THE IMPACT OF PRE-TRIP AND ON-TRIP TRAFFIC INFORMATION ON NETWORK PERFORMANCE:

CASE OF THE AMSTERDAM NETWORK

UNIVERSITY OF TWENTE.

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SUMMARY

INTRODUCTION

Road networks make an important part of society and are essential for movement of people and goods. These road networks however also pose negative effects on society one of which is congestion. Congestion of road networks leads to losses especially of time and money and has adverse environmental implications. Information technology is a concept that has found its way into modern society and advancements and new innovations in the sector are emerging more often. The application of this technology in solving traffic related problems like congestion is something has been done and more research into it is going on.

One of the ways the technology is being applied is using it to provide traffic information through the advanced traveler information system (ATIS) applications. The provision of this traffic information is done through various means one of which is use of smartphones that are gaining popularity around the world. This whole direction is adopted in traffic management because of the change in trend from just increasing road network capacities to cater for increased traffic to the efficient management and use of existing network facilities. This new technology and its application require testing prior to implementation because of the investment costs that go into making it a reality. To do the tests, carrying out traffic simulations and determining the impact of intended developments is one way to research into the expected impact of traffic information on road network performance.

OBJECTIVE

The objective of this research was to determine the impact of on-trip and pre-trip in-vehicle travel time information on network efficiency. The Amsterdam road network was used as the case study area.

METHODS

The Amsterdam road network and the associated demand during the morning peak period of a normal work day were used as a test case. The highway part of the area network was used and the traffic demand for the section was created. The network complete with the demand was then used to run simulations for the cases without information and the cases with information. On-trip and pre-trip information were implemented on the network and relayed to the drivers. The output was then analyzed to determine the efficiency of the network with and without the information. The information being in-vehicle, penetration rates were considered important and different rates were tested under various traffic conditions. The conditions under which the information was tested were varied to replicate occurrences in traffic that could lead to increased demand like accidents/incidents, road works and or events.

RESULTS

By carrying out the various simulations mentioned in the methods section and analyzing the output the results obtained are summarized in the tables i and ii below. To start with the results for the pre-trip information are presented in table i.

Information type	Scenario	Penetration rate	Impact		
			Throughput (no.of vehicles)	Congestion length (km-minutes)	Average Speed (m/s)
pre-trip -300	Normal	10%	69,0%	-2,1%	0,8%
		15%	74,0%	-6,2%	-
		20%	70,0%	-3,6%	-
		25%	54,0%	-2,3%	2,6%
Pre-trip 600	Normal	10%	71,0%	-3,0%	1,7%
		15%	72,0%	-7,7%	-
		20%	68,0%	-4,0%	-
		25%	64,0%	-3,5%	4,0%
Pre-trip 600	Lane closure	10%	3,4%	-2,6%	9,0%
		25%	4,4%	-7,2%	13,0%
Pre-trip 600	Growth	10%	2,5%	-4,3%	2,1%
		25%	5,0%	-9,1%	7,6%

Table i: Summary results for pre-trip information.

To analyze the impact of the information three performance indicators as can be seen from the table namely throughput, congestion length and average speed were used. For this information type it can be seen that the impact was positive, the throughput went up, congestion length reduced and the average speed increased as result of implementation of the information for all the scenarios considered. For the normal congestion, that is recurrent congestion the impact on throughput was more than 50%, this was because the redistribution of the traffic in space (change in route) and time (change in departure time) was effective because of the existence of capacity within the network to allow for the redistribution, therefore average speeds improved and more drivers were able to complete their trips.

The penetration rate was also seen from the presented results to have an impact on the effectiveness of the information. The best results were reported for the 15% rate of penetration after which the gains made by the information went down. This is because with increase in the number of drivers with information, the available opportunities for route change and departure time shift and the ability of those changes to be effective reduce because now more people are striving for them. It should be noted that for this information, especially for departure time shift, it was modeled for compliance, that is the drivers provided with information and the expected to change their departure time as result, that change was effected assuming all would comply. In reality not all drivers comply with information and therefore it is expected that a market penetration rate of higher than 15% would give a compliance rate of 15%.

For the traffic incidents, where the traffic demand was altered as a result of unexpected disturbance in traffic conditions, the results are positive as well. For these cases the improvement in throughput is less than 10% and the recorded improvements in congestion length and average speed are higher than he gains recorded for the normal congestion case. The first reason for that is that for the incident cases the simulation period was extended by thirty minutes because it was noted from the normal congestion cases that the simulation period was short and therefore the simulation ended with the network still congested. The extended simulation period for the base case and the cases with information for the two incident scenarios allowed more trips to be completed. With the implementation of information for these cases therefore, the resulting distribution of traffic led to improved speeds and reduced congestion length.

For throughput the improvement for the first intervals of the simulation was not much because even in the base case a similar number were able to complete their trips because of the extended simulation time and not just because of the information, the small difference in throughput can therefore be attributed to improved speeds (higher compared to base case) but these were limited by capacity constraints due to increased demand caused by the incidents. In other words the results of the normal congestion case throughout may have been influenced by the shorter simulation period and therefore if a longer simulation period had been used in the normal congestion case also it is probable that the increase in throughput would not be that big.

For the incident scenarios, better results were noted for the higher penetration rate (25%) as opposed to the lower (10%). This is because in the case of an incident, the more drivers aware of the incident and therefore able to avoid the situation by either changing route or departure or any other appropriate measure the better it is for network performance. Rates higher than 25% were not tested so it is not possible to indicate at what level the gains begin to reduce. This kind of trend was also recorded in past studies where for example (Levinson, D 2002), (Mahmassani and Jayakrishnan, 1991) and (Koutsopoulos & Lotan, 1989) noted that information is of greater value under traffic disturbances.

The results obtained however according to the results of the T test are not statistically significant at the 95 and 90% confidence levels; the only significance was recorded at the 60-70% level. The reason for this could be the wide variations that were noted between the results of the different simulation runs. In those results the 5 minute variation for the link data between the runs was quite high and this therefore required a higher number of runs in order to get better results in terms of statistical significance. With that variation and noting that the T test shows if the null hypothesis (that the two means being compared are the same/equal) is true or not the results obtained (P values of 0.333) cannot be attributed to mere chance and not the presence of information because there is about 70% possibility that the results are due to the information.

The results for the second type of information, on-trip are presented in the table ii below

Information type	Scenario	Penetration rate	Impact		
			Throughput (no.of vehicles)	Congestion length (km-minutes)	Average Speed (m/s)
On-trip	Normal	10%	-1,3%	6,2%	0,8%
		25%	-0,2%	8,0%	-0,2%
	Lane closure	10%	2,7%	0,5%	4,0%
		25%	1,3%	2,7%	3,6%
	Growth	10%	2,7%	-1,9%	0,9%
		25%	4,1%	-3,3%	1,9%

Table ii: Summary results for on-trip information.

From the table it can be seen that the impact of on-trip information is somewhat mixed. For the normal congestion case implementation of the information is seen to worsen the situation. The throughput reduces by up to 1.3%, the congestion length increases by up to 8% and for the average speed it reduces for the 25% rate of penetration and increases for the 10% case. This was an unexpected and undesired effect of the information. The reasons for this are varied also, one is the type of information, the kind of information given in this case was based on instantaneous updates of real-time travel time, if the driver responded fast to it, it could lead to route changes that are not optimal because it lack projection/prediction in the updates on the traffic build up on the chosen routes. In this case the situation would be worse. This kind of behaviour was also noted in the research by (Hall,1996), they further noted that in such information cases, when the penetration rate is increased the effect of the information on network performance becomes worse, which was also noted in this case by the fact the 10% penetration rate recorded better results compared to the 25% rate. For a different information type for example one with prediction, this kind of trend would not occur according to the reports of (Hall, 1996).

