspected in the choice process.⁹

Variation in the performance of alternatives. Incidents may lead to variability in the performance of a certain travel alternative. In that case the trial and error strategy implies the repeated choice of a certain alternative to acquire information on the distribution of its possible outcomes. This case is addressed by Chancelier et al. (2007) in the context of risk averse drivers who can choose between a route with a fixed outcome and one with an unknown distribution of outcomes. The expected value of the ‘random’ route is better than that of the ‘safe’ route. They find that drivers that are close to risk neutral will select the random route and stick to it. The opposite applies to drivers who are strongly risk averse: they are not interested in acquiring information on the distribution of the random route and will stick to the safe one. The most interesting case concerns the middle group that will start the trial and error process by experiencing the random route and then may shift to the safe route depending on the exact degree of risk aversion. A related result will be discussed in section 4.

Discrepancy between official information and actual quality of travel alternatives. The actual duration of trips may be longer than that of the official time table or of free-flow travel time. Information derived from ATIS like travel planners for public transport do not report about this gap, which implies that the trial and error strategy may yield information that is closer to the reality than information search strategy. This would also imply that the benefit curves of trial and error and of information search are no longer identical.

Impacts on performance of alternatives. A third point that deserves further attention is that in the case of congested networks, information search strategies have an impact on the performance of networks. This case is of special interest and will be discussed in the next section.

Feed-back effects of information on congestion

We now add an ingredient that was missing in the section above: information acquisition has a feedback on congestion levels on roads so that both informed and non-informed road users will be affected. In order to study this case we use a very simple network: a one link network with non-recurrent congestion and elastic demand (for details see Emmerink et al. 1996). After having discussed the results for this simple network we will discuss more complex networks and other complications. Consider a congested link that can be in two states: high capacity H and low capacity L . Low capacity is the capacity after an incident or a lane closure. We use a static model of congestion. The probability of a low capacity is denoted as p . Pre-trip information is available to a certain group of I (informed) travelers of given size N_I . When the informed travelers prepare for a trip, they know for sure in which of the two states (H versus L) the link will be. Another group of travelers is non-informed (NI). They just know the probability, p , of the low capacity condition. The demand function for transport expresses willingness to pay for the trip, where we assume heterogeneity among road users similar to the case of Figure 2. We assume that the Wardrop conditions for network equilibrium will apply (Small and Verhoef, 2007). This means that an informed road user will use the network when private benefits are at least equal to the actual private generalized costs for the prevailing state. An uninformed road user follows a similar strategy, but based on the expected generalized costs.

The above Wardrop approach leads to three equilibrium conditions: two for informed road users and one for non-informed road users. The conditions are interlinked, since the two groups make use of the same network.

The first condition is that in the high capacity case H the marginal road user's willingness to pay within the group of informed road users D_I is equal to the generalized costs C^H he experiences :

$$D_I(Q_I^H) = C^H(Q_I^H + Q_{NI}),$$

where Q_I^H denotes the number of informed travelers that uses the link under the high capacity conditions, and Q_{NI} denotes the non-informed travelers. Clearly, the generalized costs under the high capacity conditions depend on the sum of both informed and non-informed travelers. For the low capacity case L the Wardrop condition for the informed road users can be formulated in a similar way:

$$D_I(Q_I^L) = C^L(Q_I^L + Q_{NI}),$$

Since non-informed road users do not know the actual costs they will experience, they base their decision whether or not to travel on the expected costs, being the mean costs resulting from the high and low capacity costs taking into account the respective probabilities $1-p$ and p . Hence the Wardrop user equilibrium condition in their case is:

$$D_{NI}(Q_{NI}) = (1-p) \cdot C^H(Q_I^H + Q_{NI}) + p \cdot C^L(Q_I^L + Q_{NI}).$$

When the inverse demand functions D_I and D_{NI} are known, as well as the congestion cost functions C^H and C^L plus their respective probabilities, the resulting equilibrium values Q_I^H , Q_I^L and Q_{NI} , can be derived. Figure 3 gives a graphical illustration of the model under the assumption that demand and cost functions are linear.¹⁰

