Transport Reviews

ISSN: 0144-1647 (Print) 1464-5327 (Online) Journal homepage: http://www.tandfonline.com/loi/ttrv20

The economics of motorist information systems revisited

Richard H. M. Emmerink , Peter Nijkamp , Piet Rietveld & Kay W. Axhausen

To cite this article: Richard H. M. Emmerink , Peter Nijkamp , Piet Rietveld & Kay W. Axhausen (1994) The economics of motorist information systems revisited, Transport Reviews, 14:4, 363-388, DOI: 10.1080/01441649408716890

To link to this article: https://doi.org/10.1080/01441649408716890

Published online: 13 Mar 2007.

TRANSPORT REVIEWS, 1994, VOL. 14, NO. 4, 363–388

The economics of motorist information systems revisited

By RICHARD H. M. EMMERINK†, PETER NIJKAMP, PIET RIETVELD

Department of Spatial Economics, Free University, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands

and KAY W. AXHAUSEN

Centre for Transport Studies, Department of Civil Engineering, Imperial College, London SW7 2BU, U.K.

The literature on the implications of the implementation of motorist information systems is ambiguous, particularly with respect to the economic consequences. This paper aims to shed more light on the potential economic costs and benefits of these new technologies by reviewing and combining results obtained in the literature. Furthermore, future research directions, essential for an increased understanding of these systems, are pointed out. It is first argued that a motorist information system is not a normal economic good; the benefits accruing to the equipped road users are dependent on the level of market penetration. At most levels of market penetration a motorist information system is most likely to generate a positive external effect for non-equipped motorists and a negative external effect for those already equipped. However, in terms of travel time, the equipped road users will outperform the non-equipped ones. Next, the economic consequences of these peculiarities are identified, particularly with respect to the role of the government. Attention is also paid to the traffic generating properties and the market potential of motorist information systems. It is concluded that the implementation of a motorist information system will, owing to an efficiency improvement on the road network, generate more traffic. The size of this 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. This paper finally concludes 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 economic perspective in volatile road networks, i.e. networks with non-recurrent congestion.

1. Introduction

It is well known that motorist information systems may enhance the driver's 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 well understood whether and to what extent the interaction between the drivers themselves and the information may reduce potential beneficial effects of these new technologies. A few models have been developed to assess the potential of motorist information systems; however, whether these are able to capture the main characteristics of these systems is unclear (Watling 1994). Using simulation experiments, Mahmassani and Chen (1991) and Mahmassani and Jayakrishnan (1991) found that if more than 20% of the drivers are equipped with the motorist information system, the negative effects due to concentration and overreaction (Ben-Akiva *et al.* 1991) may start to exceed the beneficial effects. Concentration takes place if the

† Also affiliated to The Tinbergen Institute.

0144–1647/94 $10·00

information reduces the variations among drivers, increases uniformity of perceptions of network conditions and thus increases congestion. Overreaction occurs if drivers do not take into account fully 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.* (1993, 1994) and Watling and Van Vuren (1993), supported these findings, but stated that the level of market penetration (i.e. the percentage of drivers equipped with a motorist information system) 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 recently been conducted, see for instance Spyridakis *et al.* (1991), Bonsall (1992), Caplice and Mahmassani (1992), Allen (1993) and Conquest *et al.* (1993). 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 individual's behaviour. Following this argument, provision of more information could be interpreted as producing more complex behaviour, which could explain the divergence of the results obtained by the different studies.

Having raised some of the difficulties associated with the implementation of a properly working motorist information system, we shall nevertheless throughout this paper assume that we are dealing with such a good working 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 them and will achieve the intended benefits. Also, from a marketing point of view this assumption seems tenable, since it is not economically viable to sell malfunctioning systems in the long run. But uncertainty from the side of the potential users about the exact gains of using these systems may discourage them from adopting a system.

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 functioning motorist information system affects:

(*a*) the average road network travel time (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);
(*b*) the average road network travel time of the equipped drivers;
(*c*) 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 economic 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 shall 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 shall discuss the traffic generating potential of these new technologies.

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

The discussion will initially focus on the case of recurrent congestion, i.e. congestion due to undercapacity of the road network. Later, 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 expectations of motorist information systems are particularly high for non-recurrent network conditions.

The paper is organized as follows, § 2 reviews the literature on potential benefits of motorist information systems, § 3 discusses the externalities involved in implementing a motorist information system, while § 4 focuses on the traffic generating effects. Section 5 addresses the issue of market penetration of these systems, § 6 extends the scope to the case of non-recurrent congestion, and § 7 raises some points of the government's role in dealing with these new technologies. Finally, § 8 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% of all distance and 12% of all travel time is wasted. In another study, Jeffery (1986) found an excess travel distance of 6%. Hence, it seems sound to argue 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. In this section, relevant results from the literature will be reviewed.

Kanafani and Al-Deek (1991) presented estimated benefits of approximately 4% in most cases in their theoretical model, without taking into account non-recurrent congestion. Their estimates 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) and Emmerink *et al.* (1993) 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% for the equipped drivers, but add that even higher figures could be attained, when non-recurrent congestion was 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. Building further on Tsuji *et al.*'s (1985) model, Jeffery *et al.* (1987) asserted that the benefits through route guidance could be as large as 10% on average.

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 Mahmassani and Jayakrishnan (1988), Rakha *et al.* (1989) and Hounsell *et al.* (1991).

Mahmassani and Jayakrishnan (1988) analysed a transport network during periods of perturbation and followed the system evolution to the final equilibrium state, meaning a situation in which no driver has an incentive to switch alternatives (the final equilibrium state is not unique as shown in Mahmassani and Chang 1987). 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. Rakha *et al.* (1989) and Hounsell *et al.* (1991) found substantial travel time savings of up to 20% in experiments conducted in a network with non-recurrent congestion.