The second reason for the results obtained is the network configuration; the network tested excluded the secondary and primary roads. The implication of this and especially considering that for on-trip information the only possible response was change in route, the absence/limited number of alternative routes would have played a role in worsening the situation. The network that was used in this case had long stretches of highway and the only points for possible changes in route were at the intersection points. Therefore once a driver is past that point, any updates of information would be irrelevant because there are no alternatives anyway.(Koutsopoulos & Loan 1989) noted this in their studies and stated that highways/freeways and arterials with excess of total capacity and available alternative paths provide good opportunities for successful implementation of this kind of information systems.

Another reason for the results presented was also the simulation period and nature of the simulation tool. The simulation period which in this case was two and half hours was not enough for the simulation to run to completion and therefore allow the network to reach its peak and reduce from that to empty, the behaviour of the simulation tool also contributed to that in that once congestion started to build up, the origins were blocked and no more vehicles were released to the network. From the results presented later in this report showing variations of the performance indicators with time the most variation was noted about 30 to 45 minutes into the simulation when congestion has started setting in. This would indicate that information would be more important when the traffic conditions begin to deteriorate for example when the flow approaches capacity and congestion sets in. similar findings were reported by (Levinson. D 2002), who found that information (real-time), is most effective at about 95% of capacity flow. This could also explain why for example in the incident cases where the traffic demand is increased due to the incidents the results reported are more positive.

For the incidents, lane closure and growth, the growth scenario presented the best results for this kind of information. This was also the one that experienced the worst conditions because traffic was doubled compared to the base case. For this case positive results were reported and the 25% penetration rate posted better results than the 10% case. The reason for this is that in the case of a disturbance in traffic conditions, drivers who are unaware follow their usual behaviour but those aware of the situation make different choices (route) and this could lead to better network performance. These disturbances also indicate a case where traffic flows reach capacity faster and because the real-time updates are done in short intervals the impact of the congestion is detected and relayed early allowing route changes to be done.

For the incident scenarios comparing the pre-trip and on-trip information, it can be seen that the pre-trip information was more effective. This is partly because of the modeling of the driver response where pre-trip especially departure time shift was modeled for compliance while the on-trip the driver response was based on the route choice utility model. The second reason is the kind of information, for pre-trip the information relayed to the drivers was based on average flows for the entire period (based on base case traffic flow output) while for on-trip it was real-time being updated every 120 seconds. This would mean that in case of a problem, it would takes time before the effect of the problem spills back and is recorded by the loop detectors and in that time traffic would still be allocated even to the affected areas. When this effect is finally felt and recorded and the necessary changes made the overall impact is not as effective as that of the pre-trip information.

The results for this information (on-trip) are similar to the pre-trip in terms of statistical significance, where they were not statically significant at the 95 and 90% confidence levels. This was again different at the 60-70% levels, with p values averaging at 0.33. The reasons for this are mentioned.

CONCLUSIONS AND RECOMMENDATIONS

From the results obtained it can be concluded that if drivers are provided with descriptive pre-trip information and this information is targeted such that the drivers are given opportunities to change their departure time, routes and or their entire trips then this kind of behaviour would result in improved network performance in terms of throughput, congestion length and average network speeds. This kind of information would be effective for both recurrent and non-recurrent congestion at compliance levels of 15 to 20%.

The results also indicate that on-trip information would be more effective in cases of traffic incidents (non-recurrent congestion) with the effect on recurrent congestion being negative. Therefore under traffic disturbances having information (irrespective of quality) is better than not having information at all. The results as obtained can however not be generalized because it was noted that the configuration of the network does play a role in the expected impact. The results also did not show convincing statistical significance and therefore more tests would need to be done before more conclusions can be drawn out of them.

For future studies it is recommended to improve the modeling of the information, for example to include utility modeling for departure time choice and to include a travel time prediction for the on-trip information. Also changing the network configuration by including the secondary and primary roads could give more representative results especially if accompanied with an upgrade of the route choice model to include road attributes (to distinguish the highways from the secondary and primary roads). These would require using just a section of the complete network or a different simulation tool because the complete network would be too large for the kind of tool used here. Expanding the simulation period to maybe four hours and using the same network (in line with the PPA project)would also help to show the entire peak period, give time for completion of trips and therefore determination of travel times and the results obtained would then be better. Including both pre-trip and on-trip information in the same scenario would also be an interesting point for future studies to show what would happen should the information system be implemented at the same time and what effect the rate of penetration would have on the performance of the network under the information.

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1.0 INTRODUCTION

Traffic delays due to congestion are a common phenomenon across major cities in the world because traffic intensities are increasing faster than roads can be expanded. In addition traffic related pollution and deaths/injuries due to traffic accidents and incidents are experienced. These problems have been the subject of research and discussions in the field of transportation engineering. Several ways have been proposed and implemented in several cities across the world to mitigate these problems. One of those solutions that are of interest currently is Advanced Traveler Information Systems (ATIS).

The main function of ATIS is to provide information for travelers; the information could take the form of travel time on different routes and using different modes, the location and extent of congestion on the road network and the occurrence of accidents and/or incidents, the most appropriate time to depart and or the mode to use among others. The goal of providing the information is to help travelers make better travel related decisions under the assumption that better travel choices will lead to better network performance. The means used to provide the information range from infrastructure based outlets to personalized (in-car for example) outlets.

The objective of this research is to assess the impact of information specifically in-vehicle travel time information on the traffic network in terms of throughput. The study is limited to the road network in the city of Amsterdam. The authorities in the city have two projects namely the Amsterdam Field Trial (Praktijkproef Amsterdam; PPA) and the planned road works in the corridor Schiphol-Amsterdam-Almere (SAA). The PPA service is aimed at both regular users and visitors during the special events because these events also lead to congestion. The SAA service aims to relieve congestion associated with the subsequent road works.

The aim of the PPA is to get about 10,000 car drivers out of the road during peak period flow and to also manage more efficiently the traffic flow during big events and incidents on the Amsterdam network by reducing the congestion levels. The authorities have proposed to use information to mitigate these problems. This research concentrates on the regular traffic during the peak period with the aim of reducing congestion and getting motorists out of the road. The road works are incorporated as scenarios with the information being tested by using it to manage the effects of the road works.

The proposed information to use which is tested in this research, is KATE developed by the Netherlands Organization for Applied Scientific Research (TNO). In the literature review section, past studies on this topic are reviewed. The studies show that the impact information has varies from region to region because the impact depends to a large extent on how drivers respond to the information. The impact also depends on the kind of information and the means used to disseminate the information. Information provided should therefore be designed in such a way as to achieve the desired effect, to do this understanding of how drivers make choices and what factors play a role is important.

The rest of this report is structured this way; chapter 2 gives the research problem highlighting the specific research objectives and questions that will be the guide for the research and the method used. Chapter 3 looks into the literature and studies done in the past this subject and the methods used. Chapter 4 describes how the experimental set up for the research is done, chapter 5 the implementation of information, chapter 6 the data analysis and discussion of results and lastly the conclusions and recommendations in chapter 7.

2.0 PROBLEM DEFINITION AND RESEARCH METHODOLOGY

2.1 INTRODUCTION

Investment in ATIS services is costly and therefore proper planning and knowledge of what kind of impact the information should have is required to commit the required funds. To get the knowledge of what kind of impact the ATIS will have means that ex-ante evaluation of the services to be implemented should be done. This evaluation is possible by carrying out tests in a simulated network environment using traffic simulation tools/models.

For in-vehicle based information services this evaluation of impact prior to implementation is especially important because acceptance and usage by the target group is a prerequisite for its success. It therefore becomes important as a way to encourage usage and acceptance to determine and quantify the effect it will have. In determination of this impact a number of issues are considered; the impact will depend on the rate of usage (penetration rate of the information) and therefore it is useful to test what penetration rates lead to what quantity and form of impact. In addition the performance of the information under different conditions should be tested to determine if it is able to handle occurrence of incidents/accidents and other events on the road network. To do all these tests a simulation environment is necessary

2.2 PROBLEM DEFINITION

The city of Amsterdam is one of the most densely populated cities and the number of motorists is high. In addition the city is criss-crossed by several rivers and canals and therefore leaving little room for expansion of the road network to cater for the increasing traffic demand. The road network therefore is used extensively and as such congestion is experienced especially during the peak periods (morning and evening), in the case of accidents or incidents on the network and during special events that take place from time to time in the city.

