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The potential of information provision in road transport networks with non-recurrent congestion

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THE POTENTIAL OF INFORMATION PROVISION IN ROAD TRANSPORT NETWORKS WITH NON-RECURRENT CONGESTION

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ABSTRACT

This paper analyses the potential of Advanced Traveller Information Systems (ATIS) in a road network in which incidents are generated in a random fashion. A simulation model is applied in which the traffic flows are the aggregation of drivers' decisions. These decisions, in turn, are modelled using boundedly rational principles.

The simulation experiments focus on the relationship between the network wide performance, the level of market penetration, the quality of the information, and the en route switching propensity.

The results indicate that if drivers behave according to boundedly rational principles without being provided with information in a road network with non-recurrent congestion, the road network will not be used efficiently in terms of travel time. In these circumstances, ATIS is very useful. However, the commercial viability of ATIS might be frustrated by the quickly diminishing additional benefits to equipped drivers. Further, the complexity of the implications of ATIS is stressed by the strong interaction between, on the one hand, the level of market penetration, the quality of the information and the en route switching propensity and, on the other hand, the network wide performance.

1 INTRODUCTION

The congestion problem is affecting most metropolitan areas around the world. Due to large mobility demand (road users) and scarce supply of road infrastructure, road users are facing large, undesired, travel time delays, particularly throughout the morning and evening peak-hours. This kind of congestion is in the literature referred to as *recurrent* congestion, i.e. congestion taking place at a regular base. Travel time delays are even larger if additional, randomly incidents occur on the roads, thereby diminishing the available road capacity. Congestion of this type is referred to as *non-recurrent* congestion and is caused by bad weather (fog, heavy rain, snow etc.), traffic accidents etc. In the literature, it has been claimed that non-recurrent congestion accounts for up to 60 per cent of total congestion delays (Lindley, 1986, 1987, 1989). However, this figure should not be misinterpreted since congestion delays would not be nearly as large if the road networks were not already overcrowded with recurrent congestion.

The potential of technologically advanced systems, known under the names of Advanced Traveller Information Systems (ATIS), Road Transport Informatics (RTI), motorist information systems, Dynamic Route Guidance (DRG) systems etc., to resolve part of the congestion problem are currently under investigation, see for example the DRIVE programme of the EC (Stergiou and Stathopoulos, 1989), the ADVANCE programme (Boyce et al., 1991) and other around the world. Attention has particularly been focused on the case of recurrent congestion. However, it is slowly emerging that non-recurrent congestion is more relevant for these new technologies, since these are able to detect and broadcast the occurrence of incidents in real-time.

Recently, Al-Deek and Kanafani (1993) modelled the benefits of ATIS in corridors with incidents. They considered a network, consisting of two routes, with random incidents occurring on the (under normal conditions) more attractive one. Their model is based on *user equilibrium* assumptions, i.e. with ATIS, drivers will be diverted, so to re-establish the user equilibrium traffic flows. As a consequence, in equilibrium there are no additional benefits to equipped drivers; only in the phase leading to equilibrium, equipped drivers outperform the non-equipped ones. Depending upon their model parameters, the network wide travel time savings are quite substantial; up to 30 per cent compared to the situation without information.

In another recently conducted study, Hall (1993) presents a different picture of the benefits owing to ATIS in networks with non-recurrent congestion. He analysed non-recurrent congestion using the definition of *effective capacity*, which is the expected roadway capacity after accounting for the random occurrence of incidents. He concluded that in reality, based on Lindley's (1986) data, the average effective loss is surprisingly small, ranging between 2 and 9 per cent, depending on the length of the bottleneck under investigation. Hence, he argued that the application of ATIS might be justified as giving a reasonable assurance of arriving on time to the road users (for instance, diminishing stress and anxiety), but should not be viewed as a substitute for building new roads.

In this study we will analyse the potential of ATIS in the case of non-recurrent congestion from another perspective, and it could therefore be regarded as being complementary to the work by Al-Deek and Kanafani (1993) and Hall (1993). Our analysis will centre around the behavioural responses of the road users. These responses, in fact, determine the traffic flows in the road network. In our approach, these flows are not determined by *user equilibrium* considerations as in Al-Deek and Kanafani (1993). Neither is our analysis led by the *supply-side*, as Hall's (1993) study. We argue - as did Bonsall (1992), Bonsall et al. (1991), Dehoux and Toint (1991), Iida et al. (1992), Mahmassani and Herman (1990), Watling and Van Vuren (1993) - that the effects of ATIS on the network wide performance should be analysed there where the ATIS technology penetrates into the transportation system, hence at the drivers level. However, doing so reduces the available research tools quickly. Analytical models become either unrealistic or too complex to solve; only a simulation approach remains.