To conclude, transport researchers do not agree on the scale of the benefits obtainable from motorist information systems; estimates show large variations. One explanation for this divergence in results might be found in the actual definition of the motorist information system. Different researchers have used different methods/models/situations for assessing the benefits. Another explanation may be that the benefits depend on the shape of the network, the scale of the network and the current level of congestion. 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.* (1993). Seen from this perspective, the results obtained by different researchers are not contradictory, but rather complementary in nature.

Another important factor determining 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.* (1993) 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.* (1993). Some important parameters upon which the benefits of a motorist information system depend are shown in table 1.

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.* 1993). 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 Chen (1991) and Mahmassani and Jayakrishnan (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 over-reaction, 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.

Another approach to model these interactions is to apply some game-theoretic models. Game-theory is a natural way for analysing interactions between conflicting actors. In a way, this is the situation in road transport networks; the interactions between the drivers can be formalized as a game, in which each actor (road user) attempts to minimize his/her own travel costs by out-performing the other actors. Although being an elegant method, a major drawback of game-theory in general is the fast increase in complexity and decrease in mathematical tractability when the game becomes more realistic and the number of actors increases. This explains de Palma's (1992) analysis of a road network using a two-person game. However, the relevance of these highly simplified models for real-world situations might be questioned. Concluding, using game-theoretic approaches, there exists a tension between, on the one hand, the mathematical tractability of the model and, on the other hand, the relevance.

The issue of overreaction has been mentioned in the literature, but research addressing this point has only 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 with such research. However, it is an important issue and should be addressed in future research.

Table 1. Factors 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.* (1993).

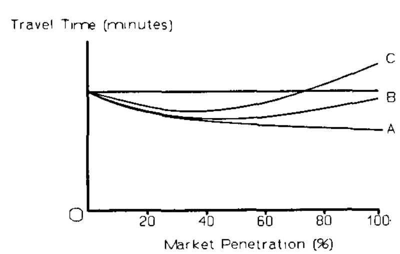

Figure 1. Network performance as a function of market penetration for three cases.

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 not, however, rule out ill-behaved functions, for instance functions with multiple local optima, but there is no clear rationale for such shapes.

In figure 1, case A depicts a situation in which the average network wide travel time is minimized at full market penetration, while in case B the optimal level of market penetration is below 100%. 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 over-reaction and/or concentration.

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 § 3.2 deals with the equipped drivers.

3.1. *Positive externality to non-equipped drivers*

As discussed in § 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:

(*a*) equipped road users are better off and non-equipped road users are worse off, the gains to the equipped road users more than offset the losses to the non-equipped ones;
(*b*) 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 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 flow towards the user equilibrium (Emmerink *et al.* 1993) 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 favouring the existence of this externality, Emmerink *et al.* (1994) and Mahmassani and associates (summarized 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 subsidized because of the 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 § 2 and the externalities to non-equipped road users in § 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. 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 purely illustrative. 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.* 1993).

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.* (1994) suggested figure 4, but due to limited empirical evidence, this does not rule out figure 3.

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 dealing with a network with non-recurrent congestion. Section 6 will address this aspect in greater detail.

In figure 3, between O and A, the benefits to equipped drivers increase with the penetration level, implying that already equipped drivers benefit if an additional driver gets access to 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 videotext effort Minitél. 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), or 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 (on welfare economic grounds) be subsidized.

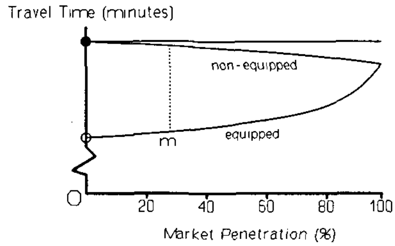

Figure 2. Travel time as a function of market penetration.

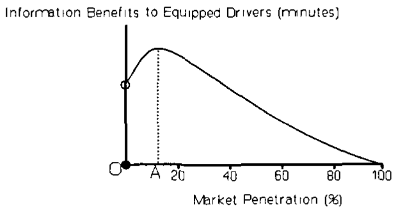

Figure 3. Information benefits to equipped drivers. Case 1.

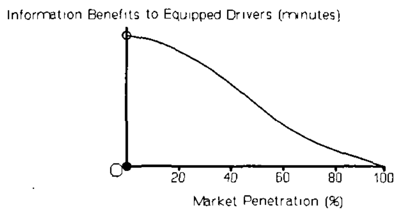

Figure 4. Information benefits to equipped drivers. Case 2.

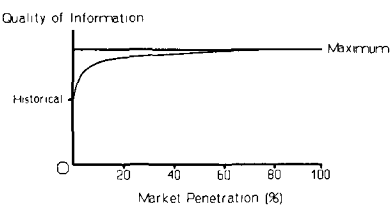

Figure 5. Relationship between quality of information and level of market penetration. Information collected via equipped drivers.

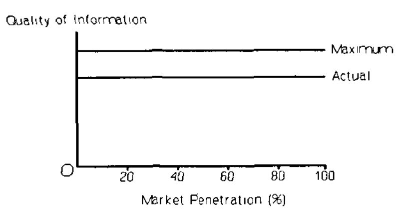

Figure 6. Relationship between quality of information and level of market penetration. Information collected via loop detectors in the road.

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 internalized. 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 this subsidy.

In figure 3, between A and 100%, 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 for the marginal driver himself to buy the equipment. Hence, in the downward sloping part, there exists 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 subsidizing argument is a stronger one than the taxing one. Then we are in the odd situation that we are actually subsidizing a good that adversely affects the people that already possess the good!

An additional complexity arises when considering 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. For instance, the primary source of real-time traffic information in the ADVANCE programme are the vehicles themselves (Boyce *et al.* 1991). 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. 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 precision and reliability of the traffic measurement technique, the reliability of the broadcasting channel, the updating frequency of the information, the delay in the transmission of the information, etc. (Watling and Van Vuren 1993). 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 subsidizing the system during the product's take-off phase.