In summary the city road network is experiencing congestion and the usage of the network and the congestion also leads to pollution. The congestion is of two forms, the first is the congestion caused by the regular traffic during the morning and the evening peak. Scheduled road works lead to lane/complete road closures and subsequent diversions; since these are planned prior the congestion caused by this traffic can also be considered under regular traffic. The other form is the congestion caused by irregular traffic for example big events like a football match in the Amsterdam arena or celebrations of such occasions as the queen’s day. Incidents and accidents also could lead to congestion. An incidence in this case could be extreme weather that makes the roads impassable or slippery and therefore reduces speed and leads to congestion.

To solve these problems efficient usage of the network has been proposed as a possible solution. The use of traffic information to achieve this is one of the proposed solutions. The information is aimed at various outcomes for example for the regular traffic using information to redistribute the traffic in time and for event traffic using event management information on sale of tickets and/or parking guidance information along with routing information to manage the extra traffic caused by the events.

As earlier motioned this research concentrates on the congestion caused by the regular traffic under different conditions (normal, accident and incidents). Using information to manage these is the subject under consideration by testing what impact the information will have. To achieve this, the main objective of the study is defined broken down to specific research questions that will have to be answered in order to quantify the impact.

The information being mentioned here to be used as a solution to the congestion issue and that which is to be tested in this research is the information service KATE developed by TNO. KATE is smartphone based information and more is mentioned in section 3.7. It is therefore an in-vehicle information service. The information provided via this platform is also personalized, that is personal information and interests of the user are known and the information given is therefore customized to meet individual needs.

Interpretation of how the information works and understanding of the sources of data used to generate the information was considered as a necessary first step toward implementing this information in a simulation environment. The schematic diagram below shows the general concept behind the operation of the information. KATE as an information service is targeted as multimodal transport but in this case only car travel was considered as per the stipulations of the PPA project. The figure 1 below gives an overview of how the information works.

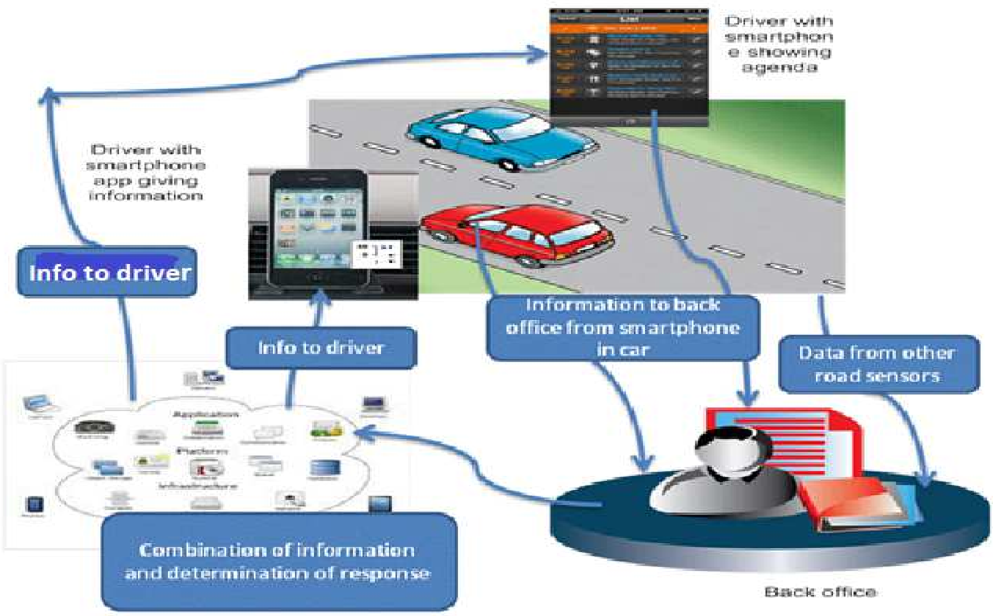


Figure 1: Schematic presentation of the information service KATE

The flow starts with a driver who has the app, this user relay information about their location to the back office. In the back office details of the user are already stored in database including personal data details. Also from continued usage of the app, user profiles are updated to include home locations and other locations the user goes to and the routes followed. When the user therefore relays the information to the back office, in turn the user gets advice on departure time and route choice. The decision made by the user as response to the information is recorded and fed back to the system to improve future advice given. The three (pre-trip, on-trip and parking) types of information implemented work differently but based on the same pattern of flow as described previously.

There are also algorithms that do short time predictions that are incorporated in the information/advice given. The data generated also by users that send their location and therefore travel times and other data is stored in the back office and is used to update the historical data and can be used for other functions as well. In addition to the information relayed by the users the other existing road sensors can also be used to provide extra data needed to improve the predictions. In its current state the KATE information service is based mainly on the back office applications. This is because it uses mainly historical data and free flow conditions. This will change once it's developed to include real-time traffic data.

Translating this information and how it works to the simulation environment was considered a major step toward carrying out this research. Of the three types of information mentioned previously only pre-trip and on-trip types were tested in this research

2.3 MAIN OBJECTIVE

The main objective of this research is to assess the impact of in-vehicle travel time information provision on the throughput on the road network in the Amsterdam area. To study the impact of information in a simulated environment, replicating the behavior of drivers is important and therefore knowledge of how drivers make choices and how they behave under the influence of information is required. In carrying out the simulation the input into the models in terms of behavior determines the output and it is that relationship between the inputs and the output that is the main concern of the study. The case of the Amsterdam network is used to test out these relations. The overall objective of this study therefore is:

Determine the impact of in-vehicle pre-trip and on-trip travel time information on road network efficiency.

2.4 RESEARCH QUESTIONS

To carry out the research and meet the main objective, 7 research questions are formulated. The questions, how they are answered and their contribution to meeting the research objective are further explained below.

1. ***What traffic problems exist in the Amsterdam area network and what performance indicators may be used to characterize them?***

The research uses the Amsterdam network as a test case for the impact information will have. Knowledge of the problems experienced and quantifying these problems will set the case that is to be solved. By using performance indicators for example travel time, length and amount if congestion and delays the case before and after implementation of the information can be tested. The outcome of the test will be used to answer the question of what impact information has. The setting up of the network and analysis of the problems experienced is done in chapter 4 of this report.

2. ***What factors affect driver route and departure time choice behavior?***

Answering this information is important in that the information provided whether pre-trip and/or on-trip is aimed at helping drivers to make better choices in terms of the route to follow and the departure time. Representing that behavior in the simulated environment in a way that it replicates as accurately as possible the real world behaviour is required so as to give results that are realistic and representative of the real-world case. Studies have been done in the past on this subject these are reviewed in chapter 3 of this report to answer this question.

3. **What is the most appropriate simulation environment to carry out this test?**

There a number of simulation tools and of different kinds that are available that can be used to conduct a test of the kind being done in this research. Looking into the different types and what each of them can do is a way to determine which of them is the most suitable for this case. To answer this question, available literary studies on the subject were reviewed and this is reported in the literature review section 3 of this report

4. **How does the provision of on-trip and pre-trip information affect drivers' route and departure time choice?**

This question answers how drivers respond to on-trip and pre-trip information and what factors play a role. This research is done by assuming a certain kind of driver behavior and response to information. The assumption is obtained from the existing body of literature. Answering this question therefore gives the basis for those assumptions that are used as input in the ITS Modeller. The question is answered in chapter 3 of the report on Literature review.

5. ***How can on-trip and pre-trip information be modeled in the ITS Modeller?***

The ITS Modeller in its current state does not incorporate the information to be tested. Further the way the information is modeled will influence how the impact can be determined. The choices made in the way of Modeling for example on how to obtain the information and how to pass it to the drivers, as well as the assumptions made to make the information work in the tool need to be clearly stated. It is these understanding that will be used to support the relation obtained between the model inputs and outputs which as mentioned earlier is the focus of the research. These details are provided in chapter 5 of the report.