In this paper, drivers' behaviour is modelled using a *boundedly rational* principle, initially proposed by Simon (1955), and introduced into the transportation field by Mahmassani and Chang (1985). In such a model, drivers are seeking a *satisfactory* outcome, rather than a *utility maximising* one. This seems a reasonable assumption, particularly in situations in which decisions are made repeatedly, as is the case with the commuting to work trip. Mahmassani and Jayakrishnan (1988) used a similar approach to analyse a transportation network during periods of perturbations, but their analysis only dealt with historical information, i.e. the road users' own experience in previous periods. In this study, we will address real-time en route information as well.

It can be questioned whether these behavioural models are able to capture drivers' decision making behaviour. However, to analyse the *potential* of information technologies in road networks, we think it is justified to assume a kind of rational behaviour. It is a further step to *predict* the impact of these technologies on network wide performance. In order to do so, the behavioural models used in this and other studies need to be validated. Research addressing this issue is still in its infancy, and is clearly beyond the scope of this paper.

In Section 5, the simulation experiments in the network with non-recurrent congestion particularly focus on the following issues:

- The influence of the level of market penetration on the network wide performance.
- The additional benefits to equipped drivers.
- The quality of the information in relation to drivers' behaviour and network wide performance.

The first point has been mentioned repeatedly in the literature. It has been envisaged that the level of market penetration is an important parameter in determining the success of these advanced technologies (Mahmassani and Jayakrishnan, 1991; Watling and Van Vuren, 1993). The second issue is particularly important from a commercial point of view. These systems are economically viable, only if there are substantial additional benefits to the equipped drivers, see for a discussion Emmerink et al. (1993c). And finally, the third issue has - as far as we know - not been given much attention in the literature. However, it seems intuitively clear, that *low* quality information could have an adverse effect on network wide performance. In the simulation experiments in this paper, we will confine the analysis to the updating frequency of the information. We acknowledge that this is only one aspect that affects the quality of the information. Some other issues involved are briefly discussed in Section 2.

The potential of ATIS to reduce travel times and congestion delays is one reason for adopting these technologies, although often regarded as being the most important one. ATIS, however, also has a potential to reduce driving stress and anxiety, increase safety, and diminish levels of pollution. In this paper, we will not address these potential beneficial effects. The impact of ATIS will be solely assessed by means of its implications for travel time reduction.

This paper builds on the work carried out by Emmerink et al. (1993a). Section 3 summarises the model description, while Section 4 discusses the model parameters used in this study. Section 5 presents the results of the simulation experiments, and finally, Section 6 summarises the main arguments. But firstly, some information quality issues are addressed in the next section.

2 INFORMATION ACCURACY

The information that is provided to the road users will ideally reflect the actual traffic flows in the network, or even better, the traffic flows in the future. However, as has been pointed out by Watling and Van Vuren (1993), this is still a hypothetical case. Some sources affecting the quality of the information are listed below.

- level of precision and reliability of the traffic measurement technique
- reliability of broadcasting channel
- delay in transmission of the information
- updating frequency of the information

In this section, only the inaccuracy of the information caused by (1) a discrete updating frequency and (2) a delay in transmitting the information will be dealt with. No attention will be paid to unreliability due to measurement errors or other biases.

Firstly, a discrete updating frequency implies that traffic data is not continuously collected, but only at discrete points in time. The reason being, for example, technical limitations of the information gathering system, or psychological arguments that continuously fluctuating information might confuse the road users. Secondly, the delay in transmitting the data reflects the time needed to transform *raw* data into a format suitable for transmission to the drivers. The process from detection to information provision is schematically depicted in Figure 1.

Figure 1 From information detection to information provision.

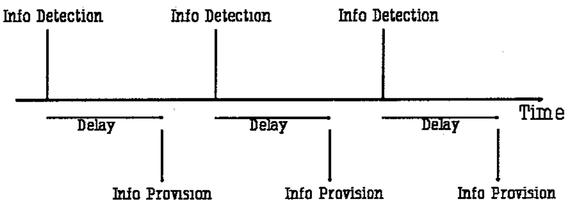
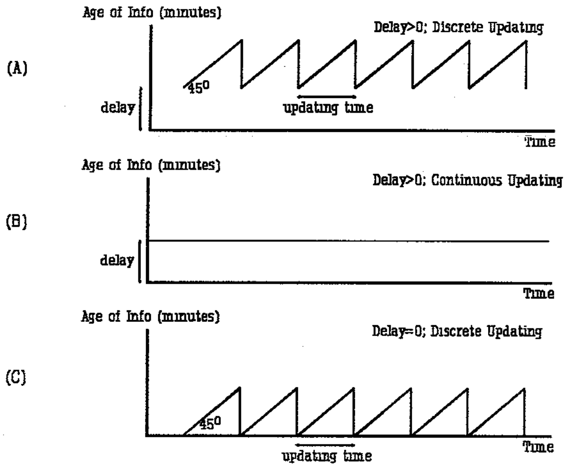


Figure 2 Updating time and delay. Three cases.