Further, figure 5 might have consequences for the shape of figures 3 and 4. The dependency between the quality of information and the level of market penetration, might give rise to information benefits to equipped drivers shaped as figure 3. This suggests that there is a rationale behind an information benefits to equipped drivers curve as in figure 3, when information benefits strongly depend on the quality of the information.

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. But, 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. To summarize, 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 § 1 enhances the efficiency of the road network, but induces several externalities and 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. Traffic generating properties of motorist information systems

The introduction of a new technology affects the supply side of a production process, which in turn influences the economic equilibrium (if existing). From economic principles it is well known that an efficiency improvement on the supply side of a production process might 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 therefore decrease the cost (price) of mobility. In the argument that follows the assumptions below are made:

(*a*) there is full market penetration (later on in this section this assumption will be relaxed);
(*b*) travel time at full market penetration is below travel time at no market penetration (case A or B in figure 1);
(*c*) the analysis is static in nature: the adjustment process leading to the new economic equilibrium is not investigated;
(*d*) an isolated road network is analysed.

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. Throughout the analysis the case of hyper-congestion i.e. the backward bending part of the speed-flow curve, is irrelevant for the static analysis conducted in the current section. The equilibrium at full market penetration is given by the intersection of the travel demand curve and the network 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 a motorist information systems ($t(2)$ compared to $t(1)$), due to the downward sloping travel demand curve.

In the analysis above, the value of $q(\text{jam})$ is unaffected by the motorist information system. Although we acknoweledge that a particularly sophisticated signal control system might increase $q(\text{jam})$, we think that information provision as defined in § 1 does not accomplish this in itself.

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 gained from motorist information systems are negligible at low levels of congestion; only beyond a certain level of congestion,

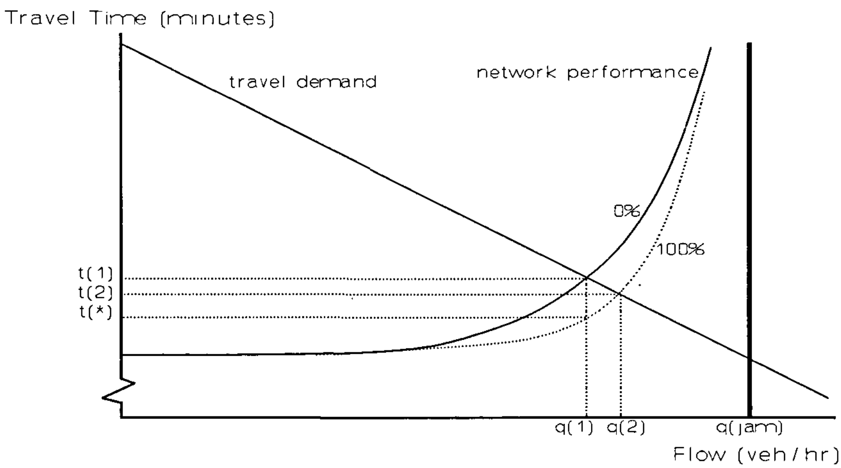

Figure 7. Traffic generation at full market penetration.

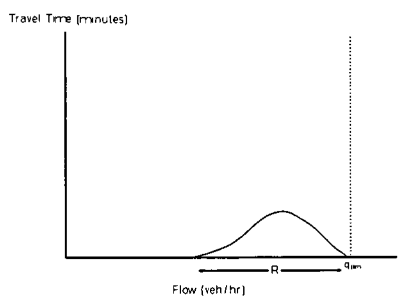

Figure 8. Network wide benefits of motorist information system as a function of the level of congestion.

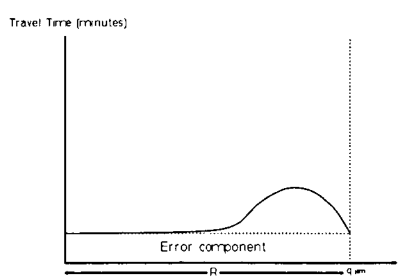

Figure 9. Network wide benefits of motorist information system as a function of the level of congestion. Drivers' misperceptions.

do 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.

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 by 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 closer to reality than figure 8, there is clearly more scope for motorist information systems; in these circumstances there will be travel time savings, and hence traffic generation at low levels of congestion as well. But be careful: if the motorist information system helps motorists to avoid searching for the location of the destination, there may also be a reduction in kilometres travelled. If we call the travel time savings first order benefits, then the reduction in travelled distance might be referred to as second order benefits. The total benefits accruing from introducing such a new technology then depend on the interaction between these two order benefits.

Another implication of figures 8 and 9 is that the benefits of a motorist information system depend on the time of the day. On the one hand, during off-peak periods benefits might be small; on the other hand, benefits increase during peak-periods. However, if the network is completely saturated in the peak-period, then the benefits might be small again. Hence, time of the day is an important factor when assessing the impact of motorist information systems.

The analysis above gets more complicated if the level of market penetration is somewhere in between 0 and 100%, say m. In this situation we assume (the plausibility of this assumption was discussed in § 1) that relation (1) holds;

$$T(\text{with information}) \leq T(\text{average}) \leq T(\text{without information}) \quad (1)$$

Here, the symbol T(with information) denotes the average travel time for drivers with information, T(without information) the average travel time without information, and T(average) the travel time averaged over all drivers. If the average travel time is used as an approximation of the experienced travel time of the average (though non-existing) road user, then a network performance function at $m\%$ market penetration similar to figure 7 can be drawn. This curve then determines the equilibrium traffic flows at $m\%$ 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 (2) to (7). This model expands the analysis to different modes of travel, but is static in the sense that the variable time of the day is omitted for simplicity.