6. ***How does the route choice model in the ITS Modeller work?***

ITS Modeller is the simulation tool used in the study and therefore how its route choice model works and what factors go into making the decision is important to show how realistic it is to the real-life situation (considering the answers to the fist research question) and also to determine how the information can be added to that choice in the tool. In addition the research concentrates on the relation between the inputs and the associated outputs and the inputs of the route choice model form a significant part of that. This question is answered in chapter four.

7. **What is the impact of pre-trip and on-trip information provision in terms of throughput on the Amsterdam area network under different scenarios?**

The answers to this question are determined by the answers to the first six questions listed above. This is the main question of the research and it gives the impact the information will have by evaluating performance indicators mentioned in question one above. To answer this question the case with and without information is evaluated and the impact of the information after eliminating the effect of the other input variables and assumptions can then be determined. This question is answered in chapter six of the report on data analysis and discussion of the results. The answer to this question is the answer to meet the main objective of the study.

Answering all the above questions in the logical order should lead to answering the main question and therefore achieving the stated main objective of the study.

2.5 RESEARCH AREA

Testing of the information provision requires a network and for this research the Amsterdam network is used. The network consists of the Amsterdam ring road and the highways feeding into it that is the A1, A2, A4, A8 and sections of the A9 south of Amsterdam. The study will look at only the motorways with the on and off ramps being included. This is because the scope of the PPA and SAA projects is limited to the highways. The second reason is that traffic simulation the whole network will be too large and would take a lot of time to run because of the many O-D relations that would be involved. The Figure 2 shows the study area of the network to be studied.

Figure 2: Amsterdam area network used as case study area

2.6 RESEARCH METHOD

To answer the research questions and therefore meet the main objective of this research, the methods below are used. The methods range from literature search to modeling and analysis of the obtained output. The Figure 3 below gives the conceptual framework of the research and after the methods used to answer each of the research question listed above is briefly described.

2.6.1 What traffic problems exists in the Amsterdam area network and what performance indicators may be used to characterize them.

Requirements:	Amsterdam area network complete with the demand set up in the ITS Modeller. Running simulations on the set up network and analyzing the output. Quantifying of problems experienced on the network in terms of chosen performance indicators.
Method:	Setting up of the physical network in the ITS Modeller, determination and implementation of the origin destination (O-D) matrix. Running simulations on the set up network and analysis of the data collected from the output.
Sources:	Amsterdam network in the Omnitrans simulation tool for the network and the associated O-D matrix.

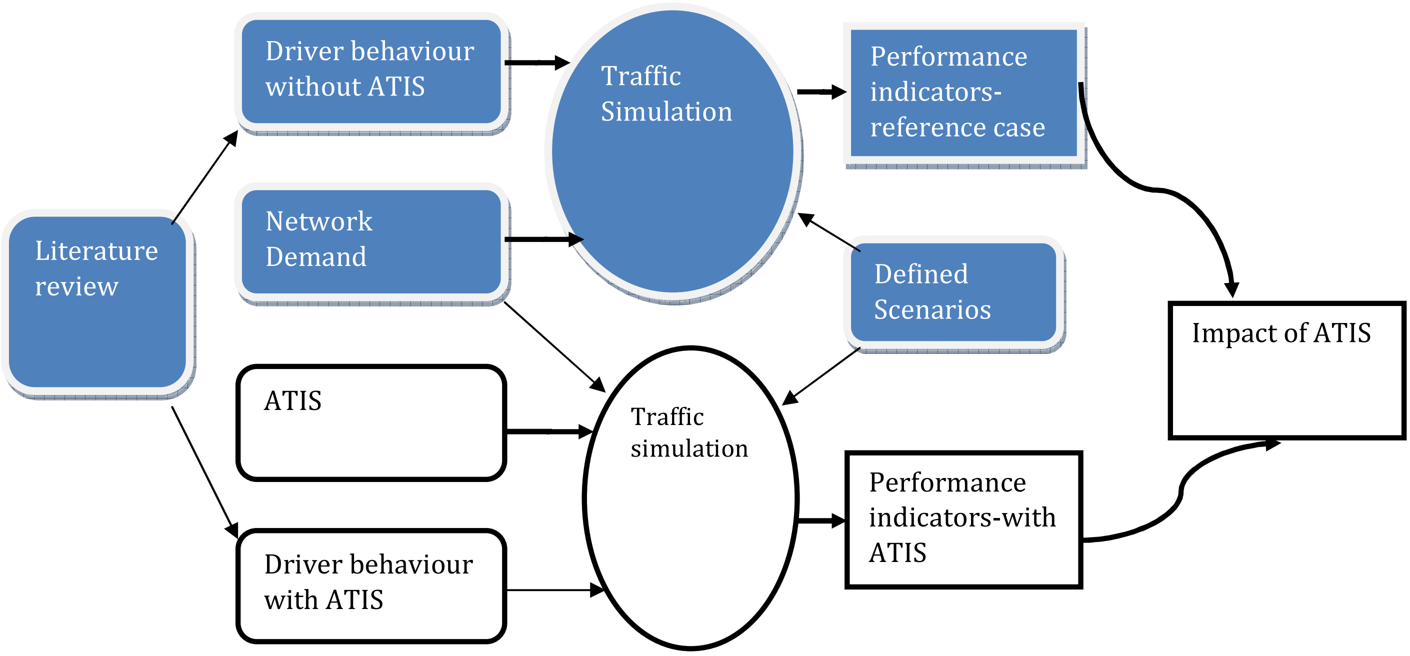


Figure 3: conceptual diagram showing the research method used

2.6.2 What factors affect driver route and departure time choice behaviour?

Method: Literature search and study

Sources: Articles, reports and journals on the subject from the internet especially scientific databases and from the TNO collection of conference proceeding s and published papers.

2.6.3 What is the most appropriate simulation environment to carry out this test?

Requirements: understanding of the different traffic simulation environments and what they each do and comparison of the merits and demerits of each as concerns the subject under study.

Method: Literature study

Sources: Internet articles and reports as well as product catalogues.

2.6.4 How does the provision of on-trip and pre-trip information affect drivers' route and departure time choice?

Method: Literature search and study

Sources: Articles, reports and journals on the subject from the internet and from the TNO collection of conference proceeding s and published papers.

2.6.5 How does the route choice model in the ITS Modeller work

Method: Literature search

Sources: Documented technical description of the ITS Modeller by the developer (TNO) and study of papers, report and articles in which the ITS Modeller was used.

2.6.6 How can on-trip and pre-trip information be modeled in the ITS Modeller

Requirements: The source of information, the form of the information, the means to transmit the information and who the recipients of the information are.

Method: Literature study on source of information and means of dissemination in real-world and other similar simulation tools. Discussing and consulting with experts at TNO and the University of Twente on the subject.

Sources: Articles, reports and journal from internet searches and recommendation from the experts.

2.6.7 What is the impact of on-trip and pre-trip information provision in terms of network efficiency on the Amsterdam network under different scenarios?

Requirements: Data on network performance under the different scenarios, appropriate performance indicators.

Method: Data analysis using analysis software of the output of the simulations run under different conditions. Comparison of the results obtained in relation to the input into the model. Performing statistical significance tests on the obtained results.

Sources: ITS Modeller output data.

3.0 LITERARURE REVIEW

This chapter looks into the existing body of literature on the subject of the influence of traffic information on network performance and the purpose is to answer the research question:

- What factors affect driver and route choice behavior?
- How the provision of information affects drivers' route and departure time choice?
- How the information can be modeled in micro-simulation tools?

The chapter is divided into sections starting with the introduction in section 3.1. In section 3.2 the topic of how drivers make route and departure time choice is discussed, in this section the factors that affect these choices are mentioned. In section 3.3 the modeling of departure time choice and route choice is discussed and the models used and their requirements are mentioned. In section 3.4 the influence of information in terms of route and departure time choices are discussed and the tools used to study that influence of information is mentioned in section 3.5. In section 3.6 and 3.7 the ITS Modeller and the information service KATE respectively are discussed and description of how they work given. The last section 3.8 gives a short conclusion of the chapter and the topics discussed in the different sections.

