The economics of motorist information systems

A discussion

Author(s):
Emmerink, Richard H.M.; Axhausen, Kay W.; Nijkamp, Peter; Rietveld, Piet

Publication date:
1993-12

Permanent link:
https://doi.org/10.3929/ethz-b-000048693

The economics of motorist information systems: a discussion

Richard H M Emmerink[+,#]

Kay W Axhausen[*]

Peter Nijkamp[+]

Piet Rietveld[+]

[+]Department of Regional Economics
Free University
De Boelelaan 1105
1081 HV Amsterdam

[#]affiliated to Tinbergen Institute

[*]Centre for Transport Studies
Department of Civil Engineering
Imperial College
London SW7 2BU

December 1993

ACKNOWLEDGEMENTS

This paper benefited from the first author's stay at the Centre for Transport Studies of Imperial College London during the summer and autumn of 1993.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

THE ECONOMICS OF MOTORIST INFORMATION SYSTEMS

Richard H M Emmerink[+,#]
Kay W Axhausen[*]
Peter Nijkamp[+]
Piet Rietveld[+]

December 1993

[+]Department of Regional Economics
Free University
De Boelelaan 1105
1081 HV Amsterdam

[#]affiliated to Tinbergen Institute

[*]Centre for Transport Studies
Department of Civil Engineering
Imperial College
London SW7 2BU

ABSTRACT

A motorist information system is not a *normal* economic good; the benefits accruing to people (road users) buying the good are dependent on the level of market penetration. Besides this *external* effect to equipped drivers, an externality to non-equipped drivers plays an important role.

This paper investigates the economic consequences of these interactions. In addition, the traffic generating properties and the market potential of motorist information systems are analysed from a theoretical perspective.

The implementation of a motorist information system will, owing to an efficiency improvement, generate more traffic on the roads. The size of this increase in efficiency, and therefore the amount of newly generated traffic, is uncertain and dependent on the kind of information system, the behavioural responses of the road users, the particular network under consideration and the level of market penetration.

Further it is concluded that, particularly in networks with recurrent congestion, the benefits to equipped drivers diminish as the level of market penetration increases. These systems have a better economical perspective in volatile road networks, i.e. networks with non-recurrent congestion.

1 INTRODUCTION

It is well known that motorist information systems could enhance drivers' knowledge of the situation in road networks, and thus improve drivers' decision-making (Ben-Akiva et al., 1991; Bonsall et al., 1991; Van Berkum and Van der Mede, 1993). However, it is far less understood whether and to which extent the interaction between the drivers themselves and the information and the drivers may reduce potential beneficial effects of these technologies. Mahmassani and Chen (1991) and Mahmassani and Jayakrishnan (1991) found that if more than 20 per cent of the drivers is equipped with the motorist information system, the negative effects, due to concentration and overreaction (Ben-Akiva et al., 1991), may start to take over the beneficial effects. Concentration takes place if the information reduces the variations among drivers, increases uniformity of perceptions of network conditions and thus increases congestion. Overreaction occurs if drivers are unable to predict the responses of other drivers provided with the same information, thereby shifting the congestion from one road to another. In these circumstances Mahmassani and Jayakrishnan (1991) argued that provision of coordinated information is necessary. Other studies, for example Emmerink et al. (1993a, 1993b) and Watling and Van Vuren (1993), supported these findings, but stated that the level of market penetration[1] beyond which the system wide performance starts to deteriorate is dependent on the kind of information provided and the behavioural responses of the drivers.

Throughout this paper, the term motorist information system will refer to an implemented on-board information system that reduces the travel time for the equipped drivers, and in addition, makes them better off than the non-equipped drivers. We acknowledge that the implementation of such a properly working system is a difficult task. Especially, since the behavioural responses of users towards such a system are very uncertain and difficult to trace. Some studies addressing this issue have been conducted, see for instance Allen (1993), Bonsall (1992), Caplice and Mahmassani (1992), Conquest et al. (1993) and Spyridakis et al. (1991). Although these studies give more insight into the behavioural issues involved, they do not indicate a clear pattern regarding users' responses. The human factor seems to generate a large variance in the results and strong conclusions can generally not be drawn.

An explanation for these results might be found in Heiner's (1983) suggestion that eliminating uncertainty - one of the purposes of a motorist information system - tends to destroy regularity and predictability in behaviour. Following this argument, provision of more information could be

[1]The level of market penetration is the percentage of drivers equipped with a motorist information system.

interpreted as guiding more complex behaviour, which could explain the divergence of the results obtained by the different studies.

Having raised some of the issues related to the problems of implementing a properly working motorist information system, nevertheless throughout this paper we will assume that we are dealing with such a good working motorist information system. In our opinion, this is justified because we think that once these new technologies are introduced on a large scale, they will gain the benefits from all the research efforts put into these technologies and will approximately achieve the intended benefits. Also from a marketing point of view this assumption seems tenable, since it does not seem economically viable to sell malfunctioning systems in the long run.

However, even a properly working motorist information system (as defined above) has some peculiar properties. This is caused by the fact that a motorist information system does not only affect the equipped drivers, but also the non-equipped ones. One could claim that a properly working motorist information system affects:

- the average road network travel time,[2]
- the average road network travel time of the equipped drivers,
- the average road network travel time of the non-equipped drivers.

The interactions between such a properly working motorist information system and the drivers - resulting in changes of the above listed travel times - affect the market potential and economical viability of these systems. With most scarce commodities, the gain obtained by buying the commodity is independent of the level of market penetration. As mentioned above, this is not necessarily true for motorist information systems. The aim of this paper is to discuss some of the economic implications of this dependency. In particular, we will focus on the externalities (both positive and negative) caused by motorist information systems, and the implications of these externalities on the economic viability. In addition, we will discuss the traffic generating potential of these new technologies.

By discussing these issues, we will ignore other potential purposes of motorist information systems, such as a decrease in stress or anxiety, an increase in safety, a decrease in pollution, etc. We reckon that particularly the potential of these technologies to reduce stress or anxiety are heavily underestimated.

[2]In a two player game in which the players represent the road users De Palma (1992) showed that this is not necessarily true, even with the provision of *perfect* information. A similar result has been obtained by Arnott et al. (1991) under *imperfect* information.

The discussion will initially focus on the case of recurrent congestion, i.e. congestion due to undercapacity of the road network. In Section 5, the more relevant case of non-recurrent congestion will be dealt with, i.e. congestion caused by incidents such as bad weather or traffic accidents. This is an important extension, since it has been claimed that non-recurrent congestion accounts for up to 60 per cent of total congestion delay (Lindley, 1986, 1987, 1989).

The paper is organised as follows. Firstly, Section 2 summarises some potential benefits of motorist information systems obtained from the literature. Section 3 discusses the externalities involved in implementing a motorist information system, while Section 4 focuses on the traffic generating effects and market penetration of these systems. Section 5 extends the scope to the case of non-recurrent congestion; Section 6 raises some points of the government's role in dealing with these new technologies. Finally, Section 7 contains some concluding comments.