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

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

$$t_{\text{with}} = t_{\text{with}}(q_{\text{with}}, q_{\text{with}} + q_{\text{without}}) \tag{4}$$

$$t_{\text{without}} = t_{\text{without}}(q_{\text{without}}, q_{\text{with}} + q_{\text{without}}) \tag{5}$$

$$q_{\text{with}} + q_{\text{without}} + q_{\text{other mode + suppressed}} = q \tag{6}$$

$$q_{\text{with}} + q_{\text{without}} \leq q_{\text{jam}} \tag{7}$$

The specification of these equations is beyond the scope of this paper. Equations (2) to (7) are purely illustrative. They provide a framework for further research, which will involve the specification of the functional forms explicitly. Here, we restrict ourselves to verbally describing this model. The endogenous variables in (2) to (7) are q_{with}, q_{without}, $q_{\text{other mode + suppressed}}$, t_{with} and t_{without}. Here, q denotes flow (measured in vehicles per hour) and t travel time. The subscripts with and without refer to the equipped and non-equipped drivers, while the subscript other mode + suppressed refers to people not choosing the private car as transport mode and latent travel demand. The exogenous variables 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. Thus making this simple model already rather complex.

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. 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 similar 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 relative attractiveness of the private car is improved, and 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 again 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.

5. 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, given a fixed demand for car mobility. Hence, the analysis that follows is a short run one. Furthermore, only one travel mode—the private car—is addressed. In addition, we will assume that the market penetration of these systems can solely be 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—were depicted in figures 3 and 4. The benefits in these figures were expressed in terms of time. In order to analyse the market potential of these systems, time has to be converted into monetary units. This can be done through using a value-of-time curve. A hypothetical value-of-time curve is shown in figure 10, where the individuals are (by convention) ordered according to decreasing value-of-time.

It is clear that road users with a high value-of-time are most likely to buy the motorist information system. If we assume that the rank order in which drivers decide to buy a motorist information system exactly corresponds with the rank order of drivers according to the value of time, 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:

(*a*) constant average costs to scale,
(*b*) decreasing average costs to scale,
(*c*) increasing average costs to scale.

Given the initially high infrastructure investment needed to implement motorist information systems, economies of scale are most likely to take place. Then, a decreasing average cost curve will result. A decreasing average cost curve has severe welfare economic implications. Decreasing average costs to scale imply that marginal costs are below average costs for each penetration level (production level), see Appendix A. In such a situation, marginal cost pricing, which maximizes social welfare (Pigou 1920), leads to losses (deficits) for the company selling the system.

Therefore, it is highly unlikely that when a private company brings the system on the market, social welfare is maximized. They will charge a price higher than the marginal cost price. To achieve a social optimum, the company should be forced to adopt marginal cost pricing, but clearly the government then has to bridge the

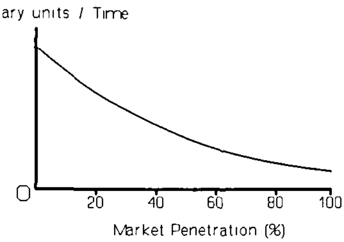

Figure 10. Cumulative distribution of the value of time of motorists.

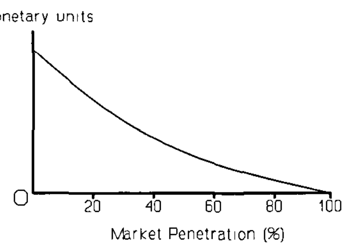

Figure 11. Willingness-to-pay as a function of market penetration.

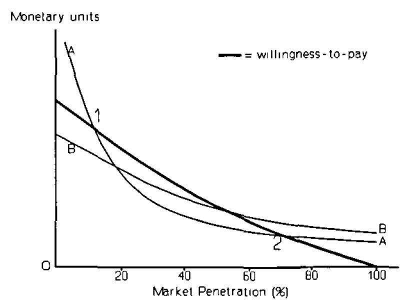

Figure 12. Market potential of motorist information system for two marginal cost curves.

operational deficit. In the last situation, government's regulations must ensure economic efficiency.

In the analysis below, the equilibrium level of market penetration is derived under the assumption of marginal cost pricing. Figure 12 shows two hypothetical marginal cost curves (both derived from a decreasing average cost curve) combined with a willingness-to-pay curve. Marginal cost curve A has two intersection points with the willingness-to-pay curve, while marginal cost curve B hits the willingness-to-pay curve only once. It can easily be seen that the point of intersection of curve B and the willingness-to-pay curve represents a stable equilibrium, in the sense that (1) the system will converge to this level of market penetration, and (2) the system will return to this level for small deviations in market penetration.

The picture is different for marginal cost curve A. For low levels of market penetration, the marginal costs of the system exceed the benefits. Hence, the new technology will not easily take off, but needs an exogenous impetus. A subsidy is needed to bring the level of market penetration to point 1. Intersection point 1 does not correspond to a stable equilibrium. For levels of market penetration exceeding point 1, the benefits to motorists outweigh the costs, and hence, more drivers will be attracted to the system. Road users will buy the system up to a penetration level corresponding with intersection point 2. This point reflects a stable equilibrium as discussed above.

The penetration level associated with point 1 can be referred to as a kind of critical mass value (Allen 1988) for the motorist information system. This term is generally used in a slightly different context referring to benefits rather than costs. Here, the critical mass value might be defined as the minimum penetration level needed to render the motorist information system beneficial to motorists. A critical mass value is a well-known phenomenon when dealing with telecommunication networks. These networks are, from a consumer's point of view, beneficial only after a sufficient number of consumers (the critical mass) has subscribed to the system. Beyond this level benefits increase as penetration increases. In figure 12, however, benefits do not increase for all levels beyond intersection point 1. They remain positive only between intersection points 1 and 2.

An exact figure for the market potential of these technologies is clearly dependent on the precise shape of the curves. The ones shown in this section are purely illustrative, and point out different possible scenarios. In this section, the objective was to provide a framework for analysing the market potential of these systems, which can be applied once the precise shape of these curves is known.

6. The case of non-recurrent congestion

The discussion in the previous sections was focused on the case of recurrent congestion. In this section we 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 and unexpectedly 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% 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. These systems 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 § 3.2 regarding equal travel times for equipped and non-equipped drivers at market penetration levels close to 100% becomes doubtful. We illustrate this with the following hypothetical situation.