3.1 INTRODUCTION

The demand for transportation has been growing and continues to grow. The growth means that the capacity of the road networks to meet the demand decreases by the day and this has resulted in the traffic congestion problems experienced around major cities the world over. Initially the problem was solved by capacity expansions of the road sections, adding lanes and construction of alternative roads (Ettema, Tamminga, Timmermans, & Arenze, 2004). This solution is increasingly becoming unpopular. This is because the land on which to expand the road sections is now scarce, the costs of doing such investments high and the externalities associated with the expansion in terms of environmental pollution and traffic safety also high.

This has led to a shift to demand management and efficient utilization of existing capacities. To achieve this, several measures have over the years been developed and deployed. Coupled with the latest advancement in technology, the solutions to the problem have also been innovative and technologically sound. This in essence is the concept of intelligent transport systems (ITS) application of technology to solve traffic and transport related problems.

The underlying concept of these solutions is that traffic flow on the network is a collective effect of individual driver choices as they move through the network. In the movement drivers have to make several choices, for example which route to use, which mode (drive or use public transport), what time to depart, the destination and also decisions on the speed to drive and other decisions important for the driver to reach their desired destination. The collective effect of these choices is what manifests as network performance.

With the understanding that it is these driver decisions that affect the performance of the network, to manage and influence the traffic flow on the network the start point will be to affect individual driver behaviour. This then leads to the challenge of understanding how travelers behave on the network and the underlying reasons for that behaviour. By understanding how they behave it may be possible then to influence that behaviour by application and implementation of certain measures and by so doing achieve a desired level of network performance.

3.2 HOW DRIVERS MAKE ROUTE AND DEPARTURE TIME CHOICES

A considerable number of empirical studies have shown that drivers use numerous criteria in formulating a route. These criteria include: travel time and its reliability, traffic conditions, driver habits and cognitive skills, road characteristics, driver experiences and familiarity with the route among many others documented in the literature.

In a travel behavior survey conducted in Taipei for instance, respondents were asked to mention and rate parameters that affect their route choice, the parameters included in the study were travel time and its reliability, route cost, traffic safety, traffic comfort, roadway characteristics, information supply, drivers habits, drivers experience, cognitive limits, socio-economic and demographic characteristics. They used the results of the survey to develop a weight assessing model (Chan, Chang, & Tzeng, 1999).

The results of the survey indicated that the weights of the parameters vary; for example travel time has the highest weight followed by traffic conditions, travel time reliability, traffic safety, travel expenses, drivers' familiarity, traffic comfort, travel distance and driver habits in that order. Weights of travel time were high on average. Travel time reliability weight variations occur in scenarios, with incident congestion scenarios having the highest value. Travel expense did not vary much hence it was not considered that important. Travel distance had low importance on average. Weights of traffic condition were very high in all scenarios. Weights for traffic safety were found to be high on average. Weights for drivers' familiarity increased under guidance information. The results of the study are consistent with other similar studies into the factors that affect route choice; in addition the study shows that the factors and how important they are varies with the prevailing traffic circumstances.

(Chang & Chen, 1990) In their research into the factors that affect drivers' route choice, found the factors travel time, number of intersections, traffic safety, traffic lights among other factors to be important. In addition drivers' habits, cognitive skills and other behavioural considerations have an impact. The authors therefore argue that viewed in this light one can see that assuming travel time as the sole criterion for determining route choice is unrealistic and at network level may result in an inaccurate representation of the network. They further noted that an important factor introduced in the recent past is traffic information and its effect on commuter behavior and route choice in particular. This is supposed to help drivers make better decisions, however the route choice depends on the drivers' reaction to the information.

The authors in addition by carrying out a telephone based interview sought to see what kind of information is more important and what other factors may have influence. They found out that commuters might value pre-trip information more than on-trip because the pre-trip information gives them opportunity to change route or departure time in advance. This was indicated in this case by the fact that the coefficient for pre-trip information was higher than for en-route

Further results of the study shows the importance of another parameter which was not considered in the other two studies mentioned earlier, that is commute distance. If the distance to be travelled is large the drivers are more likely to try out an alternative route with a view to minimize their travel distance. The provision of information according to the findings of the study is a significant determinant of route choice if the information is about travel time on alternative routes. Age was also considered with the results indicating that older drivers are unlikely to change route, choosing instead to go with familiar routes where they have experience. The other socio-economic attribute that determines route choice is gender, with the results showing that gender is the most significant of the socio-economic characteristics. For gender male drivers were found to be more likely to change their route choice as compared to the female ones.

On departure time choice, studies show that the choice as to what time to travel depends on the trip purpose, flexibility of working conditions and socio-economic and demographic factors play a role too. For trip purpose business and work trips tend to have fixed schedules as compared to event and leisure trips. The working conditions also play a role in that for people who have flexible schedules that include working from home part of the day for example are more likely to change their departure time. Information was also found to play a role, where for example pre-trip provided can make a driver depart some minutes earlier or later than usual to avoid getting into congestion.

Many publications emphasize the importance of departure time choice as a potential response to congestion. The argument for this is that in general individuals try to maximize their trip utility by both minimizing travel time and arriving as close as possible in their vicinity of their preferred arrival time. In congested settings this implies tradeoff between travel time and arrival time involving both route and departure time switches (Dick Ettema, 2004).

3.3 MODELING ROUTE AND DEPARTURE TIME CHOICE

The section 3.1 gives the factors that affect route and departure time choice, to study this, travel surveys are done as is also mentioned above. To use the results of travel surveys in traffic management and especially to design and evaluate ITS, it becomes necessary that these choices are modeled; this can then be used in simulation and such other tools to estimate the impact of traffic management measures and even evaluate policy issues.

Generally for any given origin and destination there usually is more than one possible path to make a trip. Drivers make the choice and to model that choice in traffic simulation tools, route choice models are required. Given a transportation network and an origin and destination, the route choice model predicts the probability that any given path between the origin and the destination is chosen to make the trip.

To model route choice, discrete choice model are commonly used by considering that there is a finite (discrete) set of alternative routes. Discrete choice modeling is based on the random utility theory. The random utility theory has four postulates (D.Ortuza & Willumsen, 1995)

- Individuals belong to a given homogenous population Q, act rationally and possess perfect information that is they always select that option which maximizes their net personal utility.
- There is a certain set A of available alternatives and a set X of measured vector attributes of the individuals and their alternatives
- Each option A has an associated net utility U for individual q. the modeler does not possess complete information about all the elements considered by the individual making the choice, therefore the modeler assumes that U can be represented by two parts, a deterministic and random part: $U = V + \varepsilon$.
- The individual q selects the maximum utility alternative.

In general the utility is expressed as a cost function, with travel time as the most important component. The road network is represented by nodes and links between those nodes. Every link has a utility that represents the effort to cross that link (Faber, 2007). The link utility is determined by various factors and it is that total value that gives the link cost function. Common factors for the cost function of the choice models are travel time, distance, monetary costs, scenery, traffic condition, quality of the road surface and /or reliability. An example of a link cost function is given below:

$$C = a*T_{ff} + b*D + c*M$$

Where C: Utility cost

T_{ff}: Travel time

D: Distance

M: Monetary costs

a,b, c: Parameters for driver preference (coefficients)

In order to predict which link will be chosen, the value of its utility must be contrasted with those of alternative options and transformed into a probability value of between 0 and 1. For this a variety of mathematical transformations exist which are typically characterized for having an s-shaped plot, for instance, if it's a logit function it will be:

$$P1 \frac{\exp(V1)}{\exp(V1) + \exp(V2)}$$

Where P_1: probability of alternative 1

V_1: utility of alternative 1

V_2: utility of alternative 2

Basically, the random utility based (discrete choice) models can be divided into two groups: deterministic and stochastic route choice models. Deterministic route choice models always generate the same set of paths for an O-D-pair. Stochastic methods generate an individual (or observation) specific subset because of the effect of the random variable 'ε' mentioned in postulates of the random utility models.