The age of the information as a function of time can now easily be derived. Figure 2 shows three different cases. In Figure 2A, there is both a delay and a discrete updating interval, Figure 2B illustrates a system with a delay and continuous updating, while Figure 2C shows discrete updating and no delay.

For simplicity, the simulation experiments in Section 5 only deal with a discrete updating time (Figure 2C); it is assumed that there is no delay in transmitting the information. Three updating times will be considered, 1, 5 and 10 minutes, respectively. These should give us more understanding of the impact of the age of the information, as a dummy for information quality, on network wide performance.

3 THE MODEL

The model being used is an adapted version of the one described in Emmerink et al. (1993a). For the details we refer to that paper, here we confine ourselves to highlighting the main characteristics and introducing non-recurrent congestion.

In the simulation model, drivers travel daily from the same origin to the same destination, using their past trip experience in making route choice decisions. It is assumed that departure times are fixed and that all drivers depart during one hour, see Figure 3. The road network being used is depicted in Figure 4.

Figure 3 Departure time structure.

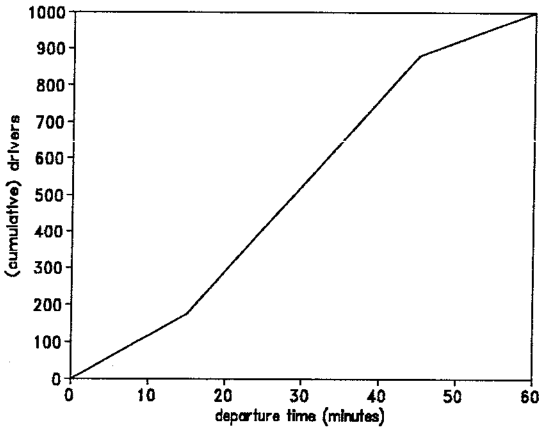
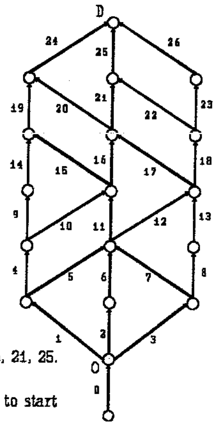


Figure 4 Road network used in simulation experiments.



Length of all links is 2 km.
Jam speed is 5 km/h for all links.
Free flow speed is 70 km/h for links 2, 6, 11, 16, 21, 25.
Free flow speed is 50 km/h for other links.
Link 0, having an infinite jam density, is needed to start the simulation.

Each simulation run consists of 200 consecutive days, and is repeated five times, to account for the stochastic start of each run.[1]

3.1 Information updating and decision making

Every driver updates his knowledge of the network (in terms of travel time) using scheme [1].

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[1] Test runs showed that a length of 200 days captures most of the dynamics in the model. Also from a theoretical perspective, 200 days - almost being equal to 10 months - seems a reasonable period.

$$ET_r^{n+1} = \alpha * NewInformation_r + (1-\alpha) * ET_r^n \qquad [1]$$

Here, ET_r^{n+1} denotes the expected travel time for route r in period n+1, while the new available information on route r is embedded in $NewInformation_r$. The parameter α lies in the closed interval [0,1] and reflects the weight given to the last travel experience. This kind of updating or *learning* has been introduced into the transportation literature by Horowitz (1984).

In the experiments reported in Section 5, driver's decisions are either based on own experience (if the driver is not equipped with an information device), or own experience in combination with en route information (if the driver is equipped). The pre-trip information updating model for these two classes of drivers is given in [2], in which index i refers to the driver.

$$\begin{aligned} ET_r^{i,n+1} &= \alpha * ExperiencedTravelTime_r^{i,n} + (1-\alpha) * ET_r^{i,n} &&: \textit{if route r chosen in period n} \\ ET_j^{i,n+1} &= ET_j^{i,n} &&: \textit{otherwise} \end{aligned} \qquad [2]$$

All drivers (both with and without information) are assumed to make their pre-trip decision following model [3].