Suppose that origin O and destination D are connected by two different routes, R_1 and R_2. With recurrent congestion and 100% of market penetration we may assume (though this is obviously not true if one of the two routes is unused) that the user equilibrium condition holds, i.e. the travel times on R_1 and R_2 are equal. Now, suppose that at time t_1 an incident occurs on R_2, thereby making R_1 the more attractive one. Then, at full market penetration of the information technology, all drivers departing after t_1 will choose R_1 to travel to destination D until the user equilibrium condition is restored, say at time t_2.

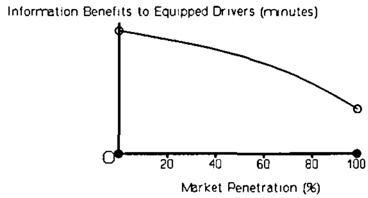

Figure 13. Information benefits to equipped drivers. The case of non-recurrent congestion.

Then, two important observations can be made in case market penetration is below 100%.

(*a*) Non-equipped drivers departing between t_1 and t_2 and deciding to travel via R_2 will clearly experience a longer travel time than if R_1 had been chosen. This implies that the information benefits to equipped drivers curve is discontinuous at 100% market penetration. As a consequence, the last road user buying the equipment will still obtain some benefits, as depicted in figure 13.

(*b*) The higher the level of market penetration, the quicker the user equilibrium conditions will be restored in the road network.

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 queuing 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 less complex. In future research, attention should shift to the non-recurrent case since:

(*a*) The traffic situation in real road networks is non-recurrent in nature. The situation on the roads differs from day-to-day.

(*b*) Motorist information systems are particularly designed for non-recurrent congestion. They are able to broadcast the day-to-day fluctuations on the roads.

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

If the purpose of any motorist information system is to minimize average network travel time given a certain level of demand for transport, figure 1 depicts which level of market penetration should be decided upon, when the traffic generating abilities are not taken into account. However, besides minimizing average travel time, there are other important issues that need to be considered and might affect the optimum level (though, 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) of market penetration.

(*a*) 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.
(*b*) An important cost component of road traffic is pollution and noise. These costs are not necessarily minimized when the average network travel time is at a minimum.
(*c*) 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 minimized when the average network travel time is at a minimum.
(*d*) 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 realized 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 and information technology. 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 relatively low marginal costs and, as a consequence, a relatively high level of market penetration. 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.

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, it is clear that every implementation technique should be largely site and system dependent.

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; see for a comment and rejoinder Hills and Evans (1993).

We should 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, and therefore, motorist information systems might implicitly help decrease the impact of the congestion externality. But, as pointed out in § 4, the impact is smaller than one might expect because lower travel times induce an increasing demand for transport.

8. 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 over-reaction 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. Hence, it can be concluded that a motorist information system is an economic good that produces both positive and negative externalities. Without the government's intervention/regulation, these externalities will cause market failures to take place. The size of these failures depending on the relative size and importance of the externalities.

By avoiding searching for the location of the destination, a motorist information system may produce a decrease in the amount of kilometres travelled. However, due to the efficiency improvement of the road network, a motorist information system will generate more demand for kilometres. 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 the motorist information system. The market potential increases when the road network is strongly volatile, i.e. a network with non-recurrent congestion. Then, the information benefits to equipped drivers might still be significantly positive at full market penetration.

If a motorist information system can be characterized by decreasing average costs to scale—which seems a reasonable assumption given the large initial investment needed—a marginal cost pricing strategy, that maximizes social welfare leads to a deficit for the company operating the system. As a consequence, the government has almost inevitably a role to play with these new technologies.

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, etc. Nevertheless, these factors influence the potential of these new technologies.

A motorist information system is only one of the available tools to tackle the congestion problem. Applied on its own, the 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.

To conclude, in this paper we have attempted to illustrate some of the economic implications that will result from the implementation of a motorist information system under different scenarios. What actually happens depends completely on the exact shape of the different curves, described in this paper. More research addressing this issue is crucial for a deeper understanding of these new technologies and might pave the way for sensible real-world implementations at a larger scale.

Acknowledgment

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.

Foreign summaries

Les publications sur les conséquences à attendre de la mise en place de systèmes d'information pour automobilistes sont loin d'être toujours claires, particulièrement sur le plan économique. L'objet de cet article est d'explorer, en termes de coûts et bénéfices, les effets de ces technologies nouvelles, en analysant et en combinant ce qui est dit dans ces publications. Cette, démarche amène à mettre en évidence des voies nouvelles pour la recherche, dans lesquelles il est indispensable de progresser pour une meilleure compréhension de ces systèmes. La prémière conclusion présentèe dans cet article est qu'un système d'information pour automobilistes n'est pas un bien économique comme les autres; les avantages que peuvent en retirer les automobilistes équipés d'instruments de réception sont fonction du degré de pénétration du marché. A presque tous les degrés de pénétration, une expansion de celui-ci entraînera des effets externes positifs pour les automobilistes non équipés, et des effets externes négatifs pour ceux qui l'étaient déjà. Toutefois, en termes de durée du trajet, les automobilistes équipés auront de meilleurs résultats que ceux qui ne le sont pas. Les conséquences économiques de ces particularités sont analysées ensuite du point de vue des pouvoirs publics; Sont évoquées aussi les potentialités d'engendrement des trafics nouveaux ainsi que les tailles de marché potential pour les systèmes d'information pour automobilistes. Les auteurs sont ainsi amenés à conclure à l'apparition d'un engendrement de trafic résultant de l'efficacité accrue du réseau due à la mise en route d'un système d'information. Le volume de trafic ainsi engendré est incertain et dépend de facteurs tels que la nature du système d'information, les réactions des automobilistes concernés, les caractéristiques du réseau et le degré de pénétration du marché. La conclusion finale est que, surtout sur les réseaux où la congestion est endémique, les avantages des automobilistes équipés diminuent lorsque le degré de pénétration du marché augmente. Les avantages économiques de ces systèmes d'information apparaissent principalement sur les réseaux volatiles, c'est-à-dire ceux où la congestion n'est pas endémique.