The deterministic approach to traffic assignment assumes travelers to be perfectly informed utility maximizers. They are assumed to have complete knowledge of the whole network; they know all routes, they know the travel times and costs. Travelers determine their best alternative from utility maximization. Stochastic models use perceived knowledge. This is usually modeled by a random utility model where the stochastic error term is added to the utility of each alternative. This makes the stochastic models best suited to study the impact of information provision, the addition of information being aimed at reducing uncertainty (Eric van Berkum & mede, 1993).

The modeling of departure time choice; In (Dick Ettema, 2004) it is modeled similar to route choice using preferred arrival time and calculating the utility of arriving at destination within the preferred time. In this case the static O-D matrix is converted to dynamic by creating departure profiles. In the study by Ettema, 2004 using S-Paramics, the individual vehicle units are modeled with mental capacity to update their experiences and use this to make the next departure time choices. In this case the choice is based on individual decision with the vehicles modeled with the ability to make the individual choices and update their choices by learning for the historical data (pre-runs).

3.4 THE INFLUENCE OF INFORMATION IN TERMS OF ROUTE AND DEPARTURE TIME CHOICES

From the section above on how drivers make route and departure time choice, it comes out that among the factors affecting the choice is information. With that knowledge and by applying information technology leads to the use of ITS to provide of information, these specific systems are called Advanced Traveler Information systems (ATIS). The underlying assumption being, informed drivers make informed choices in terms route choice, mode choice, departure time among others. The better choices would then result in proper distribution of traffic in space and time through the network with the end result that there is improvement in network performance in terms of reduced congestion, more efficient flow and reduced impact on the environment.

The ATIS systems work on two assumptions; One, drivers are incapable of accurately acquiring the provided information on their own and two that the provided information is relevant to the drivers choice preference. Studies indicate that with the inclusion of information especially travel time the attribute of information becomes the most important determinant of route choice (Tawfik & Rakha, 2012).

With the introduction of traffic information into the picture of route and departure time choice, the question then becomes what kind of information should be given. (Dia & Panwai, 2007) In their study of driver behavior under the influence of information, they studied the effect of altering the message presented to the drivers. They had five different message types from qualitative, quantitative, predictive and to prescriptive. They found out that the prescriptive information that advised the driver to take the best alternative was the most effective. The predictive showed the expected travel time in 15 and 30 minutes and was also good in getting people to alter their route choices. The quantitative gave the expected length of delay on route and also the travel time on the best alternative; this too was found to have effect, though the prescriptive had more. The qualitative simply said there was congestion and was the least effective according to their results.

Using the results above they developed discrete choice models to describe the driver behavior, they found that, young drivers and those with flexible work schedules have a higher propensity to change their route choice. Females were found to be less willing to change their route, the influence of familiarity (years of experience) was not so much. These factors are the determinants of the driver response to the information.

(Zhang & Levinson, 2006)Carried out a study to find determinants of route choice and the value of information, this was done by use of instrumented vehicles in combination with questionnaires. The results are as with previous studies which show that drivers are more likely to choose a route that has less travel time, higher speed, less number of stops and better aesthetics. Drivers also prefer routes that are easier to drive, efficient, pleasant and familiar. For the influence of information they found that the following attributes play a role; information accuracy, attitude toward traveler information, familiarity with alternative routes, level of congestion, travel patterns (distance, frequency, and commute time), socio-economic and demographic factors and the perceived information acquisition and processing cost

Further they found out that the presence of pre-trip information for a route makes a route more attractive, this is for the case of infrastructure based information. The value of information is especially high for commute, visit and event trips and less significant for recreational and shopping trips. When making commute, event and visit trips drivers tend to choose routes that they are familiar with than unfamiliar routes.

Pre-trip information also plays a role in helping to reduce uncertainty over travel time variations encountered on the trip. With the pre-trip information drivers could change most attributes of their journey including departure time, route choice, mode choice, whether or not to make the trip and destination choice. (Chan-Jou, 2000) found out that commuters might value pre-trip information more than en-route, because it gives them the situation on their routes in advance, which gives them opportunity to change more variables of the trip like; to change route/and or departure time, mode, destination and whether or not to make the trip at all. (Chan-Jou,2000) on further investigation on the factors that affect route choice with emphasis on traffic information found out that pre-trip information was one of the significant factors.

from their wok they conclude that the higher in the travelers decision making chain the information is provided the larger the number of variables of behavior that are susceptible to be influenced. In addition, the earlier in advance of the intended journey the information is provided, the greater the scope for change. The down side is that there is greater uncertainty regarding the journey at that point and the information given is more predictive and therefore prone to change.

The kind of traffic information whether it is pre-trip or on-trip is provided using various means. The information could be passed on through radio services, through the print media, through the internet in which case one has to search for it, through variable message signs and in the recent past also in vehicle through for example smartphone applications. Whichever source of the information is used studies have shown that it is the content, reliability, relevance and quality of the information that matters. The response to the information and hence the impact of the information being less dependent on the source.

3.5 TOOLS USED TO STUDY THE IMPACT OF INFORMATION

With the understanding of driver choice behavior and the impact information is likely to play in influencing that choice behavior, the next step is to look into how the behavior affects the performance of the traffic network, that is what specific impact information has on and how this can be estimated by traffic managers. The estimation of the impact is important for purposes of investment considering that the provision of traffic information requires quite an amount of investment it is important to understand the impact it will have beforehand. It is also important for the design of the measures, the ATIS systems required for these function have to be designed, tested, redesigned or changed if necessary before the actual implementation.

In a study to find out the impact of information provision (Levinson, 2002) using micro-simulations show information has benefits. The typical information benefits according to their findings are at a maximum on the precipice of congestion, when vehicles are arriving at a rate of 95% of the capacity, while non-recurring congestion benefits are much greater. With advanced traveler information system each traveler individually, and the road network as a whole, could be made more productive according to their findings. In their findings they indicate that information is more effective for dealing with non-recurrent congestion than for recurrent. They also found out that as more and more drivers become informed (considering different penetration rates of an in-car information system) the travel time savings become less, which is a conclusion from most studies into the impact of information.

From the existing literature estimating the impact of information provision has been done by using simulation tools. In this case the information is modeled and so is the driver response to the information and the impact it has on the traffic network done by analysis of the output of the case with information and without. (Eric van Berkum,1993) in their research note that Since traffic flows are generated by individual drivers, the study of the impact of information should be on the influence of information systems on individual travel behavior.

In summary therefore researches into the determination of the impact of information provision can be categorized into three groups (Ahn, 2005). The first is evaluation at network level by using a simulation tool. The second involves behavior analysis using random utility models. The third involves conducting field tests. In traffic simulation, there are three types of simulation tools, microscopic, mesoscopic and macroscopic. It is important to look into them and what they can do with the view to find out the most suitable for carrying out impact analysis for information provision. The most common of the simulation tools are the microscopic and the macroscopic with the mesoscopic being an in between, bearing some characteristics of both.

3.5.1MACROSCOPIC MODELS

Macroscopic models study traffic from an overall average kind of view by looking at the traffic in terms of density, speed and flow. These were the first to be developed by scientists and looked at traffic flow as being similar to fluid flow though a river or a pipe system. The models attempt to classify the average behavior of a system or group as opposed to the specific behavior of each individual entity (Cluitmans, Griez, Jacobs, & Mehlkop, 2006).

The primary advantage of macroscopic models is that they have relatively simple calculations and therefore require less computational power. Their disadvantage is the loss of small details or dynamics that can be modeled with microscopic tools. Macroscopic models are suited for transportation planning and other related issues that require wide network implementation and for evaluating policies covering larger regions.

3.5.2MICRO-SIMULATION MODELS

These models attempt to model the movement of individual vehicles in a traffic system. They are in typical sense functions of position, velocity and acceleration. These models were created to try and emulate the way humans behave with items like car following, lane changing, route choice, vehicle characteristics of acceleration etc. In this way they can also be used to model driver behavior to account for driver reaction in real-life situations. The underlying principle here is that the dynamics of a traffic stream is a result of a series of drivers' attempts to regulate their speed and acceleration.