2 BENEFITS FROM MOTORIST INFORMATION SYSTEMS

In the literature it has been suggested that road networks are not used as efficiently as possible. For instance, King (1986) and King and Mast (1987) found that about 6 per cent of all distance and 12 per cent of all travel time is wasted. In another study, Jeffery (1986) found an excess travel distance of 6 per cent. We can conclude that there is some room for travel time and distance savings through better information. However, there is no consensus about the type and size of the gains that can be obtained from motorist information systems. Here, some results from the literature will be discussed.

Kanafani and Al-Deek (1991) presented benefits equal to approximately four per cent in most cases in their theoretical model, without taking into account non-recurrent congestion. Their estimations were based on achieving the system optimum - Wardrop's second principle (Wardrop, 1952) - in the road network through the motorist information system at full market penetration. As discussed in Bonsall et al. (1991) this is in itself a highly debatable assumption and affects the plausibility of their figures.

Using a stochastic model in which a motorist information system is assumed to guide vehicles toward the expected shortest travel time routes, Tsuji et al. (1985) found benefits ranging from 9 to 14 per cent for the equipped drivers, but add that even higher figures could be attained, when non-recurrent congestion would be considered. Tsuji et al. (1985) ignored an important aspect of these technologies; they assumed that the flow of guided vehicles did not affect the unguided vehicles, implying that unguided vehicles do not receive any direct or indirect benefit from the motorist information system.

In other studies it has been suggested that most benefits of motorist information systems will be obtained in volatile, non-recurrent congested networks. See for example, Dehoux and Toint (1991) and Van Vuren and Van Vliet (1992). Dehoux and Toint (1991) stated that one of the purposes of the application of systems that provide information to road users is to produce substantial changes in traffic patterns over short periods of time in order to resolve traffic jams more quickly. Research efforts investigating the effectiveness of motorist information systems in such situations have been carried out by Hounsell et al. (1991), Mahmassani and Jayakrishnan (1988) and Rakha et al. (1989).

Mahmassani and Jayakrishnan (1988) analysed a transportation network during periods of perturbation and followed the system evolution to the *final equilibrium state*.[3] However, their simulation experiments only dealt with historical information (the road users' own experience in previous periods) and thus did not involve the application of a motorist information system. Hounsell et al. (1991) and Rakha et al. (1989) found in experiments conducted in a network with non-recurrent congestion substantial travel time savings of up to 20 per cent.

To conclude, transportation researchers do not agree on the scale of the benefits from motorist information systems; estimates show large variations. One explanation for this divergence could be found in the actual definition of the motorist information system. Different researchers have used different methods/models/situations for assessing the benefits. It might be one of the properties of motorist information systems that the benefits are highly dependent on the setting of the situation. This has recently been suggested by Watling and Van Vuren (1993) and Emmerink et al. (1993a). Seen from this perspective, the results obtained by different researchers are not contradictory, but complementary in nature.

Another important determinant of the benefits of motorist information systems is the level of market penetration, defined as the percentage of road users equipped with the system. Mahmassani and Jayakrishnan (1991) showed with simulation experiments that a high level of market penetration could easily lead to overreaction and a deterioration of the network wide performance. However, Watling and Van Vuren (1993) and Emmerink et al. (1993a) argued that the allowable level of market penetration is strongly dependent on the kind of information provided, see for a more rigorous discussion Emmerink et al. (1993a). Some conclusions of that study are given in Table 1 and show the parameters upon which the benefits of a motorist information system depend.

[3]The terminology *final equilibrium state* in Mahmassani and Jayakrishnan (1988) indicates a situation in which no driver has an incentive to switch alternative. The *final equilibrium state* is not unique as shown in Mahmassani and Chang (1987).

Table 1 Issues affecting the benefits of motorist information systems.

- type of motorist information system
- type and quality of the supplied information
- current traffic flows in the road network
- structure of the road network
- behavioural responses of road users
- frequency of occurrence of non-recurrent congestion
- level of market penetration

Source: Emmerink et al. (1993a)

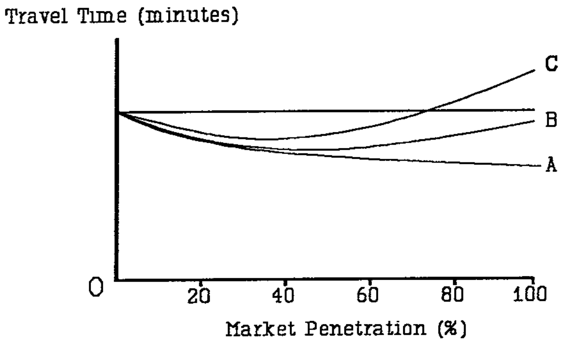
The current traffic flows in the road network (see Table 1) determine whether concentration will take place if we assume the user equilibrium - Wardrop's first principle (Wardrop, 1952) - at full market penetration (see Emmerink et al., 1993a). Then, the current (or initial) situation in the road network is of crucial importance for the success of any motorist information system. This argument has been supported by Mahmassani and Jayakrishnan (1991) and Mahmassani and Chen (1991) who showed that the usefulness of information provision is strongly dependent on the initial conditions in the network.

The behavioural responses of the road users (see Table 1) determine whether overreaction will occur. In the literature, it has been envisaged that so-called *myopic* switching behaviour induces overreaction, i.e. drivers always selecting the best path in terms of travel time (Mahmassani and Chen, 1991). In these circumstances, a threshold (bound), implying that drivers will switch alternative only if the improvement in expected travel time exceeds the threshold, may enhance the network wide performance.

The issue of overreaction has been mentioned in the literature, and research addressing this point has been carried out on a small scale. However, research assessing the impact of concentration, directly related to the current traffic flows in the road network (see Table 1), has - as far as we know - not been conducted. In a way, this is surprising, since all these systems could potentially suffer from concentration; it is conceivable that motorist information systems decrease the initially existing heterogeneity amongst drivers, which is the source for concentration. The fact that concentration has been given sparse attention is in our view caused by the difficulties associated with such research. However, it is an important issue and should be addressed in future research.

Figure 1 - ceteris paribus - depicts the travel time as a function of market penetration for three cases. The curves in Figure 1 are well-behaved (continuous and differentiable) and have only one local (and therefore global) optimum. We do, however, not rule out ill-behaved functions, for instance with multiple local optima, but there is no rationale for such a shape.

Figure 1 Network performance as a function of market penetration for three cases.



In Figure 1, case A depicts a situation in which the average network wide travel time is minimised at full market penetration, while in case B the optimal level of market penetration is below 100 per cent. In both case A and B, at full market penetration the network is still better off with information. Case C depicts a situation in which this is no longer true due to overreaction.

The impact of motorist information systems on the network wide performance is an aggregate of the effects on equipped and non-equipped drivers. The next section deals with these two groups, respectively.

3 EXTERNALITIES

In this section, the externalities involved in the implementation of a motorist information system are discussed. Section 3.1 discusses the externality to the non-equipped drivers, while Section 3.2 deals with the equipped drivers.