Die Literatur über die Auswirkungen einer Einführung von Informationssystemen für Autofahrer ist besonders im Hinblick auf ökonomische Konsequenzen vieldeutig. Dieser Artikel zielt darauf ab, mehr Licht auf die möglichen volkswirtschaftlichen Kosten und Nutzen dieser neuen Technologien zu werfen, indem Ergebnisse aus der Literatur analysiert und verknüpft werden. Darüber hinaus werden zukünftige Forschungsrichtungen, die für ein zunehmendes Verständnis dieser Systeme von ausschlaggebender Bedeutung sind, beschrieben. In diesem Artikel wird zunächst herausgestellt, daß ein Autofahrer-Informationssystem kein Gut im volkswirtschaftlichen Sinne ist; die Nutzen, die sich für den ausgestatteten Straßenbenutzer ergeben, sind abhängig vom Stand der Marktdurchdringung. Auf den meisten Stufen der Marktdurchdringung erzeugt ein Autofahrer-Informationssystem höchstwahrscheinlich einen postiven Effekt für die nicht-ausgestatteten Autofahrer und einen negativen externen Effekt für die schon ausgestatteten. Trotzdem werden die ausgestatteten Straßennutzer die nichtausgestatteten ausspielen, wenn man an die Reisezeit denkt. Als nächstes werden die ökonomischen Folgen dieser Eigenarten untersucht, besonders mit Blick auf die Rolle der Regierung. Aufmerksamtkeit wird auch den verkehrserzeugenden Eigenschaften und dem Marktpotential der Autofahrer-Informationssysteme geschenkt. Es wird der Schluß gezogen, daß die Einführung eines Autofahrer-Informationssystems aufgrund einer Leistungssteigerung des Straßennetzes mehr Verkehr erzeugen wird. Der Umfang des neu-induzierten Verkehrs ist ungewiß und hängt von der Art des Informations-systems, den Verhaltensaňderungen der Straßennutzer, dem

speziell betrachteten Netz und dem Grad der Marktdurchdringung ab. Am Ende dieses Artikels wird festgestellt, daß speziell in Netzen mit ständig wiederkehrenden Stauerscheinungen der Nutzen für die ausgestatteten Fahrer in dem Maße abnimmt wie der Grad der Marktdurchdringung sich steigert. Diese Systeme haben eine bessere ökonomische Perspektive in 'unbeständigen' Straßennetzen d.h. in Netzen mit nicht ständigen Stauerscheinungen.

La literatura es ambigua respecto a las implicancias de la implementación de sistemas de información a los automovilistas, particularmente respecto a sus consecuencias económicas. Este trabajo intenta aportar algo de claridad al tema de los potenciales costos y beneficios económicos de estas nuevas tecnologías, a través de la revisión y combinación de resultados reportados en la literatura. Tambièn se indican direcciones de investigación futura esenciales para aumentar la comprensión de tales sistemas. En el trabajo se argumenta, en primer lugar, que un sistema de información a automovilistas no es un bien económico normal; los beneficios para los usuarios equipados dependen del nivel de penetración del mercado. Para la mayoria de los niveles de penetración del mercado, el sistema probablemente generarà un efecto externo positivo para los automovilistas no equipados, y uno negativo para los ya equipados. Sin embargo, en términos de tiempos de viaje, los usuarios equipados superaràn a los no equipados. A continuación se identifican las consecuencia económicas de estas peculiaridades, particularmente respecto al rol del gobierno. También se presta atención a las propiedades de generación de tráfico y al mercado potencial de este tipo de sistemas. Se concluye que la implementación de un sistema de información a automovilistas debiera generar mayor cantidad de tráfico debido a un mejoramiento de loa eficiencia de la red de transporte. El tamaño de este tráfico generado es incierto y dependerá del tipo de sistema, del comportamiento (respuesta) de los usuarios, de la red específica que se esté considerando y del grado de penetración del mercado. El trabajo finalmented concluye que, particularmente en redes con una congestión recurrente, los beneficios a los conductores equipados tenderán a disminuir a medida que aumenta la penetración del mercado. De esta forma, se anticipa que estos sistemas debieran tener una mejor perspectiva económica en redes volátiles, esto es, sin congestión recurrente.

Appendix

Let x be the level of production and $c(x)$ the costs to produce x. Decreasing average costs implies that

$$\mathrm{d}\frac{c(x)}{x}\Big/\mathrm{d}x < 0$$

consequently,

$$\mathrm{d}\frac{c(x)}{x}\Big/\mathrm{d}x = \frac{\frac{\mathrm{d}c(x)}{\mathrm{d}x}x - c(x)}{x^2} < 0$$

and hence we arrive at

$$\frac{\mathrm{d}c(x)}{\mathrm{d}x} < \frac{c(x)}{x}$$

stating that decreasing average cost implies that marginal costs are below average costs for all levels of production x.

References

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

BEN-AKIVA, M., and LERMAN, S. R., 1985, *Discrete Choice Analysis: Theory and Application to Travel Demand* (Cambridge, Massachusetts: MIT Press).

BEN-AKIVA, M., DE PALMA, A., and KAYSI, I., 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 PARRY, T., 1990, Driver's requirement for route guidance, in *Proceedings of 3rd International Conference on Road Traffic Control* (London, U.K.: IEE).

BONSALL, P. W., PICKUP, L., and STATHOPOULOS, A., 1991, Measuring behavioural responses to road transport informatics, in: *Advanced Telematics in Road Transport* (Amsterdam: Elsevier), pp. 1457–1487.

BOYCE, D. E., KIRSON, A. M., and SCHOFER, J. L., 1991, Design and implementation of ADVANCE: the Illinois dynamic navigation and route guidance demonstration program. ADVANCE working paper series, 5 (August).