The primary advantage of microscopic models is the ability to study individual driver motion and also the macroscopic factors flow and density can still be studied. The disadvantage is the high computational powers required which is becoming a lesser problem with the advances in computer technology. An additional advantage of micro-simulation models is that individual behaviour can be modeled in accordance with behavioural principles found in psychology, physiology and economics that go beyond the utility maximizing assumptions used in analytical models.

The other advantage of these models especially with the advent of ITS, is that they can be used to assess the impact of new ITS systems before they are implemented because they are able to deal with modeling of driver behavior when exposed to these ITS systems. These models can handle more detailed networks with features like traffic lights and ramp metering being possible to implement. The size of the network needs to be small as compared to macroscopic models to achieve the levels of detail.

From the above description of the two models, it is clear that for this study of the impact of information, the appropriate choice would be a microscopic model. This is because with these models it is possible to look at individual driver behaviour which is the basis of the impact; information is provided to individual drivers, the drivers' response to the information is also individual depending on driver goals, preferences and habits but the individual impact collects up to an impact on the link and network level. Further the on-trip information to be tested is provided per driver and depends on the location of the driver on the network and the available routes to their destination. Therefore drivers belonging to the same O-D pair could be assigned depending on their location (distance from destination), prevailing conditions, time and available alternative routes. Grouping these as would be the case in a macro simulation tool would therefore not give accurate results.

There are many commercially available microscopic tools that can be used for these kinds of studies. In this case the ITS Modeller developed by TNO is used. The ITS Modeller is a micro-simulation tool developed especially to model the effect/impact of ITS applications. The modeling environment can simulate the ITS applications whether in-vehicle or infrastructure based and newly developed applications can be easily added by modeling them and linking them to the ITS Modeller. The tool is under development and is yet to go commercial. The route choice model used in the tool is one of the items under development, currently being based on mainly travel time and therefore gives opportunity to test and improve it further to represent more realistic route choice behaviour and also add information and test to see what impact the information actually has on the traffic network. The ITS Modeller is further discussed in the section 3.6 below.

3.6 ITS MODELLER

ITS Modeller is a micro-simulation tool developed by TNO to study the impact of Intelligent Transport Systems. Its modeling environment can simulate intelligent transport systems. Several roadside and in-vehicle systems, as well as cooperative systems are incorporated in the model. New systems can be modeled easily and added to the ITS modeller. The figure 4 below gives a representation of the model. It functions as shell for existing traffic simulation models allowing modeling of non-standard driver and vehicle behavior. It offers a flexible tool for testing different algorithms and different penetration rates. It enables assessment at the network level of traffic flows of large number of vehicles and cost benefit analysis can be easily performed.

The ITS Modeller differs from other commercially available simulators by allowing researchers to include tailor-made models that describe the technical and behavioral effects of ITS applications, and thereby investigate the effect of these applications on the traffic system's performance.

In the ITS Modeller vehicle motions are controlled by defined model configurations, the models define the behavior of the vehicle and its' driver. The combination of a vehicle and its' driver is called an actor. There are several types of actor models, the general philosophy of the tool is to have one model for each aspect of driving for example for car following and for lane change. These models are then combined to create a comprehensive driving model. The ITS Modeller contains the following types of models:

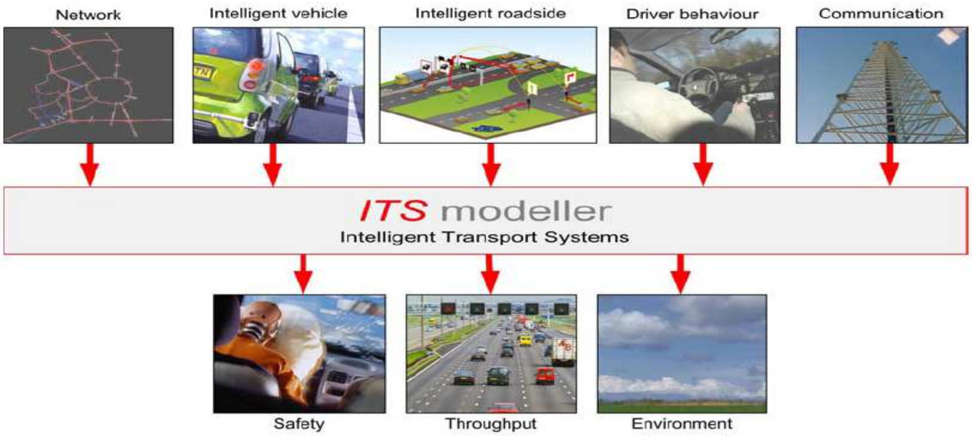


Figure 4: Representation of the features of the ITS Modeller

Model	How it functions
Acceleration	They determine the desired longitudinal behavior of the driver; acceleration and deceleration. Each model describes one aspect of longitudinal behavior such as free driving, car following or braking. Overall the desired acceleration is determined as the minimum of the outputs of all the selected models.
Preferred lane	These models determine the lane that the driver would like to drive in but do not actually execute the lane change. The desired lane can either be mandatory (off ramp) or voluntary (overtaking).
New lanes	These models determine whether a lane change is actually executed.
Vehicle	These models constrain the desired acceleration yielded by the acceleration models to the vehicle's capabilities.
Routes	These are models that provide a new route. If more than one model provides a route, the first valid route id selected.
Route costs	These models determine the cost of a route.
Sensors	These models allow passing information from a sensor (roadside or in-vehicle) to the other models. In each simulation step, the sensors are executed before all other models; this is used to supply the driver with information form road signs or in car warning systems. It can also be used to activate or deactivate certain models as an example when the cruise control is switched off it is modeled as a sensor
Messages	These models allow actors to transmit information to other actors
Diagnostics	These allow actors to report arbitrary information to the database

Table 1: Constituent ITS Modeller models and their functions

3.7 KATE

The information to be tested in the study is also provided by a mobile platform developed by TNO called KATE. KATE (TNO, 2012) is an acronym for the Keen Android Travel Extension, a mobile platform developed by TNO; the platform comprises modules to predict travel patterns, agendas, a database containing travel profiles, surveys, serious games and more. There are some applications developed and some being developed within the platform, they include the file alarm app, an app for management of big events like queens day celebrations and a smart routing app. File alarm is a smartphone based app that gives specific travel advice to users at the same time providing data to highway authorities and transport managers from the car or public transport. The advice given by the file alarm app is multimodal.

The app is linked to the smartphone calendar of the user and therefore checks the agenda, sees where the person needs to go to, checks the route and gives information relevant information. Through monitoring profiles are created, the app knows when the person is at home and information about destinations and route choices and also mode are stored and with time this provides information into the pattern of the concerned user. With this is becomes possible to give customized travel advice, the historical data on past revealed route choices is used in an algorithm to generate the customized advice. The advice in this case being mainly pre-trip, since the app knows the agenda of the day, alerts are send some minutes before start of appointment to indicate departure and the available modes of transport displayed with the corresponding travel times.

The second app is a parking guidance app used to manage by guiding to parking places traffic during events like the queens day celebrations. With this app a user is guided from their location and when they are within the city limits of Amsterdam, they are given information on available parking facilities, the capacity and are also directed there. The app was tested during the celebrations of the Queens Day festivities in April, 2013.

The third app within the KATE platform is the smart routing application. The application is supported by a back end server with current road and public transport information, alerts and other monitoring activities. From the database individual preferences can be deduced and used together with the current state of traffic (yet to be incorporated) to give route choice advice that is also based on past revealed route choices. The algorithm for the app gives different weights for the various factors involved in route choice, for example more weight is given to a route used in the last day than a route used six months ago in determining the route choice advice.

For this study the routing information (on-trip) and pre-trip information will be considered.