3.1 Positive externality to non-equipped drivers

As we have seen in Section 2, a motorist information system could produce significant benefits, the size depending on the characteristics of the information system and road network under consideration. Assuming that equipped drivers will always be better off, these benefits are caused by one of the following two reasons:

- Equipped road users are better off and non-equipped road users are worse off. The gains to the equipped road users offset the losses to the non-equipped ones.

- All road users are better off.

The first option has been mentioned by Bonsall and Parry (1990). They argued that if equipped drivers change their behaviour from day to day in the light of the information available, the non-equipped drivers could be faced with a less predictable system, thus reducing their ability to achieve user optimal routes. In this way, non-equipped drivers might be worse off due to the volatile behaviour of equipped drivers. We, however, do not regard this as being a plausible option; particularly from a theoretical perspective, this argument can be questioned. In our opinion, information provided to drivers will spread the congestion more evenly throughout the network, or more precisely, information will direct the traffic flows towards the user equilibrium (Emmerink et al., 1993a) and therefore, travel times on alternative routes connecting an origin and a destination will slowly converge. Hence, the non-equipped road users are faced with a network in which the traffic flows are more balanced and as a consequence, the positive externality arises. This externality implies that *the higher the level of market penetration of the motorist information system, the lower the travel times to the non-equipped road users.* The exact size of this externality cannot be inferred from the literature, and will, like the network wide benefits, be strongly dependent on the kind of information, the network under consideration etc. (see Table 1). Besides the theoretical arguments in favour of the existence of this externality, Emmerink et al. (1993b) and Mahmassani and associates (summarised in Mahmassani and Herman (1990)) provided some (limited) evidence obtained by simulation experiments.

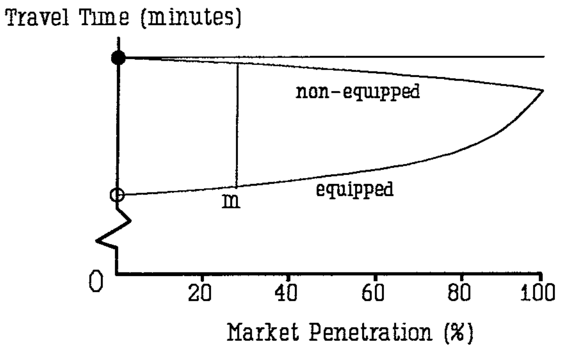
The existence of this externality raises an interesting question about the pricing policy of motorist information systems: Should these systems be partly subsidised because of these beneficial effects to non-equipped drivers? An answer to this question is not straightforward, since besides this positive externality, the introduction of motorist information systems induces another externality, which is addressed in the next section.

3.2 Negative and/or positive externality to equipped drivers

After having discussed the beneficial effects of motorist information systems on the network wide performance in Section 2 and the externalities to non-equipped road users in Section 3.1, it is now time to turn to the effects to the road users that are equipped with the system. In fact, they are causing the changes in the traffic flows. We assume that - ceteris paribus - only the level of market penetration determines the travel times in the network.

For the network under consideration it is assumed that the (hypothetical) relation between travel time and level of market penetration as depicted in Figure 2 holds.[4]

Figure 2 Travel time as a function of market penetration.



With this figure, the *information benefits to equipped drivers* curve can be derived. Given a certain level of market penetration m, the benefits to the equipped drivers are equal to the distance between the curve for non-equipped and equipped drivers, since these are the travel time savings obtained from buying the motorist information system. Dependent on the shape of the travel time curves for equipped and non-equipped drivers, the *information benefits to equipped drivers* curve will look like Figure 3 (having a peak at market penetration level A) or Figure 4 (monotonically decreasing). The simulation experiments in Emmerink et al. (1993b) suggested Figure 4, but due to limited empirical evidence, this does not rule out Figure 3.

[4]Empirical evidence on the exact shape of these two travel time curves is not readily available, though many pilot studies are currently being carried out. The curves in Figure 2 are sketches. However, obviously the non-equipped curve lies above the equipped curve, and on theoretical grounds these two curves cross at full market penetration (Emmerink et al., 1993a).

Figure 3 Information benefits to equipped drivers. Case 1.

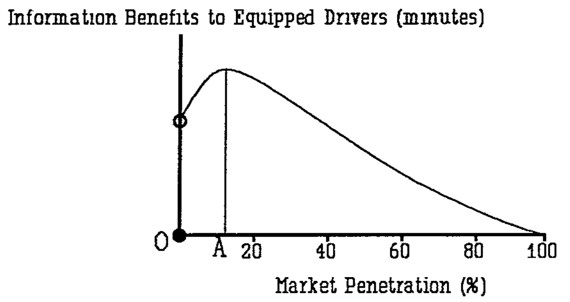
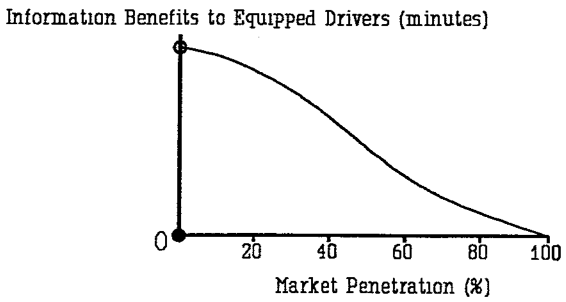


Figure 4 Information benefits to equipped drivers. Case 2.



The *information benefits to equipped drivers* curve is discontinuous at zero market penetration, since there will be clear travel time savings to the first driver to be equipped. Furthermore, we have assumed that the *information benefits to equipped drivers* is continuous at full market penetration, implying that the last road user to be equipped will not obtain any additional gains from the information system. Here, the underlying assumption is that at full market penetration the traffic flows in the road network will represent the user equilibrium. While justifiable on theoretical grounds for recurrent congestion, this assumption becomes doubtful when we are dealing with a network with non-recurrent congestion. Section 5 will address this aspect in greater detail.

In Figure 3, between O and A, the benefits to equipped drivers are increasing, implying that drivers already being equipped will benefit if an additional driver is buying the system. In other terms, between O and A there is a positive externality for the already equipped drivers. To our knowledge, there are not many economic goods possessing this property. One of the few we can think of are telecommunication networks, for instance the French videotex effort Minitel. Other examples are the currently quickly growing Internet-based information services. In these systems, the *willingness-to-pay* is strongly dependent on the number of subscribers (Allen, 1988), in terms of this paper the level of market penetration. From the government's point of view, the positive externality has the interesting implication that the buyer of the motorist information system should be subsidised. According to the economic literature, the subsidy should be equal to the total benefits generated for the already equipped drivers. Then road users are paying the *true* price for the information system; the externality is internalised. Moreover, recalling the arguments given in the previous section, the size of the benefits to the non-equipped drivers caused by the marginal equipped driver should also be added to the subsidy.

In Figure 3 between A and 100 per cent, and along the whole x-axis of Figure 4, the *information benefits to equipped drivers* curve is downward sloping. This implies that a marginal equipped driver adversely affects the already equipped drivers, but since the information benefits are still positive, it is beneficial in terms of travel time for the marginal driver himself to buy the equipment. Thus, in the downward sloping part, there exist a negative externality to the already equipped drivers. This is an argument for levying a tax on these systems in this part of the curve. However, we should bear in mind that the positive effects to the non-equipped drivers might outweigh the negative effects to the already equipped road users, implying that the subsidising argument is a stronger one than the taxing one. Then we are in the odd situation that we are actually subsidising a good that adversely affects the people that already possess the good!