$$\begin{gathered} \textit{Assume route r has been chosen by driver i in period n. Driver i's} \\ \textit{decision in period } n+1 \textit{ is route r if the following expression holds:} \\ ET_r^{i,n} * (1 - bound) \le ExperiencedTravelTime_r^{i,n} \le ET_r^{i,n} * (1 + bound) \\ \textit{Otherwise the route with the highest utility will be chosen in period } n+1. \end{gathered} \qquad [3]$$

The $ExperiencedTravelTime_r^{i,n}$ denotes the experienced travel time of driver i for route r in period n. On the one hand, if the bound is larger than zero, this model does not contain a direct utility maximising incentive. The alternative having highest utility - where utility is defined as minus expected travel time - is chosen only if the individual is not satisfied with the previously made decision. On the other hand, if the bound is zero this model collapses to a utility maximising model, and could therefore be seen as an extension of such a model.

These kind of models - *boundedly rational* models - are based on *satisficing* principles, originally proposed by Simon (1955), and introduced into the transportation field by Mahmassani and Chang (1985). For theoretical properties of boundedly rational decision making models, we refer to Mahmassani and Chang (1987).

The information provided to equipped drivers during the trip is assumed to be in terms of expected remaining travel time. Following Mahmassani and Jayakrishnan (1991), en route switching behaviour is modelled using scheme [4].

Start driver i's trip according to the decision based upon own experience. Calculate before entering a new link the expected remaining travel time of all the available routes k based upon the en route information. These travel times will be denoted by RTT_k^i. [4]
Calculate $\min_k RTT_k^i$ ***and suppose this occurs for k=m. Assume further that the current route is route r. If*** $RTT_m^i < RTT_r^i * (1 - bound)$ ***and*** $RTT_r^i - RTT_m^i > \tau$ ***driver i will switch to route m. Otherwise driver i will continue on route r.***

The bound in [4] is specified following [5], to model a slowly decaying influence of the pre-trip decision during the en route decision making process.

$$\textit{bound} = (\#\textit{ of links remaining}) * \textit{en\_route\_bound} \quad [\ ] \tag{5}$$

As discussed in Section 2, the en route information is updated with a fixed frequency; as a consequence, the information is - strictly speaking - not exactly real-time.

3.2 Non-recurrent congestion

It is assumed that non-recurrent congestion can take place on links 1 to 26 in Figure 4.[2] An incident can only occur once a day at a specific link, and in such a situation the capacity of that link is always halved (the maximum density decreases with 50 per cent). The duration of any incident is equal to 15 minutes; the starting time of an incident is a random number, taken from the interval [0,45].

Every day, for each link, a Bernoulli trial is performed to decide whether or not an incident will take place. In Section 4, the *success* probability of the Bernoulli trial is discussed, together with the other parameters used in the model.[3]

4 MODEL PARAMETERS

The parameters used in the simulation experiments are listed in Table 1. Table 2 shows the parameters that have been varied throughout the simulation experiments, leading to 96 different cases.[4] The updating time, ranging from 1 to 10 minutes, was conceived as being a reasonable estimate for the available technologies. The en_route_bound in [5] has been varied to test the interaction between the network wide performance, the en route *willingness-to-switch* and the quality of the information (the

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[2] Link 0 is needed to start the simulation.

[3] The term *success* refers to the occurrence of an incident.

[4] The updating frequency is irrelevant when there is no market penetration.

updating frequency). The lower the en_route_bound in [5], the higher the switching propensity, and visa versa.

Table 1 Model parameters.

Parameter	Value
Length of run	200 days
Number of runs	5 runs
Number of drivers	1000 drivers
Departure times of drivers	see Figure 3
Link capacity per km in macroparticles	32 macroparticles
Link capacity per km under an incident	16 macroparticles
α in formula [2]	0.4 []
Bound in model [3]	0.2 []
τ in model [4]	1 minute
delta t	0.2 minutes
incident duration	15 minutes
starting time of incident	random number from [0,45]

For clarification of the definitions, see Emmerink et al. (1993a).

Table 2 Experimental design of simulation experiments.

Parameter	Values
Market penetration	0, 5, 20, 50, 75, 100 (%)
Information updating time (upd)	1, 5, 10 (minutes)
en_route_bound in [5]	0.02, 0.05 []
Bernoulli(p)	0.08, 0.19, 0.38 []

The decision for the Bernoulli(p)-value was a more difficult one. The literature does not agree on certain p-values, and in addition, this value seems to be heavily dependent upon the kind of road network under consideration. Recently, Hall (1993) briefly reviewed some results in the literature; these suggested a very low value for p, and an incident duration ranging between 30 and 70 minutes. However, Keller et al. (1983) reported significantly different figures; highly varying p-values, and significantly lower incident durations (between 10 and 30 minutes). Since the focus of this paper is on the *potential* of information provision during incident periods, we decided to generate a relatively large number of incidents in the network and therefore chose relatively high p-values. To be precise, the p-values have been chosen to have on average 2, 5 and 10 daily incidents in the network. This corresponds to p-values of 0.08, 0.19 and 0.38. However, to compensate for these high probabilities we chose a relatively short incident duration of 15 minutes. In doing so, we created a volatile network, which leaves ample room to analyse the potential of information technologies on network performance.