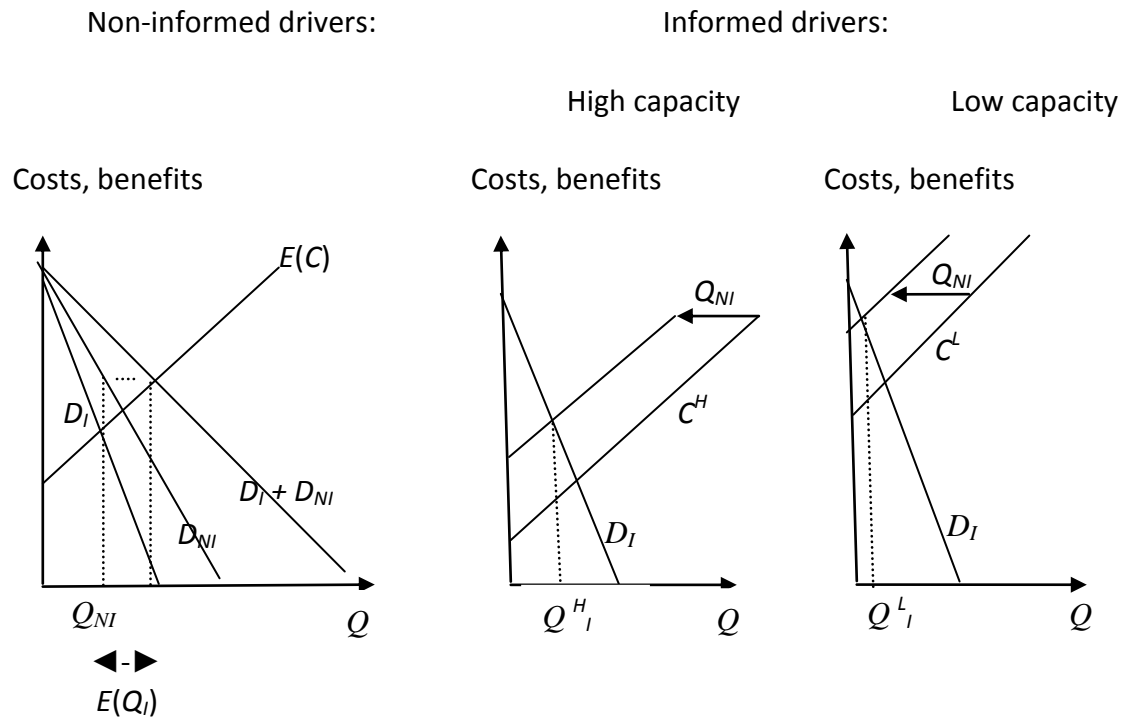


Figure 3 Network equilibrium with informed and non-informed road users

In the left hand panel the non-informed road users equate their willingness to pay and expected marginal link travel costs, considering the effects of the behavior of the informed road users on their expected travel costs. They base their decision on the expected number of informed drivers: $E(Q_I) = (1-p) \cdot Q_I^H + p \cdot Q_I^L$. Similarly, in the right hand panel the equilibrium conditions are given, leading to the number of informed road users that make use of the link under H and L capacity conditions, and where the number of uninformed road users is also accounted for as can be seen from the shift in the cost curve implying higher trip costs related to the volume of uninformed road users using the road.

The impact of the information provision can be determined by comparing the present case with that where there are no uninformed road users. The model results (details can be found in Emmerink et al., 1996) indicate that road use becomes more selective due to the responses of informed road users: under high capacity conditions it increases, while under low capacity conditions it decreases. The balance of the two effects is positive: more

travelers will make use of the road. Also, it is interesting to know that the provision of information will lead to an increase of both informed and uninformed travelers. The second result reveals a positive welfare spill-over of the information provided to informed travelers. The information provision will induce informed road users not to use the link in the low capacity condition and this means that there is more room for uninformed road users under this condition. Another important result is that while information provision leads to an increase of overall road use, it reduces at the same time the expected link travel costs. This is a strong sign that provision of information is welfare enhancing in this context. It can even be shown that in this context *all* road users benefit from the information provision, no matter whether they belong to the informed or the uninformed group. The degree to which they benefit will vary, however. The benefits of the informed road users tend to be higher than those of the non-informed road users. The nature of the benefits of the non-informed road users is entirely external: they are induced by the behavioral adjustments of the informed road users. For the informed road users the benefits are highest among those road users that will adjust their driving behavior due to the information provision. Note that this result is similar to the result found above in the context of information provision to correct for wrong cost perceptions.