An additional complexity arises when we consider the real-world implementation of a motorist information system. If a central computer collects the information via the computer unit in the vehicles of the equipped drivers (two-way communication links), then it is likely that the quality of the information shows a dependency on the level of market penetration as depicted in Figure 5.[5] In Figure 5, the quality of the information is low (the information will be strongly historically based) at small levels of market penetration, rendering the information system unreliable under these circumstances. Clearly, this is due to the fact that the network is not yet fully covered by the equipped drivers. As the level of market penetration increases, the quality of the information improves quickly.[6] Therefore, it seems a prerequisite for motorist information systems implemented in this way, that the initial level of market penetration - i.e. the level of market penetration directly after implementation - exceeds a certain (*critical*) threshold value in order to be able to provide a reliable information service. To achieve this *critical* level, the company/government selling the equipment might consider subsidising the system during the product's take-off phase.

However, if the information is collected via loop detectors in the road, the quality of the information is independent of the level of market penetration. However, due to the inaccuracy of these detectors, the information will be relatively unreliable compared to a system that collects information via equipped drivers, see Figure 6.

---

[5]For instance, the primary source of real-time traffic information in the ADVANCE program are the vehicles themselves (Boyce et al., 1991).

[6]In Figure 5 we have assumed that eventually (as the level of market penetration increases), the information provided to the drivers is a perfect representation of the actual situation in the network. However, in real-world implementations it is questionable whether this quality level will be obtained. Sources for error in the traffic information collection and distribution process are the level of precision and reliability of the traffic measurement technique, the reliability of the broadcasting channel, the delay in the transmission of the information etc. (Watling and Van Vuren, 1993).

Figure 5 Relationship between quality of information and level of market penetration. Information collected via equipped drivers.

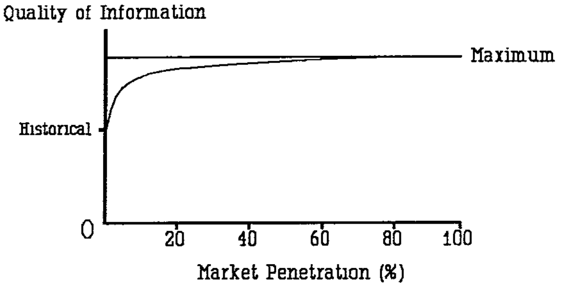
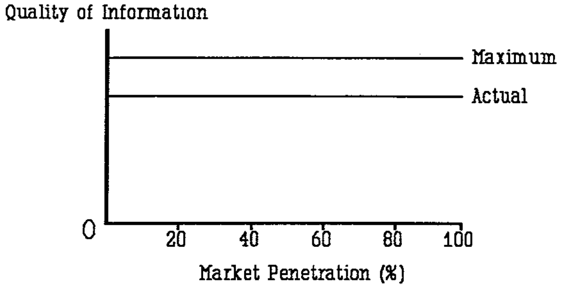


Figure 6 Relationship between quality of information and level of market penetration. Information collected via loop detectors in the road.



To summarise, at most levels of market penetration a motorist information system is most likely to generate a *positive* externality for non-equipped drivers and a *negative* externality for already equipped ones. However, in terms of travel time the equipped road users will still outperform the non-equipped ones. Hence, a motorist information system as defined in Section 1 enhances the efficiency of the road network, but possesses the awkward property that already equipped road users are adversely affected by marginal equipped drivers. The next section is devoted to the long run consequences of such an efficiency improvement.

4 ECONOMIC ADJUSTMENT

The introduction of a new technology disturbs the equilibrium (if existing) in a road network. In Section 4.1 this issue is addressed. Then, Section 4.2 discusses the issues involved in the market penetration of motorist information systems.

4.1 Long run traffic generation

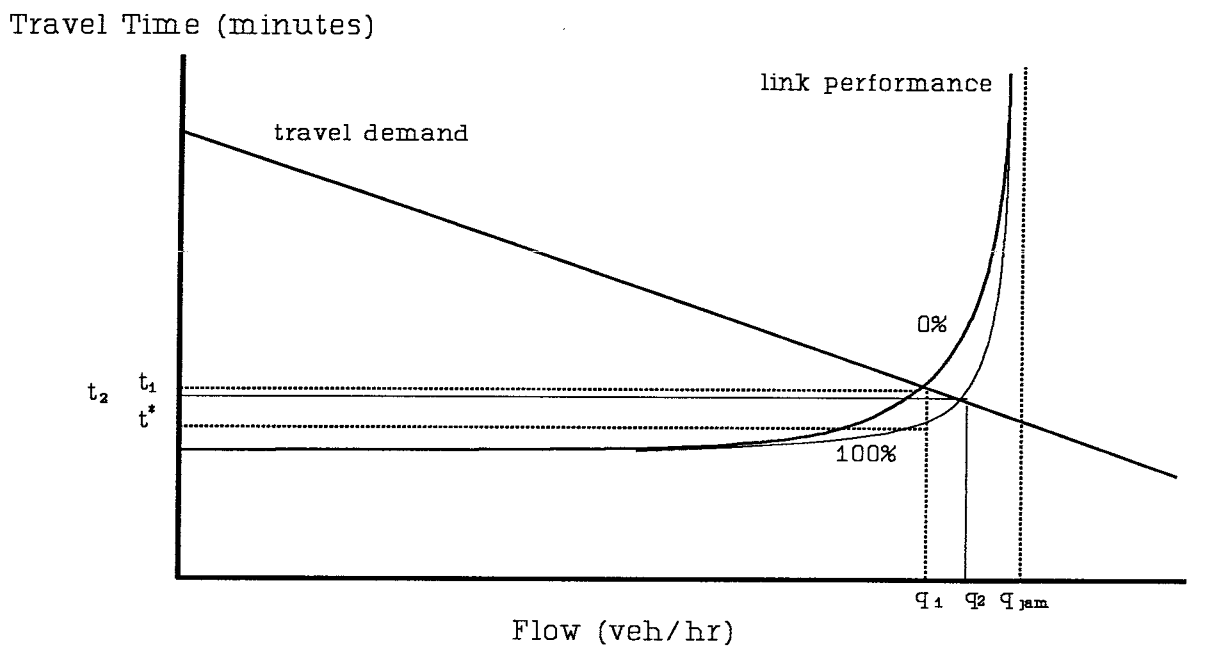
It is well known from economic principles that an efficiency improvement on the supply side of a production process could result in more demand in the long run, due to a decrease in price. A similar kind of argument holds for motorist information systems, as these systems are designed to increase the efficiency of road transport networks, and hence decrease the cost (price) of mobility. In the argument that follows we make three assumptions:

- full market penetration (later on in this section this assumption will be relaxed),

- travel time at full market penetration is below travel time at no market penetration (case A or B in Figure 1),
- the analysis is static in nature: the adjustment process leading to the new economic equilibrium is not investigated.