5 RESULTS OF THE SIMULATION EXPERIMENTS

In this section, the results of the simulation experiments are presented. As discussed in the previous section, 96 different cases have been simulated, and each case is repeated 5 times, to account for the stochasticity of a run. Unless stated otherwise, the performance indicators used to analyse these cases are the average travel time for drivers *with* information, *without* information, and the *network wide* travel time. Formula [6] shows the calculation of these performance indicators.[5]

$$\sum_{r=1}^{5}\sum_{p=0}^{199} X_{p,r}^{m} \qquad m = \textit{average, with, without.} \qquad [6]$$

$$X_{p,r}^{m} : \textit{average travel time for group } m \textit{ in period } p \textit{ and run } r.$$

In studies concerning recurrent congestion, attention is generally focused on the network performance at *steady state*. In these circumstances, steady state is defined as a situation in which no driver has an incentive to switch alternative (Mahmassani and Herman, 1990). In a road network with non-recurrent congestion, however, drivers equipped with an information device might switch alternative when faced with an incident, even after the system has been simulated for a long period of time. As a consequence, a steady state might not be reached. Due to the relatively large number of incidents generated in the road network, this is the case with the simulation experiments conducted in this paper. Therefore, the travel time performance indicator is based on a run average as specified in [6]. In the next sections, the results of the simulation experiments are discussed.[6]

5.1 General observations

Figure 5 depicts a trend prevailing in all conducted experiments. The volatility in daily network wide travel time shows a decrease as the level of market penetration increases. Furthermore, the network wide travel time is significantly lower as a large part of the drivers has access to the information. This brings us to an important conclusion regarding boundedly rational behaviour.

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[5] On purpose, a *run-in* period has not been used; the average is taken over all periods. The reason being that excluding the first days from the performance indicator calculation implies that the different speed of network knowledge acquisition for drivers with and without information is neglected.

[6] The variance of the five different runs of the conducted experiments were very small. Hence, the results reported in this paper are statistically significant.

If drivers behave according to a boundedly rational model without being provided with information in a network with non-recurrent congestion, they are unable to choose routes leading to an efficient use of the road network in terms of total travel time.

Figure 5 shows that a significant efficiency improvement is available through information provision. Comparing these results with simulation experiments in a network with recurrent congestion (Emmerink et al., 1993a; Mahmassani and Herman, 1990), it becomes clear that information provision is more useful in a network with non-recurrent congestion. In Emmerink et al. (1993a) it was found that information provision in a network with recurrent congestion is particularly useful during the process leading to a steady state; at steady state, the reduction in travel time did (although statistically significant) not exceed 5 per cent.

Figure 5 Daily network wide travel time for 1 run. upd=1, p=0.19, en_route_bound=0.05.

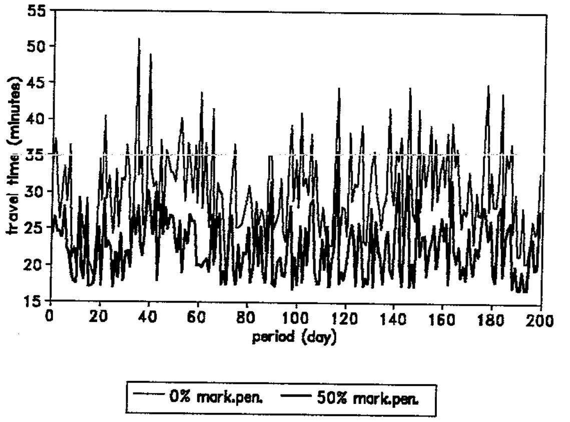

Figure 6 Benefits for different groups of drivers. upd=1, p=0.19, en_route_bound=0.05.