Finally, we consider the impact of the share of informed road users on the welfare gains. In this model, there is a monotone increasing relationship between the share of informed road users and welfare gains. However, the increase takes place at a decreasing rate, implying that the marginal welfare gains are considerably higher for the first 10% of the road users who receive information compared with the last 10%. This suggests that where the marginal cost of information provision is positive, the optimum level of information provision is probably not that 100% of the road users will have access to it. The point is that there is a possibility that information provision will lead to overreaction of road users, an issue addressed later in this section.

It is important to note that the information provision usually brings the system closer to its optimum, but that the optimum itself cannot be reached. There remains a gap between the user equilibrium with full availability of information and the system optimum. This is illustrated in Table 1, where the various combinations of information provision and congestion charging are outlined. In this section we only considered cases 1 and 2. The system optimum (case 4) can be reached via the combination of information provision and congestion charging at its optimal level. Thus, when the aim is to achieve

the system optimum, congestion pricing cannot be dropped. In situations where congestion pricing is not feasible, information provision strategies can help in getting closer to the welfare maximum. Note that it matters for the optimal congestion charge whether information is provided. When in this model all drivers are non-informed, the optimal charge would be uniform, independent of whether the high or the low capacity regime applies.¹¹ When some drivers would be informed, however, the optimal congestion charge would be different in both regimes.

Table 1 Combinations of information provision and congestion charging

	Information provision: no	Information provision: yes
Congestion charging: no	1	2
Congestion charging: yes	3	4

Given the positive externalities that non-informed drivers experience there might be a case for subsidies to stimulate the supply, or use, of information provision. This will be investigated in more detail in the next section.

Broader review of literature

The results presented here depend on a number of specific features of the model such as network structure, and specific cost and demand parameters. We will briefly review to what extent results depend on these features. The one link network structure may be extended to larger networks. Most of the results obtained here will also apply in the context of more general networks. However, the result that *all* road users benefit from information supply does not hold true in more general network structures. In particular when information supply on a certain link leads to the situation that informed road users would shift to another congested link that is employed by road users with another combination of origin and destination, welfare in the latter group may be negatively affected (Emmerink et al., 1997). Another extension of the model discussed above concerns the inclusion of risk aversion. De Palma and Picard (2005) and de Palma et al. (2009) discuss the case where road users differ in their risk aversion parameter. Equilibrium travel time in the system then depends on the distribution of this parameter. They arrive at a similar result as Emmerink et al. (1997): information provision may be welfare reducing for some road users when it induces changes in travel behavior that aggravate congestion in particular parts of the network.

The result that *aggregate* welfare increases when more road users have access to better information is also found in a paper by Arnott et al. (1996) which addresses a static model of congestion based on the bottleneck model using isoelastic demand and user costs functions. However, there is also a line of literature that underlines that this result does not necessarily hold under more general settings. Schelling (1978) already hinted at the possibility of overreaction to information leading to a decrease in overall system performance when too many actors have access to information. Similar results were found among others by Ben-Akiva et al. (1991) and Emmerink et al. (1995), due to the phenomenon of concentration. These results are obtained in modeling contexts that do not entirely rely on equilibrium contexts with fully rational road users (see also Mahmassani and Liu, 1991).

A major contribution to this theme was provided by Arnott et al. (1999) in a paper based on a dynamic bottleneck model for congestion. Commuters decide on whether and when to depart for work taking into account generalized commuting costs, including queueing costs before passing the bottleneck and scheduling costs related to arriving early or late at work. The uncertainty in the model relates to the capacity of the bottleneck which depends on weather conditions and other factors. Arnott et al. (1999) base their analysis on constant elasticity demand and schedule delay cost functions. They distinguish three information regimes: zero information, perfect information and imperfect information. They show that their earlier result with a static model (Arnott et al., 1996) is not robust: in the dynamic model context it is possible that — in the absence of congestion pricing — a refinement of information from zero information to imperfect information has adverse effects on aggregate welfare.

Demand for information

An important distinction in the benefits of information provision to road users is the one between decision making benefits and travel cost benefits. Decision making benefits accrue to road users that change their behavior based on information provision, by choosing another route, or deciding on whether or not they will travel. Travel cost benefits accrue to all road users, irrespective of whether the road user is informed himself. It is clear that without decision making benefits there cannot be travel cost benefits.¹²

When studying the demand for information, decision making benefits are the key element, since it is decision making benefits that drive the benefits of information. When we adopt the model of the preceding section several groups of road users can be distinguished according to their benefits of road use (see Table 2).