Implementing a motorist information system leads to an improvement of the efficiency of the network which translates into a decrease in road user's travel time to t^* (Figure 7). Thus, an equilibrium situation - before adopting the motorist information system - is turned into a disequilibrium: given the decrease in travel time, more people would like to travel.

Figure 7 Traffic generation at full market penetration.



The economic equilibrium at full market penetration is given by the intersection of the *travel demand* curve and the *link performance function at full market penetration (100%)*, see Figure 7. Owing to the implementation of the new technology, the equilibrium traffic flow has shifted from q_1 to q_2, generating an extra amount of traffic equal to q_2-q_1. Although the flow in the road network increases, the corresponding equilibrium travel time is *below* the equilibrium travel time without motorist information system (t_2 compared to t_1), due to the downward sloping travel demand curve.

In the analysis above, the value of q_{jam} is unaffected by the motorist information system. Although we acknowledge that particularly a sophisticated signal control system might increase q_{jam}, we think that information provision as defined in Section 1 does not accomplish this by its own.

We think that the network wide benefits under the implementation of a motorist information system are dependent on the level of flow in the network as depicted in Figure 8. This figure indicates that the benefits owing to motorist information systems are negligible at low levels of congestion; only beyond a certain level of congestion, network wide benefits start to accrue. At low levels of flow - given that the drivers are familiar with the road network - the information provided to the drivers is of no use. On the other hand, at jam flow, information is of no use either, since the flows in the road network are at a maximum; there is no room for further efficiency improvement through information.

Figure 8 Network wide benefits of motorist information system as a function of the level of congestion.

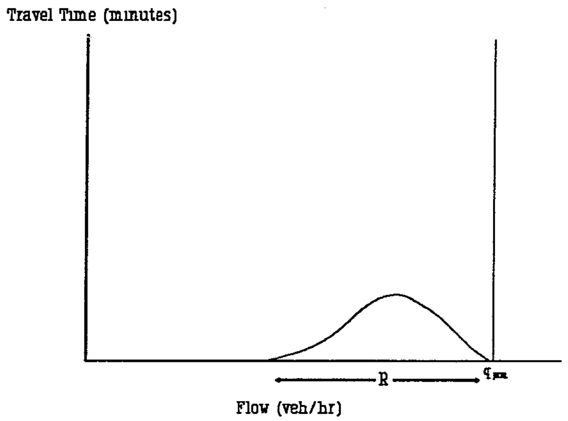
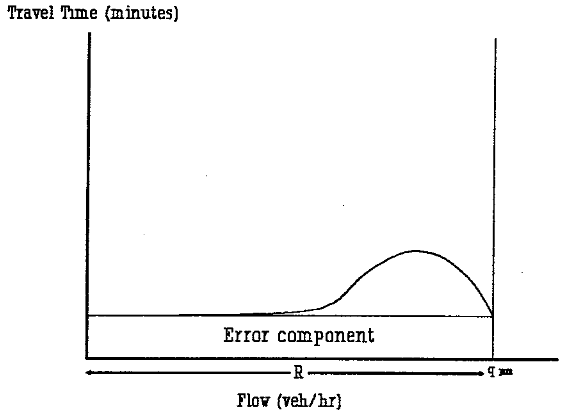


Figure 9 Network wide benefits of motorist information system as a function of the level of congestion.



Given the traffic generating abilities as the travel time savings owing to the motorist information system are large, it follows that new traffic is generated only in certain flow ranges, depicted with R in Figure 8.

Figure 9 shows another possible shape of the benefits curve. This curve is based on the assumption that in general many drivers possess little or no reliable information concerning travel and route alternatives and may be uninformed of road conditions on any specific day. Such unawareness could lead to misperceptions on the part of the drivers as to the relative desirability of alternative travel decisions (Ben-Akiva et al., 1991). This unawareness is depicted in Figure 9 as the *error component*. Further, Figure 9 assumes that the motorist information system completely takes away the error component. If this figure is more conform to reality than Figure 8, there is clearly more scope for motorist information systems; in these circumstances there will be travel time savings, and thus traffic generation at low levels of congestion as well.

The analysis above gets more complicated if the level of market penetration is somewhere in between 0 and 100 per cent, say m. In this situation we assume that relation [1] holds[7].

$$T(with\ information) \leq T(average) \leq T(without\ information) \quad [1]$$

Here, the symbol *T(with information)* denotes the travel time for drivers with information, *T(without information)* the travel time without information, and *T(average)* the travel time averaged over all drivers. If we use the average travel time as an approximation of the experienced travel time of the *average* road user, then a *link performance function at m per cent market penetration*, similar to Figure 7 can be drawn. This curve then determines the equilibrium traffic flows at m per cent market penetration. However, we should bear in mind that this solution is an approximation; in the road network there is no driver experiencing travel time *T(average)*. An exact and at the same time more general model is given in equations [2] to [7]. This model expands the analysis to different modes of travel.

$$q_{with} = q_{with}(t_{with}\ ,\ t_{without} - t_{with}\ ,\ c_{with}) \quad [2]$$

$$q_{without} = q_{without}(t_{without}\ ,\ c_{without}) \quad [3]$$

$$t_{with} = t_{with}(q_{with}\ ,\ q_{with} + q_{without}) \quad [4]$$

$$t_{without} = t_{without}(q_{without}\ ,\ q_{with} + q_{without}) \quad [5]$$

$$q_{with} + q_{without} + q_{other\ mode} + q_{suppressed} = q \quad [6]$$

$$q_{with} + q_{without} \leq q_{jam} \quad [7]$$

The specification of these equations is beyond the scope of this paper. We will restrict ourselves to verbally describing them. The endogenous variables in equations [2] to [7] are q_{with}, $q_{without}$, $q_{other\ mode}$, t_{with} and $t_{without}$. Here, q denotes flow and t travel time. The subscripts *with* and *without* refer to the equipped and non-equipped drivers, while the subscript *other mode* refers to people not choosing the private car as transport mode and *suppressed* represents latent travel demand. The exogenous variables

[7]The plausibility of this assumption was discussed in Section 1.

are c_{with}, $c_{without}$, q and q_{jam}. Here, c refers to the costs associated with using the private car, q is a fixed total (maximum) travel demand value, and q_{jam} is the maximum possible flow in the road network.

Equation [7] imposes a physical limitation on the mobility by private car. Equation [6] distributes travel demand between the two competing modes (i.e. private car and all other modes) and not travelling at all. This could for instance be modelled using a logit model (Ben-Akiva and Lerman, 1985). However, the attractiveness of travelling by private car is partly determined by the level of market penetration, and therefore, the logit model should be applied simultaneously with the other equations in order to find a *general equilibrium* solution.

Equations [4] and [5] are the mathematical representation of Figure 2 and describe the attractiveness of the motorist information system; they form the supply side of the model. Finally, equations [2] and [3] represent the demand side of our simple model for travel demand.

In fact, this model describes the simplest travel demand situation with a motorist information system, i.e. three different ways of travelling: with information system, without information system and using another mode. Nevertheless, it illuminates the complexity of such a system, due to all the interactions and externalities. Bearing in mind that the exact size (and even some of the directions) of the interactions are unknown or uncertain, assessing the impact of motorist information systems is an extremely difficult task.