CAPLICE, C., and MAHMASSANI, H. S., 1992, Aspects of commuting behaviour: preferred arrival time, use of information and switching propensity, *Transportation Research*, **26A** (5), 409 418.

CONQUEST, L., SPYRIDAKIS, J., HASELKORN, M., and BARFIELD, W., 1993, The effect of motorist information on commuter behaviour: classification of drivers into commuter groups. *Transportation Research*, **1C** (2), 183–2-201.

DEHOUX, PH., and TOINT, PH. L., 1991, Some comments on dynamic traffic modelling in the presence of advanced driver information systems, In *Advanced Telematics in Road Transport* (Amsterdam: Elsevier), pp. 964–980.

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 LINDSEY, R., 1992, The potential benefits of a combined route guidance and road pricing system: An economic analysis, Internal working paper.

EMMERINK, R. H. M., AXHAUSEN, K. W., NIJKAMP, P., and RIETVELD, P., 1993, Concentration, overreaction, market penetration and Wardrop's principles in an ATIS environment, TI Tinbergen Institute Discussion Paper, 93–230.

EMMERINK, R. H. M., AXHAUSEN, K. W., NIJKAMP, P., and RIETVELD, P., 1994, Effects of information in road transport networks with recurrent congestion, *Transportation*, to be published.

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.

HILLS, P., and EVANS, A. W., 1993, Road congestion pricing: A comment and a rejoinder, *Journal of Transport Economics and Policy*, **27** (1), 91–105.

HOUNSELL, N., MCDONALD, M., and BREHERET, L., 1991, Models and strategies for dynamic route guidance, in: *Advanced Telematics in Road Transport* (Amsterdam: Elsevier), pp. 89–98.

JEFFERY, D. J., 1986, Route guidance and in-vehicle information systems, in: *Information Technology Applications in Transport*, edited by P. W. Bonsall and M. Bell (Utrecht: VNU Science Press), pp. 319–351.

JEFFERY, D. J., RUSSAM, K., and ROBERTSON, D., 1987, Electronic route guidance by autoguide: the research backgrounds, *Traffic Engineering and Control*, **28** (11), 525–529.

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

KANAFANI, A., and AL-DEEK, H., 1991, A simple model for route guidance benefits, *Transportation Research*, **25B** (4), 191–201.

KING, G. F., 1986, Driver performance in highway tasks, *Transportation Research Record*, **1093,** 1–11.

KING, G. F., and MAST, T. M., 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 CHANG, G.-L., 1987, On boundedly rational user equilibrium in transportation systems, *Transportation Science*, **21** (2), 89–99.
MAHMASSANI, H. S., and CHEN, P. S.-T., 1991, Comparative assessment of origin-based and en route real-time information under alternative user behaviour rules, *Transportation Research Record*, **1306**, 69–81.
MAHMASSANI, H. S., and HERMAN, R., 1990, Interactive experiments for the study of tripmaker behaviour dynamics in congested commuting systems, in: *Development in Dynamic and Activity-Based Approaches to Travel Analysis*, edited by P. M. Jones (Aldershot, U.K.: Avebury), pp. 272–298.
MAHMASSANI, H. S., and JAYAKRISHNAN, R., 1988, Dynamic analysis of lane closure strategies, *Journal of Transportation Engineering*, **114** (4), 476–496.
MAHMASSANI, H. S., and JAYAKRISHNAN, R., 1991, System performance and user response under real-time information in a congested traffic corridor, *Transportation Research*, **25A** (5), 293–308.
PIGOU, A. C., 1920, *Wealth and Welfare* (London, U.K.: Macmillan).
RAKHA, H., VAN AERDE, M., CASE, E. R., and UGGE, A., 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*, pp. 296–303.
RUMAR, K., 1990, Driver requirements and road traffic informatics, *Transportation*, **17** (3), 215–229.
SPYRIDAKIS, J., BARFIELD, W., CONQUEST, L., HASELKORN, M., and ISAKSON, C., 1991, Surveying commuter behaviour: designing motorist information systems, *Transportation Research*, **25A** (1), 17–30.
STERGIOU, B., and STATHOPOULOS, A., 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* (London, U.K.: Gollancz).
TSUJI, H., TAKAHASHI, R., KAWASHIMA, H., and YAMAMOTO, Y., 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 VAN DER MEDE, P. H. J., 1993, The impact of traffic information, Ph.D thesis, Universiteitsdrukkerij, Delft.
VAN VUREN, T., and VAN VLIET, D., 1992, *Route Choice and Signal Control* (Aldershot, U.K.: Avebury).
WARDROP, J., 1952, Some theoretical aspects of road traffic research, *Proceedings of the Institute of Civil Engineers*, **1** (Part II), 325–378.
WATLING, D., 1994, Urban traffic network models and dynamic driver information systems, *Transport Reviews*, **14**, 219–246.
WATLING, D., and VAN VUREN, T., 1993, The modelling of dynamic route guidance systems, *Transportation Research*, **1C** (2), 159–182.

Editorial suggestions for further reading

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

Parking Guidance and Information (PGI) systems are installed in town centres to provide benefits to the user and to the system. They are intended to assist individual drivers in the search for vacant spaces and to reduce the inconvenience of unnecessary queues at popular car parks. On the management side PGI systems can help to distribute the demand for parking spaces more efficiently so that car-park turnover and occupancy levels are improved and traffic performance is enhanced.

System effectiveness is directly related to user behaviour. If a proportion of drivers fail to comply with the information provided, then the performance capability of the system is reduced. Measurement of the effect of PGI systems is usually restricted to measurement of the aggregate change in demand arising from the display of different legends. However, this approach reveals little about the underlying decision process used by drivers.