Table 2 Relationship between trip benefits and demand for information

Road use benefits : Very high (1) to very low (4)	Type of decision as non- informed road user	Type of decision as informed road user	Part of information demand market?
1	Will always use the link	Will always use the link	No
2	Will always use the link	Will only use the link in high capacity state	Yes
3	Will never use the link	Will only use the link in high capacity state	Yes
4	Will never use the link	Will never use the link	No

Table 2 shows that there are two groups of road users that are affected by information in their decisions: segments 2 and 3. Segment 2 concerns road users that without information would always use the link, whereas when they are provided with information would only use it when it is in its high capacity state.

Segment 3 represents the road users that without information would never use the link, whereas when they are provided with information would only use it in the high capacity state. Car drivers in segments 1 and 4 would not change their behavior on the basis of information. Hence the potential market for travel information consists of segments 2 and 3 only. Of course the size of this market for information depends on the parameters of the demand function for transport, the probability of incidents and the parameters of the cost function.

Segments 2 and 3 of the range of travel benefits imply positive decision making benefits. In these segments there will be a positive demand for information when the price of information – denoted as π – would be zero. For positive values of π the group of road users with a potential interest in trip making would shrink. Let us consider road users in segment 2. When they have information that the L state will prevail, this group of road users will not make the trip, whereas when they are not informed they will still make the trip. When state L prevails, the net benefits of being informed for this group are therefore:

$$C^L(Q)-D(Q).$$

Thus, for the marginal traveler Q_{EN}^L (EN refers to the model feature that demand for information is endogenous) in segment 2 we have

$$p[C^L(Q_{EN}^L)-D(Q_{EN}^L)] = \pi.$$

For market segment 3 the decision making issue for the road users is that with information they will use the link in the high capacity state, whereas without information they will not make the trip. Hence they compare the benefits of the trip with the costs in the high capacity state. The equilibrium condition for travelers in segment 3 therefore reads:

$$(1-p).[D(Q_{EN}^H)-C^H(Q_{EN}^H)] = \pi.$$

Combining these two segments, we find that the total number of road users who are prepared to pay π for information equals $Q_{EN}^H(\pi) - Q_{EN}^L(\pi)$, which can be written as a function of the cost and demand parameters, leading to a downward sloping inverse demand function for transport information. This means that we arrive at an interesting parallel between the demand for transport and the demand for transport information: they share the property that they have the nature of *derived demand* (Quinet and Vickerman, 2004). Just as the demand for transport depends entirely on the parameters of the underlying demand and supply functions for the goods and services to be consumed, the demand for travel information depends entirely on the demand and cost parameters of the underlying transport system. De Palma *et al.* (2009) enrich this result by incorporating risk aversion as one of the relevant parameters. It is road users with intermediate levels of risk aversion who may benefit most from information provision: road users with low risk aversion will just take the route with the highest variation, and road users with high risk will do the opposite. For the intermediate group the information is useful to determine which of the routes is best.

An important question concerns the optimal price of information π . The transport market studied here is characterized by negative congestion externalities. When these are not corrected by means of congestion pricing, positive information externalities will occur.

The benefits of information acquisition will not only be experienced by the informed road users, but also by the non-informed ones as already shown above. Hence one may expect that standard marginal cost pricing will not lead to a welfare optimum. Indeed, Zhang and Verhoef (2006) find that when externalities prevail the optimal price of information may even be negative, which would provide a case for a subsidy on information provision. Empirical research of Zhang and Levinson (2008) indicates that the maximum willingness to pay for this type of information is rather low (up to 1 \$ per trip). One of the reasons for the low valuation is that road users may distrust the accuracy and timeliness of information.

Further issues

In the stylized models discussed above we focused on some essentials for the economics of information on transport. In this section we briefly discuss a few issues that are important and could lead to refinements in the models mentioned above.