The discussion above is based on a demand-supply analysis. This is just one way of looking at travel demand. A different approach, applicable in large congested urban areas has been proposed by Thomson (1977). He argued that the attractiveness of alternative travel modes should be equal in equilibrium:

> "... if the decision to use public or private transport is left to the free choice of the individual commuter, an equilibrium will be reached in which the attractiveness of the two systems is about equal, because if one is faster, cheaper, and more agreeable than the other, there will be a shift of passengers to it, rendering it more crowded while the other becomes less so, until a position is reached where no one on either system thinks there is any advantage in changing to the other." (p. 165)

Applying this theory to our situation leads to the following reasoning. Due to the implementation of the motorist information system, the private car is the more attractive travel mode. Therefore, some people will shift from public transport to the private car. This process will continue until an equilibrium situation settles down in which both alternatives are equally attractive.

As argued above, the traffic generating impact of motorist information systems is - amongst other things - dependent on the level of market penetration. Issues affecting the penetration of these new technologies are discussed in the next section.

4.2 Market penetration

The previous section dealt with the traffic generating features of motorist information systems. It was argued that as these systems are designed to improve the efficiency of road networks, travelling by private car becomes more attractive, and more people will use this mode. In this section, the market potential of these systems is modelled. The analysis that follows is a short run one; total travel demand is fixed, and only one travel mode - the private car - is addressed. In addition, we will assume that the market penetration of these systems is solely determined by their potential to generate travel time savings. Other beneficial factors, such as a decrease in stress or anxiety, are not considered.

The benefits accruing to a marginal driver being equipped with a motorist information system - the *information benefits to equipped drivers* curve - are depicted in Figure 4. The benefits in these figures are expressed in terms of time. In order to analyse the market potential of these systems, time has to be converted into monetary units. We can do so by using a *value-of-time* curve. Two hypothetical *value-of-time* curves are shown in Figure 10, where the individuals are ordered according to decreasing *value-of-time*.

Figure 10 *Value-of-time* as a function of market penetration. Two cases.

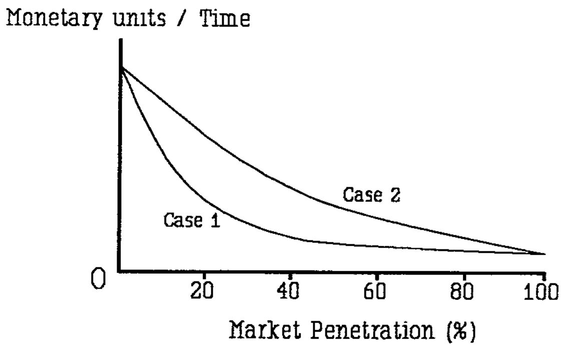
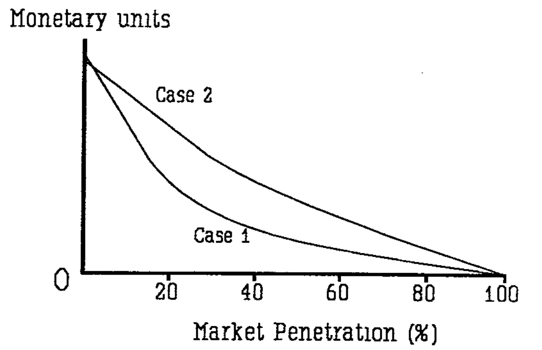


Figure 11 *Willingness-to-pay* as a function of market penetration. Two cases.



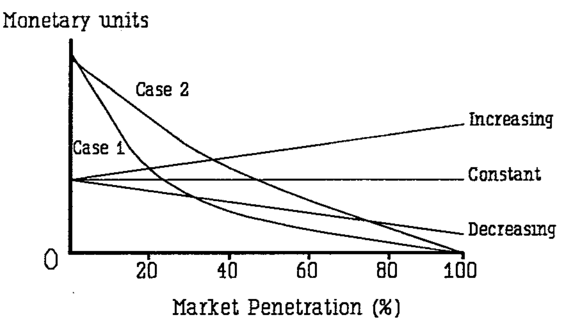
Given that road users with a high *value-of-time* are most likely to buy the motorist information system, we can *vertically multiply* Figure 4 and Figure 10 to obtain Figure 11. Then, Figure 11 depicts the *willingness-to-pay* as a function of the level of market penetration. The *willingness-to-pay* curve touches the x-axis at full market penetration, since the *information benefits to equipped drivers* are zero at this level.

Once the *willingness-to-pay* curve is known, the level of market penetration that will establish is completely determined by the cost structure of the motorist information system under consideration. Three different structures can be considered:

- constant costs to scale,
- decreasing costs to scale,
- increasing costs to scale.

Figure 12 shows a hypothetical situation in which the cost structures are assumed to be linear.[8] Given the initially high infrastructure investment needed to implement motorist information systems, we think that the decreasing costs to scale curve is the most likely one. The level of market penetration where the *willingness-to-pay* and *cost* curve intersect determines the market potential of the technology.

Figure 12 Market potential of motorist information system for two *willingness-to-pay* curves.



An exact figure for the market potential of these technologies is clearly dependent on the precise shape of the curves. In this section we have only attempted to provide a framework to analyse the market potential of these systems, which can be applied once the precise shape of these curves is known.

[8]We have assumed that the *cost* curve is below the *willingness-to-pay* curve at zero market penetration. If not, there is no market potential for these systems at all.

5 THE CASE OF NON-RECURRENT CONGESTION

The discussion in the previous sections was focused on the case of recurrent congestion. In this section we will investigate the case of non-recurrent congestion. Non-recurrent congestion is congestion caused by incidents; one could for instance think of bad weather (fog, heavy rain, snow, etc.) or traffic accidents. These incidents suddenly decrease the capacity of a certain part of the road network by a significant amount, directly leading to congestion. According to Lindley (1986, 1987, 1989), non-recurrent congestion accounts for 60 per cent of total congestion delay. However, this figure should not be misinterpreted, since non-recurrent congestion delays would not be nearly as large if road networks were not already overloaded due to the recurrent congestion.

Another argument for extending the scope of the analysis to the non-recurrent case is the observation that particularly in these circumstances the expectations of motorist information systems are high. They are said to be able to solve traffic jams in situations of non-recurrent congestion quicker (Dehoux and Toint, 1991).

Taking non-recurrent congestion into consideration, the assumption made in Section 3.2 regarding equal travel times for equipped and non-equipped drivers at market penetration levels close to 100 per cent becomes doubtful. We will illustrate this with the following hypothetical situation.