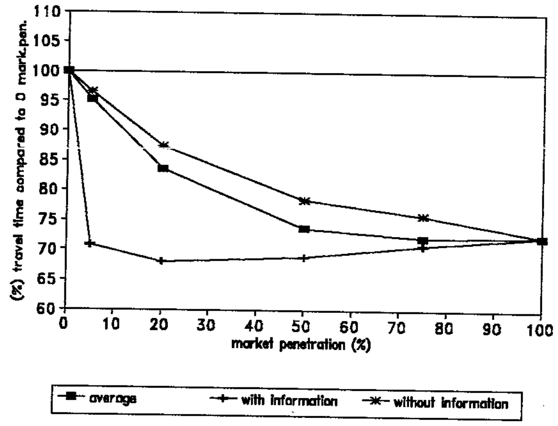

Figure 6 shows a typical graph of both the network wide benefits and the benefits to the different groups of drivers as a function of the level of market penetration.[7] As discussed in detail in Emmerink et al. (1993c), a motorist information system is an economic good of which the benefits to the buyers depend upon the level of market penetration. This is underlined by the experiments in this paper, as shown in Figure 6. There it can be seen that

the additional benefits to equipped drivers decrease quickly as the level of market penetration increases.

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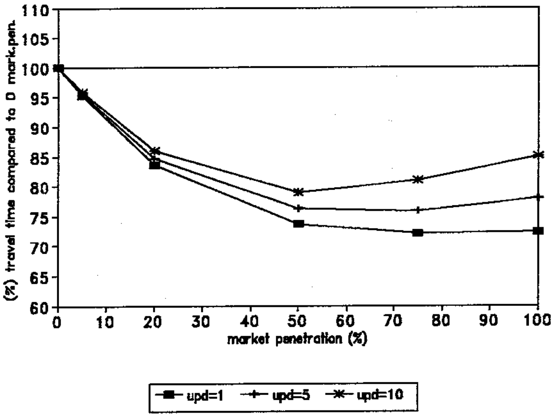
[7] Strictly speaking, the *with information* curve is discontinuous at 0 market penetration, since there are clearly benefits to the first equipped driver. Furthermore, the *without information* curve might be discontinuous at full market penetration in a network with non-recurrent congestion (Emmerink et al., 1993c).

Moreover, non-equipped drivers are also affected by the information device, and their benefits also depend upon the level of market penetration as well.

5.2 Updating frequency and network wide performance

A decrease in the updating frequency has an adverse effect on network wide performance, as depicted in Figure 7. The size of this negative effect is dependent on the level of market penetration. As the level of market penetration increases, more drivers respond to the *old* (not frequently updated) information, and hence the information does not accurately reflect the situation in the road network. As a consequence, overreaction as defined in Ben-Akiva et al. (1991) and discussed in Emmerink et al. (1993b) takes place. At full market penetration, the size of this negative effect is larger than 12 per cent in our model. However, the network wide situation is at full market penetration still considerably better than with no market penetration. The negative effect, associated with overreaction, does not completely offset the benefits owing to information provision.

Figure 7 Network wide performance as a function of market penetration for three updating times. p=0.19, en_route_bound=0.05.



The relatively large gaps between the curves shown in Figure 7 might also have been affected by the structure of our test network, depicted in Figure 4. Each driver has to make a maximum of six (!) consecutive decisions. Clearly, the larger the number of decisions, the more likely it is that one of these was based on relatively *old* information. However, on the other hand one might argue that many decision points leave ample room to the drivers to correct past route choices.

Furthermore, Figure 7 shows that the *optimal* network wide performance is (1) not reached at full market penetration of the information technology, and (2) is dependent on the quality (updating frequency) of the information. The first point has been mentioned repeatedly in the literature, see for instance Mahmassani and Jayakrishnan (1991), Watling and Van Vuren (1993). Concerning the second point, Emmerink et al. (1993a) found similar results regarding the dependency between the optimal level of market penetration and the quality of the information. Mahmassani and Jayakrishnan (1991) argued that in such a situation *coordinated guidance* becomes necessary. Coordinated guidance could lead the traffic flows - in theory - towards a system optimum. To achieve this, some drivers have to be diverted from their user optimal routes to system optimal ones. However, as discussed by Bonsall et al. (1991), it is highly unlikely that these drivers will comply with the information. An incentive to *force* them to comply is needed; a kind of pricing is the most obvious one.

5.3 Number of incidents and network wide performance

The Bernoulli success parameter was set equal to 0.08, 0.19 and 0.38, to have on average 2, 5 and 10 incidents in the road network. Figure 8 shows the effectiveness of information provision for these three incident rates with an updating time of 1 minute.

Figure 8 Effects of information for three incident rates. upd=1, en_route_bound=0.05.