Multiplicity of information search channels

Like in all domains of information acquisition, traffic information can be obtained via various channels. Some of the channels are low-tech and involve information exchange on traffic conditions within social networks, and people directly observing incident queues. Also radio reports play an important role in information acquisition. Other channels involve higher tech components such as route planners that are available for free everywhere on the internet.¹³ DRIPs (Dynamic Route Information Panels) are placed at congested places in networks to inform road users on conditions on alternative routes. Automatic route guidance equipment is gradually becoming standard in many countries. Among the current ATIS developments are the provision of dynamic information via automatic route guidance services or cell phones. Since the information from these various sources are close substitutes, the value added to the consumer of *additional* services may be relatively small. In terms of prices, a good number of information channels are just available for free. These include dynamic information obtained via DRIPs and via the radio. As a consequence the willingness to pay for new ATIS services may be smaller than is sometimes thought (see also Emmerink, 1996). Note also that the rapidly developing use of automatic route guidance equipment in cars has led to relatively low prices to install it, and marginal costs are zero. In this competitive setting, dynamic route information must be of high quality in terms of reliability, customer orientation and timeliness before road users will be prepared to pay for it.

Information availability and comfort

The above analyses focus on the use of information in specific choice contexts. One of the outcomes (see Table 2) was that depending on one's willingness to pay for a trip to a certain destination, people will be prepared to pay for information in order to avoid making the wrong decisions in terms of trip generation or route choice. There is also another possible view on the demand for information. Travelers may just feel uncomfortable in situations where the consequences of their choices are uncertain (Grotenhuis et al. 2007). They want to know what is going on in the network, even when it would not help them to make better decisions. This means that even travelers who do not experience decision making benefits as defined in Section 4 may have a positive willingness to pay for information. This in turn implies that there is also a market for information provision to improve the general comfort level, possibly in the form of comfort enhancing equipment in vehicles, or subscriptions to services that provide information on incidents, or combinations of both.

Compliance

Compliance is an important theme when studying traffic information systems. Emmerink (1998) and Yin and Yang (2003) indicate that there is a large variation in compliance rates among road users. Many road users just ignore traffic information because they think it may not be sufficiently reliable, it may be outdated, or since they don't want to change their original travel plan and are afraid that changing it may lead to unexpected surprises. They may also ignore information since they expect that this information would lead to an overreaction by other road users so that the available route alternatives would become too crowded. In addition, road users may not entirely trust the traffic information since they are afraid the information is given with the aim of achieving the system optimum (aiming at the maximization of total surplus) implying that their individual interest might be sacrificed for the overall public benefit.

Integration of transport modes.

Progress in ATIS has been substantial during the last decades, but it has resulted in rather fragmented services. The information provider is usually linked to a particular transport mode such as road, rail or bus. And even within modes, often a certain limitation can be observed in the information provided. For example, information on congestion on national roads is usually not easily connected to information on urban roads. And within

public transport route planners are sometimes confined to a particular transport company, or a particular mode. This lack of integrated information services on transport networks is a clear manifestation of a lack of integration in a broader sense. These signs are visible both within the public sector where there are strong barriers against horizontal and vertical integration, and the private sector where various companies find it difficult to coordinate their activities. However, there are signs in some countries that gradually the institutional barriers against integration are getting lower. This would be an important step towards truly integrated transport systems (for example: road use by car, parking facilities, train, metro), where clients are not hindered by the lack of integration between such facilities in the making of their travel plans.

Uncertainty on destination quality

In the present paper we focus on uncertainty about travel costs as a driver in the demand for information. There is of course also another source of uncertainty that is relevant here: uncertainty about the quality of the destination of a trip. This includes uncertainty about destinations in the case of trips purposes such as holiday trips, shopping, and various types of recreational visits. Here too there is the issue of choosing information acquisition strategies like search versus trial and error. The benefits of visiting trips destinations further away can be analyzed in a way similar to the *EB* curve for transport alternatives sketched in Figure 1 (see Rietveld and Woudenberg, 2003). Here too we observe the emergence of advanced information services that are provided by individual suppliers to increase their visibility towards customers and information services on the overall supply within a certain market. Similar to what we observed in section 2, this may be expected to lead to shift from trial and error to information search by means of advanced information technologies services, having implications for travel behavior, in particular destination choice.

Conclusion

Incomplete information on travel alternatives leads to travel behavior that is not optimal since travelers will not realize some of the better alternatives. Hence, information acquisition has potential welfare benefits, of course depending on the cost of information. We analyzed the costs and benefits of two main ways of information acquisition: information search – for example by means of ATIS – and trial and error. In the case of search the costs relate to pre-trip efforts, whereas in the case of trial and error the costs are incurred while making a trip. They relate to the loss in utility from not choosing the

best known alternative, but rather trying another alternative in the hope that this one may even be better. Based on the analysis of costs and benefits of both search alternatives, our analysis leads to the conclusion that the share of ATIS as an information acquisition mode will increase, although there will remain situations where trial and error is the better strategy.