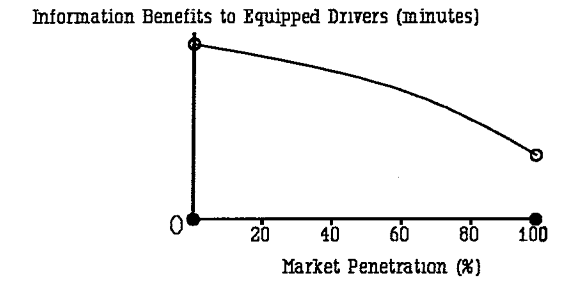
Suppose that origin O and destination D are connected by two different routes, $Route_1$ and $Route_2$. With recurrent congestion and 100 per cent of market penetration we may assume that the user equilibrium condition holds, i.e. the travel times on $Route_1$ and $Route_2$ are equal.[9] Now, suppose that at time t_1 an incident occurs on $Route_2$, thereby making $Route_1$ the more attractive one. Then, at full market penetration of the information technology, all drivers departing after t_1 will choose $Route_1$ to travel to destination D until the user equilibrium condition is restored, say at time t_2.

Then, two important observations can be made in case market penetration is below 100 per cent:

- Non-equipped drivers departing between t_1 and t_2 and deciding to travel via $Route_2$ will clearly experience a longer travel time than if $Route_1$ had been chosen. This implies that the *information benefits to equipped drivers* curve is discontinuous at 100 per cent market penetration. As a consequence, the last road user buying the equipment will still have some benefits, as depicted in Figure 13.
- The higher the level of market penetration, the quicker the user equilibrium conditions will be restored in the road network.

[9] This is obviously not true if one of the two routes is unused.

Figure 13 Information benefits to equipped drivers. The case of non-recurrent congestion.



In particular, the first observation has important consequences for the economic viability of motorist information systems. The fact that the *information benefits to equipped drivers* curve is discontinuous at full market penetration clearly increases the market potential of these systems; even at high levels of market penetration there are still substantial benefits to not yet equipped drivers. As a consequence, the *willingness-to-pay* (see Figure 11) is not zero at full market penetration, leading to a larger market potential.

Recently, Al-Deek and Kanafani (1993) expanded the argument given above with a simple deterministic queueing model for a two-route network, and found similar results. The equipped drivers benefit during the time-span leading to the user equilibrium, while at user equilibrium there are no additional benefits to equipped drivers.

In the past, research assessing the impacts of motorist information systems was strongly focused on recurrent congestion, the reason being that modelling recurrent congestion is more straightforward. In future research, attention should shift to the non-recurrent case since:

- The traffic situation in real road networks is non-recurrent in nature. The road situation differs from day-to-day.
- Motorist information systems are particularly designed for non-recurrent congestion. They are able to broadcast the day-to-day fluctuations on the roads.

6 Motorist information systems as a tool for achieving government's objectives

If the purpose of any motorist information system is to minimise average network travel time, Figure 1 depicts which level of market penetration should be decided upon, not taking the traffic generating abilities into account. However, besides minimising average travel time, there are other important issues that need to be considered and might affect the *optimum* level of market penetration:[10]

- The cost structure of a motorist information system might affect the level of market penetration. If the initial (fixed) costs of the system are high, it might - from a costing point of view - be viable only at relatively high levels of market penetration.

- An important cost component of road traffic is pollution and noise. These costs are not necessarily minimised when the average network travel time is at a minimum.

- An often underestimated cost component of road traffic are the safety costs. These in fact are a more than substantial part of the total costs of transport, the actual amount depending on the technique used to evaluate the value-of-life (Jones-Lee, 1990). These costs are generally not minimised when the average network travel time is at a minimum.

- In addition, Rumar (1990) claimed that motorist information systems might interfere with the driver's primary task of driving and therefore have a potential of decreasing safety on the roads. This is obviously opposite to what these systems would like to accomplish (Stergiou and Stathopoulos, 1989).

Furthermore, the level of market penetration that will be realised might well be dependent on the policy of the government with respect to road-pricing. It is well known that these two technologies (road-pricing and motorist information systems) need a similar kind of road infrastructure. Then, if it is the government's policy to adopt road-pricing, there might be economies of scale, rendering the additional costs of implementing a motorist information system small. This could lead to high levels of market penetration.[11]

All the factors mentioned above add to the complexity of determining the *optimal* level of market penetration - if existing - from a social welfare point of view. Recalling the other issues affecting the benefits of these systems as mentioned in Section 2, it is clear that every implementation technique should be largely site and system dependent.

---

[10]Due to the uncertainty and unreliability of drivers' responses towards these new technologies it cannot be taken for granted that such an *optimum* level exists. A better term would be a *satisfactory* level.

[11]Here, we are solely pointing at economies of scale regarding the cost structure of the simultaneous implementation of these technologies. De Palma and Lindsey (1992) addressed the economic consequences of a combined implementation of these technologies.

Although the outcomes of implementing these technologies are still highly uncertain, the government should in our view pursue the analysis of the potential of these systems. In particular, it is worthwhile paying more attention to the simultaneous implementation and application of congestion-pricing and motorist information systems. As argued in Bonsall et al. (1991), it is unlikely that road users can be diverted from user optimal routes in order to obtain a system optimum. To accomplish this, a motorist information system should be accompanied by some pricing mechanism, thereby making a strong case for the joint implementation of these two technologies. The contribution by De Palma and Lindsey (1992) is - as far as we know - the only study addressing this issue. However, we should be careful with implementing congestion-pricing. As pointed out by Evans (1992), congestion-pricing creates perverse incentives for governments to partly exploit their monopoly power in road provision.

We would like to close this discussion by stressing that motorist information systems in themselves do not tackle the congestion externality. They provide a so-called *second-best* solution, i.e. they do not cure the congestion problem at its source. However, when these systems are able to diminish the general level of congestion in the network, the monetary value of the externality decreases in size. Therefore, implicitly motorist information systems help in decreasing the impact of the congestion externality.

7 CONCLUDING COMMENTS

Past research assessing the benefits of implementing motorist information systems show large variations. It seems that the benefits are strongly dependent on the kind of system, the behavioural responses of the road users, the particular network under consideration, the level of market penetration etc. Especially, the phenomena of overreaction and concentration might play an important role in adversely affecting the network wide performance.

The discussion in this paper was based on the assumption that we are dealing with a properly working motorist information system, i.e. a motorist information system that reduces the travel time for the equipped drivers, and in addition, makes them better off than the non-equipped ones. Under this assumption, and the assumption of Wardrop's user equilibrium at full market penetration, it can easily be derived that the so-called *information benefits to equipped drivers* are a decreasing function of the level of market penetration. Moreover, they are zero at full market penetration. Therefore, a marginal equipped driver adversely affects the already equipped ones. However, this marginal driver will have a positive influence on the non-equipped drivers. We can conclude that a motorist information system is an economic good that causes both positive and negative externalities.

Due to the efficiency improvement of the road network, a motorist information system will generate more traffic on the roads. The flow in the road network increases, but the new equilibrium travel time is below the one before implementation. The market potential of these new technologies is strongly dependent on the *value-of-time* curve, the *information benefits to equipped drivers* curve and the *cost* structure of motorist information system. However, the market potential increases when we are dealing with highly volatile road networks, i.e. networks with non-recurrent congestion.

In this paper we did not address the other potential implications of motorist information systems, such as a decrease in stress and anxiety, decrease in pollution, an increase in safety. Nevertheless, these factors have an important role to play in the assessment of these technologies.