This study looks at the impact of PGI systems on behaviour at a disaggregate level, using an attitudinal questionnaire and a Stated Preference exercise administered in Kingston-upon-Thames. Different demographic groups and legend styles are tested and compared. The impact of occupancy information is shown to have a significant effect on car park choice probabilities, although other factors affecting choice should not be overlooked by car-park managers and PGI system designers. (Author)

BONSALL, P., 1992, The influence of route guidance advice on route choice in urban areas. *Transportation*, **19** (1), pp. 1–23.

The paper begins by reviewing what is known about route choice processes and notes the mismatch between this knowledge and the route choice assumptions embedded in the most widely used assignment models. Empirical evidence on the influence of route guidance advice on route choice is reviewed and, despite its limited nature, is seen to suggest that users are reluctant to follow advice unless they find it convincing and that, the more familiar they are with the network, the less likely they are to accept advice. Typically only a small minority of journeys are made in total compliance with advice.

Results from an interactive route choice simulator (IGOR) are summarized and are seen to reveal that compliance depends on the extent to which the advice is corroborated by other factors, on the drivers' familiarity with the network and on the quality of advice previously received. It is noted that the IGOR results are in a form which would enable response models to be calibrated.

Recent approaches to the modelling of route choice in the context of guidance are discussed. Some are seen to make no allowance for the fact that drivers are unlikely to comply with all advice and several are not able to represent the benefits which guidance might bring in the context of sporadic congestion or incidents.

As an alternative, a two phase model comprising a medium term strategic equilibrium and a day-specific simulation with explicit representation of driver response is proposed. (Author)

KOUTSOPOULOS, H. N., and XU, H., 1993, An information discounting routing strategy for advanced traveler information system. *Transportation Research*, **1C** (3), pp. 249–264.

Although there is a lot of enthusiasm and hope that in-vehicle information and route guidance systems will become an integral part of the solution to the traffic congestion problem, there are still a lot of technological and other problems that need to be addressed before such systems operate successfully. This paper examines design aspects of advanced traveler information systems (ATIS) such as frequency of information update, location of information nodes and, most importantly, approaches to estimate the travel times for use in routing decisions and suggestions. In particular, a routing strategy based on information discounting for travel time projection is developed. The importance of the above issues and their implications on the effectiveness of ATIS are demonstrated with a small network. (Author)

MAHMASSANI, H. S., and CHEN, P. S.-T., 1993, An investigation of the reliability of real time information for route choice decisions in a congested traffic system. *Transportation*, **20** (2), pp. 157–178.

This paper investigates the reliability of information on prevailing trip times on the links of a network as a basis for route choice decisions by individual drivers. It considers a type of information strategy in which no attempt is made by some central controller or coordinating entity to predict what the travel times on each link would be by the time it is reached by a driver that is presently at a given location. A specially modified model combining traffic simulation and path assignment capabilities is used to analyse the reliability of the real-time information supplied to the drivers. This is accomplished by comparing the supplied travel times (at the link and path levels) to the actual trip times experienced in the network after the information has been given. In addition, the quality of the decisions made by drivers on the basis of this information (under alternative path switching rules) is evaluated ex-post by comparing the actually experienced travel time (given the decision made) to the time that the driver would have experienced without the real-time information. Results of a series of simulation experiments under recurrent congestion conditions are discussed, illustrating the interactions between information reliability and user response. (Authors)

See also:

ADLER, J. L., RECKER, W. W., and MCNALLY, M. G., 1993, A conflict model and interactive simulator (FASTCARS) for predicting en route driver behaviour in response to real-time traffic condition information, in the same issues of *Transportation*, pp. 83–106.

and YANG, H., KITAMURA, R., JOUANIS, P. P., VAUGHN, K. M., and ABDEL-ATY, M. A., 1993, Exploration of route choice behaviour with advanced traveler information using renewal network concepts, in the same issue of *Transportation*, pp. 199–223.

RUMAR, K., 1990, Driver requirement and road traffic informatics. *Transportation*, **17** (2), pp. 215–229.

Initially the driver's role as a link in the driver–vehicle–road-traffic control-chain is discussed in a historical perspective. The gradual changes and the advantages and problems arising from these changes are discussed from behavioural point of view.

Then the driver tasks are analysed. A separation is made between trip planning, navigation, road following, traffic interaction, rule compliance, other than traffic task, car handling and speed choice. The relations between and the weights of these subtasks are discussed. Some existing driver behaviour models are reviewed in relation to the above mentioned tasks.

Finally an effort is made based on the analyses of driver tasks and driver models to specify some general and some more specific potential advantages and problems with expected future RTI-systems. (Author)

STERGIOU, B., and STATHOPOULOS, A., 1989, Traffic models and Road Transport Informatics (RTI) systems. *Traffic Engineering and Control*, **30** (12), pp. 580–586.

As the network capacity of the European road infrastructure is not expected to increase substantially in the next 10 or 20 years, car-ownership and travel demand are continuously increasing with important growth rates. The results are enormous delays in congested urban areas, a high number of accidents and adverse environmental conditions in terms of air pollution and noise from traffic.

It is envisaged that a new concept, 'the introduction of Road Transport Informatics (RTI)' applied in road traffic (affecting vehicles and road infrastructure), might offer a variable alternative solution through the increase of road capacity and network efficiency.

The Commission of the European Communities proposed and the European Council of Ministers adopted in July 1988 a three-year programme, DRIVE, which has the initiative of preparing the introduction of RTI systems in the road transport sector. Following two calls for proposals, and evaluation of those received by the DRIVE Central Office to various research institutions, universities and private firms up to the end of 1989.

One of the areas of scientific interest the DRIVE programme is the transport planning process, and especially transport modelling and traffic-flow simulation. The introduction and use of RTI systems are expected to have considerable implications is those areas.

The purpose of this article is (*a*) to examine the state of practice in the area of traffic modelling; (*b*) to examine which RTI systems will, most probably, be introduced; (*c*) to examine the effect of RTI introduction on transport modelling; and (*d*) to examine how DRIVE projects are expected to meet these requirements. (Authors)