The demand for information can be derived as a function of the parameters of demand and costs functions of transport, hence demonstrating the nature of the demand for information as a derived demand. In the case of car use in congested networks ATIS not only provides benefits to the individual traveler, but also induces feedback on travel times in such a way that non-informed travelers are affected. In most network structures these effects on other road users are beneficial. For example Levinson (2003) reports some 7% as the median decrease in travel times in a series of studies. However, as we have demonstrated in section 4, there are cases where the provision of information leads to aggravation of congestion in a particular way, negatively affecting groups of drivers. There might even be situations where provision of information has adverse effects on aggregate welfare. Such adverse effects of information provision can be prevented when congestion pricing is adopted.

We conclude that, although negative welfare effects of information provision cannot be ruled out, in the majority of the cases one may expect information provision to be welfare enhancing, not only for informed travelers, but also for non-informed ones. This would imply the existence of positive externalities in the information market, which makes a case for public supply of such information (such as information panels) or subsidies to users or private providers of information services.

References

- Arnott, R., de Palma, A., and Lindsey, R., 1996, Information and usage of free-access congestible facilities with stochastic capacity and demand, *International Economic Review*, **37**, 181-203.
- Arnott, R., de Palma, A., and Lindsey, R., 1999, Information and time-of-usage decisions in the bottleneck model with stochastic capacity and demand, *European Economic Review*, **43**, 525-548.
- Ben-Akiva, M., de Palma, A., and Kaysi, I., 1992, Dynamic network models and driver information systems, *Transportation Research A*, **25**, 251-266.

- Chancelier, J-P. de, Lara, M., and de Palma, A., 2007, Risk Aversion, Road Choice, and the One-Armed Bandit Problem, *Transportation Science*, **41**(1), 1-14.
- Chorus, C., 2007, *Traveler Response to Information*, PhD Dissertation Delft University of Technology.
- Danas, A., 1980, Arrival of passengers and busses at two London bus stops, *Traffic Engineering and Control*, **21**, 453-478.
- de Palma, A., and Picard, N., 2005, Route Choice Decision and Travel Time Uncertainty, *Transportation Research: A; Policy and Practice*, **39**(4), 295-324.
- de Palma, A., Lindsey, R., and Picard, N., 2009, Risk Aversion, the Value of Information and Traffic Equilibrium, *Transportation Science*, forthcoming.
- Emmerink, R.H.M. 1998, *Information and Pricing in Road Transportation*, Springer, Berlin.
- Emmerink, R.H.M., Nijkamp, P., and Rietveld, P., 1995, The potential of information provision in a simulated road transport network with non-recurrent congestion, *Transportation Research C*, **3**, 293-309.
- Emmerink, R.H.M., Verhoef, E., Nijkamp P., and Rietveld, P., 1996, Information provision in road transport with elastic demand: a welfare economic approach, *Journal of Transport Economics and Policy*, **30**, 117-136.
- Emmerink, R.H.M., Verhoef, E., Nijkamp, P., and Rietveld, P., 1997, Information in road networks with multiple origin-destination pairs, *Regional Science and Urban Economics*, **27**, 217-240.
- Exel, N.J.A., and Rietveld, P., 2009a, Could you also have made this trip by another mode? An investigation of perceived travel possibilities of car and train passengers, *Transportation Research Part A*, **43** (4), p.374-385.
- Exel, N.J.A., and Rietveld, P., 2009b, A note on perceptions of public transport travel time and their effect on choice-sets among car drivers, *Journal of Transport and Land Use*, forthcoming.
- Fosgerau, M., 2009, The marginal social cost of headway for a scheduled service, *Transportation Research B*, forthcoming.
- Grotenhuis, J-W., Wiegman, B., and Rietveld, P., 2007, The Desired Quality of Integrated Multimodal Travel Information in Public Transport: Customer Needs for Time and Effort Savings, *Transport Policy*, **14**, 27-38.
- Levinson, D., 2003, The value of advanced traveler information systems for route choice, *Transportation Research C*, **11**, 75-87.
- Mahmassani, H., and Liu, Y.S., 1991, Dynamics of commuting decision behavior under advanced traveler information systems, *Transportation Research C*, **7**, 91-107.
- Mood, A.M., Graybill, F.A., and Boes, D.C., 1974, *Introduction to the Theory of Statistics*, McGraw-Hill, New York.
- Nelson, P., 1970, Information and Consumer Behavior, *The Journal of Political Economy*, **78**, 311-329.
- Quinet, E., and Vickerman, R., 2004, *Principles of Transport Economics*, Edward Elgar, Cheltenham.