A motorist information system is only one of the available tools to tackle the congestion problem. Applied on its own, its impact might be small in practice. However, combined with a congestion-pricing strategy, transport planners have a strong tool to influence traffic flows in road networks.

8 REFERENCES

Al-Deek, H. and A. Kanafani (1993) Modeling the benefits of advanced traveler information systems in corridors with incidents, *Transportation Research*, **1C** (4) 303-324.

Allen, D. (1988) New telecommunications services: network externalities and critical mass, *Telecommunications Policy*, **12** (3) 257-271.

Allen, P.A. (1993) Driver response to parking guidance and information systems, *Traffic Engineering and Control*, **34** (6) 302-307.

Arnott, R., A. de Palma and R. Lindsey (1991) Does providing information to drivers reduce traffic congestion?, *Transportation Research*, **25A** (5) 309-318.

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

Ben-Akiva, M., A. de Palma and I. Kaysi (1991) Dynamic network models and driver information systems, *Transportation Research*, **25A** (5) 251-266.

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

Bonsall, P.W. and T. Parry (1990) Drivers' requirements for route guidance, In *Proceedings of 3rd International Conference on Road Traffic Control*, IEE, London.

Bonsall, P.W., L. Pickup, and A. Stathopoulos (1991) Measuring behavioural responses to road transport informatics, In *Advanced Telematics in Road Transport*, 1457-1487, Elsevier, Amsterdam.

Boyce, D.E., A.M. Kirson and J.L. Schofer (1991) Design and implementation of ADVANCE: The Illinois dynamic navigation and route guidance demonstration program, ADVANCE working paper series, 5 (August).

Caplice, C. and H.S. Mahmassani (1992) Aspects of commuting behavior: Preferred arrival time, use of information and switching propensity, *Transportation Research*, **26A** (5) 409-418.

Conquest, L., J. Spyridakis, M. Haselkorn and W. Barfield (1993) The effect of motorist information on commuter behavior: classification of drivers into commuter groups, *Transportation Research*, **1C** (2) 183-201.

Dehoux, Ph. and Ph.L. Toint (1991) Some comments on dynamic traffic modelling in the presence of advanced driver information systems, In *Advanced Telematics in Road Transport*, 964-980, Elsevier, Amsterdam.

De Palma, A. (1992) A game-theoretic approach to the analysis of simple congested networks, *Transportation Economics*, **82** (2) 494-500.

De Palma, A. and R. Lindsey (1992) The potential benefits of a combined route guidance and road pricing system: An economic analysis, internal working paper.

Emmerink, R.H.M., K.W. Axhausen, P. Nijkamp and P. Rietveld (1993a) Concentration, overreaction, market penetration and Wardrop's principles in an ATIS environment, Tinbergen Institute Research Series Paper, forthcoming.

Emmerink, R.H.M., K.W. Axhausen, P. Nijkamp and P. Rietveld (1993b) Effects of information in road transport networks with recurrent congestion, Tinbergen Institute Research Series Paper, forthcoming.

Evans, A.W. (1992) Road congestion pricing: when is it a good policy?, *Journal of Transport Economics and Policy*, **26** (3) 213-243.

Heiner, R.A. (1983) The origin of predictable behaviour, *American Economic Review*, **73** (4) 560-595.

Hounsell, N., M. McDonald and L. Breheret (1991) Models and strategies for dynamic route guidance, In *Advanced Telematics in Road Transport*, 89-98, Elsevier, Amsterdam.

Jeffery, D.J. (1986) Route guidance and in-vehicle information systems, In P.W. Bonsall and M. Bell (Eds.), *Information Technology Applications in Transport*, 319-351, VNU Science Press, Utrecht.

Jones-Lee, M.W. (1990) The value of transport safety, *Oxford Review of Economic Policy*, **6** (2) 39-60.

Kanafani, A. and H. Al-Deek (1991) A simple model for route guidance benefits, *Transportation Research*, **25B** (4) 191-201.

King, G.F. (1986) Driver performance in highway navigation tasks, *Transportation Research Record*, **1093**, 1-11.

King, G.F. and T.M. Mast (1987) Excess travel: causes, extent and consequences, *Transportation Research Record*, **1111**, 126-134.

Lindley, J.A. (1986) Quantification of urban freeway congestion and analysis of remedial measures, Federal Highway Administration RD-87/052, Washington, D.C.

Lindley, J.A. (1987) Urban freeway congestion: quantification of the problem and effectiveness of potential solutions, *ITE Journal*, **57** (1) 27-32.

Lindley, J.A. (1989) Urban freeway congestion problems and solutions: an update, *ITE Journal*, **59** (12) 21-23.

Mahmassani, H.S. and G.-L. Chang (1987) On boundedly rational user equilibrium in transportation systems, *Transportation Science*, **21** (2) 89-99.

Mahmassani, H.S. and P.S.-T. Chen (1991) Comparative assessment of origin-based and en route real-time information under alternative user behavior rules, *Transportation Research Record*, **1306** 69-81.

Mahmassani, H.S. and R. Herman (1990) Interactive experiments for the study of tripmaker behaviour dynamics in congested commuting systems, In P.M. Jones (Ed.), *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*, 272-298, Avebury, Aldershot.

Mahmassani, H.S. and R. Jayakrishnan (1988) Dynamic analysis of lane closure strategies, *Journal of Transportation Engineering*, **114** (4) 476-496.

Mahmassani, H.S. and R. Jayakrishnan, (1991) System performance and user response under real-time information in a congested traffic corridor, *Transportation Research*, **25A** (5) 293-308.

Rakha, H., M. Van Aerde, E.R. Case and A. Ugge (1989) Evaluating the benefits and interactions of route guidance and traffic control strategies using simulation, In *Proceedings of Vehicle Navigation and Information Systems (VNIS) Conference*, 296-303.

Rumar, K. (1990) Driver requirements and road traffic informatics, *Transportation*, **17** (3) 215-229.

Spyridakis, J., W. Barfield, L. Conquest, M. Haselkorn and C. Isakson (1991) Surveying commuter behavior: designing motorist information systems, *Transportation Research*, **25A** (1) 17-30.

Stergiou, B. and A. Stathopoulos (1989) Traffic models and Road Transport Informatics (RTI) systems, *Traffic Engineering and Control*, **30** (12) 580-586.

Thomson, J.M. (1977) *Great Cities and Their Traffic*, Gollancz, London.

Tsuji, H., R. Takahashi, H. Kawashima and Y. Yamamoto (1985) A stochastic approach for estimating the effectiveness of a route guidance system and its related parameters, *Transportation Science*, **19** (4) 333-351.

Van Berkum, E.C. and P.H.J. Van Der Mede (1993) *The Impact of Traffic Information*, PhD thesis, Universiteitsdrukkerij, Delft.

Wardrop, J. (1952) Some theoretical aspects of road traffic research, In *Proceedings of the Institute of Civil Engineers*, **1** (Part II) 325-378.

Watling, D. and T. Van Vuren (1993) The modelling of dynamic route guidance systems, *Transportation Research*, **1C** (2) 159-182.