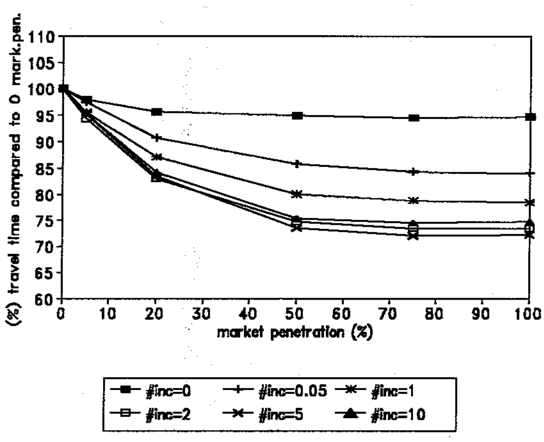
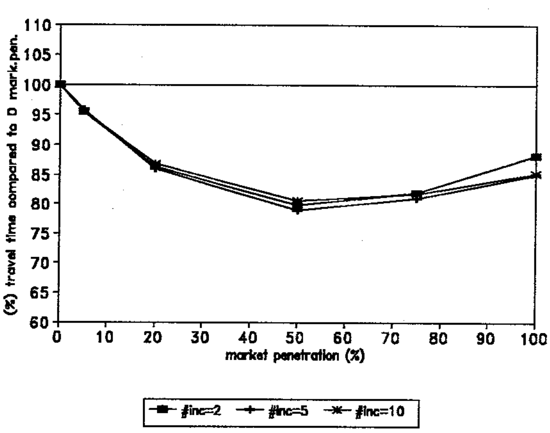


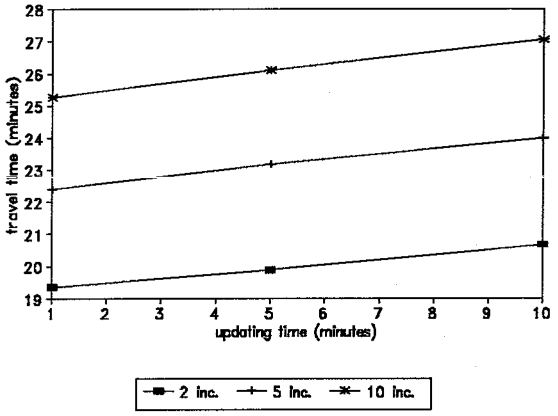
Figure 9 Effects of information for three incident rates. upd=10, en_route_bound=0.05.



Surprisingly, the percentage of travel time improvement for the three different scenarios (2, 5 and 10 incidents) is practically identical.[8] With an updating time of 10 minutes, the result is similar, as depicted in Figure 9.

Figure 10 illustrates the dependency between the network wide travel time and the updating interval for the three incident rates at 50 per cent market penetration. Clearly, the network wide travel time increases both with the incident rate and the updating interval. The increase is approximately linear, and the curve shifts parallel for different incident rates.

Figure 10 Dependency between updating frequency and incident rates. 50% market penetration, en_route_bound=0.05.



5.4 En route switching propensity and network wide performance

The en_route_bound determines the willingness-to-switch routes during the trip. If the en_route_bound is relatively large, then switching during the trip will only take place if the gain in expected travel time is significant.

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[8] This result was so surprising, that we decided to carry out some experiments with smaller incident probabilities, 0, 0.02 and 0.04, respectively. For these incident probabilities, the efficiency improvement owing to information provision was clearly smaller. The curve with zero incidents obviously reflects the network with recurrent congestion.

Figure 11 Effects of en_route_bound on network wide performance. upd=1, p=0.19.

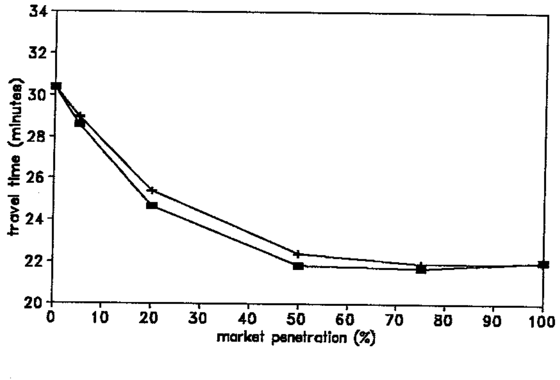


Figure 12 Effects of en_route_bound on network wide performance. upd=10, p=0.19.