- Rietveld, P., and van Woudenberg, H.E.S., 2003, The utility of travelling when destinations are heterogeneous. How much better is the next destination as one travels further? *Journal of Geographical Systems*, **5**, 207-222.
- Schelling, T., 1978, *Micromotives and macrobehavior*, Norton, New York.
- Small, K.A., and Verhoef, E.T., 2007, *The Economics of Urban Transportation*, Routledge, London.
- Tirachini, A.J., Hensher, D.A., and Jara-Diaz, S.R., 2008, Restating modal investment priority with an improved model for public transport analysis, working paper, Universidad de Chile, Santiago.
- Yang, F., Liu, F.X., He, R.R., Ban, X., and Ran, B., 2003, Bilevel formulation for optimal traffic-information dissemination, *Transportation Research Record*, **1836**, 21-28.
- Yin, Y., and Yang, H., 2003, Simultaneous determination of the equilibrium market penetration and compliance rate of advanced traveler information systems, *Transportation Research A*, **37**, 895-912.
- Zhang, L., and Levinson, D., 2008, Determinants of route choice and value of traveler information, *Transportation Research Record*, **2086**, 81-92.
- Zhang, R., and Verhoef, E.T., 2006, A monopolistic market for advanced traveller information systems and road use efficiency, *Transportation Research A*, **40**, 424-443.

Notes

¹ Also the case of a biased perception of the *variation* in travel times may affect behavior.

² These results describe general tendencies. In particular cases exceptions may occur. In section 3 we will note that improving information supply does not invariably improve the performance of transport systems.

³ This section bears some relationship with section 3 of the chapter by Chorus and Timmermans on Personal Intelligent Travel Assistants. The common element of both is the use of utility concepts to compare situations with and without information. The two approaches differ in that Chorus and Timmermans address a one shot learning context, whereas I consider sequential search strategies. Another difference is that Chorus and Timmermans focus on uncertainty resulting from day-to-day variability in a network, whereas my focus in the present section is on uncertainty resulting from lack of information on travel alternatives that do not necessarily experience day-to-day variations in their quality.

⁴ Travelers may also adopt search heuristics implying non-arbitrary trials. This will be briefly discussed later in this section.

⁵ Note that we use an ex-ante perspective here to keep the analysis manageable. $E(B_{j-1})$ represents the expected utility of $j-1$ draws at the start of the information search. Actual information search will lead to realizations B_{j-1} that will be higher or lower than $E(B_{j-1})$, which may have an effect on the length of the search process.

⁶ In some cases alternatives may not be independent (for example in route choice). This can typically be modeled by nested logit models. In the present context of information acquisition this means getting information on one particular alternative has additional information benefits for related alternatives. This will be shortly discussed at the end of this section.

⁷ If the trip really is made only once, there is no opportunity to improve on the choice by trial and error as the term is used in the conventional sense. But also in this context it may still be an optimal strategy, as we will see below.

⁸ Editor note: The implications of correlations between alternatives are discussed in by Walker and Ben-Akiva in their chapter on discrete choice models.

⁹ Explicit modeling of this would substantially complicate the analysis. The forms of the various functions in Figure 1 will not change, but their precise locations certainly will. Note that this issue is related to the theme of search heuristics. Clever search strategies would imply that such interdependences are taken into account in the choice of alternatives to be explored.

¹⁰ Linearity of cost functions is needed for graphical illustration. Otherwise the expected cost function shown in the left-hand panel of Figure 3 does not solely depend on $E(Q_i)$, but also on the exact values of Q_i^H and Q_i^L .

¹¹ This reasoning is based on the implicit assumption that drivers do not know the day-specific state or day-specific charge for the link before making decisions. If they did know the day-specific charge — but not the day specific state — before making decisions, a differentiated charge would of course make sense.

¹² An exception occurs in the case of aversion to uncertainty, discussed in section 5.

¹³ Editor note: See also the chapter by Chorus and Timmermans on Personal Intelligent Travel Assistants.