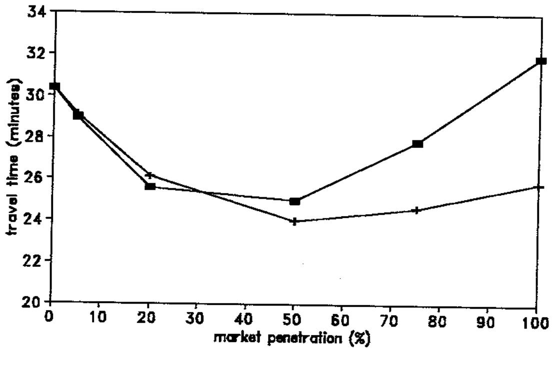


Figure 11 and Figure 12 depict the effects of the en_route_bound on the network wide performance for two different updating times. Firstly, Figure 11 shows that if the updating time is small - rendering high quality information - the model with the lowest bound outperforms the other one. However, at higher levels of market penetration the gains are almost identical. This situation has changed in Figure 12, where the updating time is 10 minutes. Here, at low levels of market penetration, the model with the higher en route switching propensity performs best. However, at higher levels of market penetration, this is reversed, and at full market penetration, the model with the largest bound performs significantly better. This result is what we intuitively would expect:

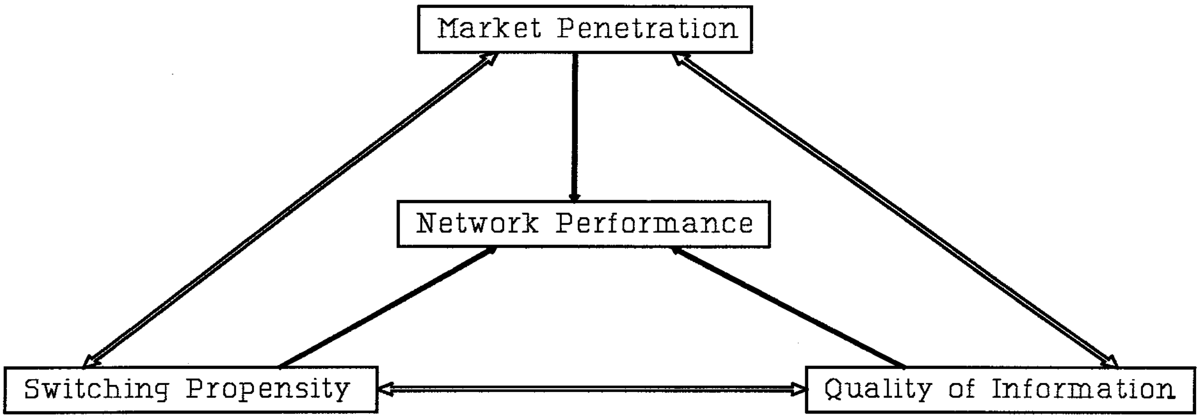
> *With relatively unreliable information, drivers should switch only if the gain in expected travel time is large.*

The relationship between these three parameters (switching propensity, market penetration, quality of information) and the network wide performance is schematically illustrated in Figure 13.

Figure 13 should be interpreted in the following manner. To preserve an *efficient* road network performance the *rules* listed below should be taken into account:

- If the level of market penetration is relatively low, then the quality of the information is not crucial.
- If the level of market penetration is relatively high, then the switching propensity should be relatively low.

Figure 13 Network wide performance in relation to switching propensity, market penetration and information quality.



- If the quality of the information is relatively low, then the switching propensity should be relatively low.

6 CONCLUDING COMMENTS

Recently, the potential of ATIS to resolve part of the non-recurrent congestion problem is attracting more attention. This paper follows that trend through a simulation of traffic flows in a road network in which incidents are generated in a random fashion. A behavioural approach has been chosen to acknowledge that the effects of ATIS on the network wide performance have to be analysed there where the new technology penetrates into the transportation system, i.e. at a drivers level. Hence, traffic flows in this study were not determined by user equilibrium considerations, but by the aggregation of drivers' decisions.

Drivers' behaviour is modelled using boundedly rational principles. These models have not yet been rigorously validated in a transportation context. As a consequence, the results derived in this paper cannot simply be generalised to real road networks. However, they give a clear indication of what to expect in a *boundedly rational world.*

The simulation experiments focused on the relationship between the network wide performance in the road network with randomly generated incidents and

- the level of market penetration,
- the quality of the information as reflected by the updating frequency,
- the switching propensity during a trip.

The following results were obtained:

- If drivers behave according to a boundedly rational model without being provided with information in a network with non-recurrent congestion, they are unable to use the road network efficiently in terms of total travel time.
- The additional benefits to equipped drivers decrease quickly as the level of market penetration increases.
- The *optimal* network performance is dependent on the level of market penetration, the quality of the information and the en route switching propensity.

To conclude, there is clearly more scope for ATIS in road networks with non-recurrent congestion. ATIS has a potential to improve the efficiency of road networks. However, particularly due to the complexity of human behaviour with respect to these new technologies, the beneficial effects remain uncertain.

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