3.8 LITERATURE REVIEW CONCLUSIONS

From the above literature discussion it is noted that drivers 'behaviour affects the performance of the network. Among the key choices drivers make that affects the network is route choice and departure time choice. These choices are affected by attributes of the route, the driver and prevailing conditions. The provision of information is one of the factors that have been found to affect these choices. The one factor that was found in all of the past studies as the determinant of route choice behaviour was travel time. In addition to this other factors that were common from the studies are; travel time reliability, familiarity with the network(experience), distance and to a lesser extent the socio-demographic factors of the driver as well as network factors (aesthetics, number of stops, curvature of the route).

For departure time choice the factors that go into determining it from the reviewed literature include the trip purpose, the flexibility of working conditions and socio-demographic factors as well (mainly gender and age).

As for driver response to information, the common responses include change or route, change of departure time and change of mode. The decision as to whether or not to carry out these changes as response to information were found to depend on the same factors as mentioned above for route and departure time choice. In addition attributes of the information like accuracy, relevance and quality were also found to be important. As for the type of information there is consensus that quantitative descriptive/prescriptive information is the most effective.

The tools used to study the impact of information vary and especially for ex-ante evaluation traffic simulation tools are used. In the reviewed literature where information was studied mainly micro-simulation tools were used. Comparison of these tools in section 3.5 showed that for this particular study the most appropriate would be a micro-simulation tool.

In summary the most important factor in determination of route choice behaviour is travel time. The most common driver's response to information is changing route, departure time or mode. And micro-simulation tools are most common tool used to do these kinds of studies

4.0 EXPERIMENTAL SET UP

In this section of the report the experimental set up used in the research is described. This gives the background information required to set up the network, implement the information, collect data and carry out the analysis. The section also describes the design considerations and the assumptions that were made in implementing the information along with the conceptual models of the information implemented.

The first section introduces the ITS Modeller and especially the route choice model, section 2 describes the information implemented that is the default behaviour and the conceptual model of the information. Section three describes the case study area, setting up of the network and preparation for data collection. Section four gives the description of the information implemented in the research, the conceptual models and the design choices and assumptions made in order to implement this information in the ITS Modeller.

4.1 ROUTE CHOICE MODELING IN THE ITS MODELLER

The route choice model in the ITS Modeller is a discrete choice model in which individual Vehicle-Driver Units (actors) select a route from a set of alternative routes (TNO report, 2008). The route choice model consists of the following steps.

- Route set generation
- Pre-trip route assignment

ROUTE SET GENERATION

Route sets are generated using a Monte Carlo method. The Monte Carlo method tries to iteratively find the shortest path between each O-D pair. The shortest path is found using the Dijkstra shortest path algorithm. In each iteration a new shortest path is found and added to the set if it was not already there. The number of times this process is repeated (number of iterations performed) is determined by a predefined set.

For this research the number of iterations was set to 25. Checks were done for 10, 15 1nd 20 and 25 was found to be the least number of iterations that can produce alternative routes. At 25 the number of alternative routes generated was found to be reasonable. In addition increasing the number of iterations was found to significantly slow down the initialization of the simulation. Therefore 25 was a good value to get a reasonable set of alternative routes that would give opportunity for route choice changes with the implementation of information if it is required as a response and also not so high that it would slow down the simulation start up.

PRE-TRIP ROUTE ASSIGNMENT

This part of a route choice model assigns a route from the route set to the vehicles entering the network. It models the selection of the route from the set of routes that a driver knows. The route assignment is done by a logit model; the logit model uses the link cost function of the form given in the formula below to assign the appropriate route.

$$C_i = a*T_{ff} + b*D + c*M$$

Where: C_i- cost function of link i

T_{ff} –Free flow travel time

D-Distance

M-cost

a,b,c- Coefficients

The link cost function gives the utility of each link and by considering all links in a route, the utility of that route can be obtained. With the assumption of utility maximization for a given driver the utility of the alternative routes are obtained and transformed into probability values (between 0 and 1). The route with higher probability has a higher chance of being chosen.

Because not all drivers choose the same route the logit distribution assigns drivers to all the routes with the most attractive routes (based on the value of the link cost function) receiving a higher percentage of the drivers and the percentage reduces to the least attractive.

COMPARISON OF ITS MODELLER ROUTE CHOICE TO LITERATURE FINDINGS

Considering the outcome of the literature review (factors affecting driver route choice) and the above description of how the route choice model in the ITS Modeller works there a number of issues that were noted.

- The most important factor was found to be time, which is the factor also used in this route choice model. But the literature also indicates that assuming travel time as the only factor affecting route choice could be erroneous.
- The other factors noted were travel time reliability, experience (familiarity with the network), and commute distance and to lesser extent socio-demographic characteristics. These factors are not modeled in the ITS Modeller route choice default model and including them would improve the accuracy of the route choice model according to the findings of the literature review.
- Although the factors noted above are missing from the route choice model in the ITS Modeller, the link cost function given by the stated formula can allow for modification to incorporate some of the missing factors.
- Some of the modifications that could be done include: change of the distance coefficient from zero to an appropriate value determined from travel surveys and/or literature. Another is the definition of the factor M in the cost function and giving it an appropriate coefficient. The factor M (cost) can for example define travel time reliability, where due to congestion a link/path with higher congestion levels/unstable travel time can have a higher cost compared to a path that is more stable. The other modification could be to include experience/familiarity with the network, this would mean for drivers who are familiar with the network they are aware of links/sections with congestion issues and avoid such.

It was therefore decided that an update of the route choice model to incorporate some of the missing factors would be appropriate as part of this research because the information proposed to be implemented would affect route choice behaviour of the drivers. Modeling that driver behaviour as accurately as possible would mean also proper modeling of the information both of which are necessary inputs for the research. The update implemented is discussed in section 4.4.

4.2 KATE INFORMATION

The information service KATE is still under development and two out of the three information services it is meant to support; pre-trip information and on-trip were tested in this research as earlier mentioned. The pre-trip information is already being tested in the real life case. The implemented pre-trip information works by reading the agenda of the owner of the smartphone and therefore user of the app, by monitoring the user and from created profiles it can tell what location the user is. From the agenda it can determine where the user needs to be and at what time and therefore gives advice on what time to depart, mode to use and which route to use

The advice given is obtained from free flow conditions of traffic and has not yet been updated to include live traffic data in the current state of the information. The current state therefore has information and all process based in the back office but plans are underway to upgrade it to incorporate live traffic, weather, and incident management and travel time predictions in giving the advice.

The expected update of the pre-trip information is meant to incorporate the historical data and live traffic data and incorporate algorithms to determine travel times and do short term predictions and give the appropriate advice to the users. In this way it is expected that the users of the information can get information on what travel times are experienced on different routes along with predicted travel times and therefore advice on appropriate departure time and best route. In addition data is collected from the behaviour of the users under the information and this is then used in future when giving advice on route and departure time.

The on-trip information or smart routing is yet to be implemented under the KATE platform. The conceptual plan for the proposed information is more or less like for the pre-trip information where historical data is combined with live traffic data and using an algorithm to predict the expected travel time on the different routes and give advice to the users. The advice just like in the pre-tip information is designed to include past choices of the user as recorded over time subject to appropriate weighting criteria. The difference with the pre-trip is the point at which the information is relayed. Pre-trip is at or before departure and the on-trip is during the trip.

The two kinds of information are meant to update the user’s knowledge of the current traffic network state and give them advice on the best time to depart and the best route to use to reach their destination within the required time. The expected driver/user behaviour under this information is change in departure time, change in route choice and change in mode. The conceptual diagram below shows how the information should work on the overall level. The live traffic data for the information is obtained from other road sensors as well as also from the users of the information (floating car data).

From the figure 5 to generate the information, three sources of data are considered, historical data that is stored in the databases (back office), this could be from a few days in the past to a couple of years in the past. The information relayed by the app users as they use the network is also added to the database and the historical data is therefore updated. The live traffic information is obtained from the information relayed by the app users and combinations with other road sensors used if necessary. The feedback part of the information loop is important in this case in that, it's factored in the advice to be given, this is especially useful for smart routing.

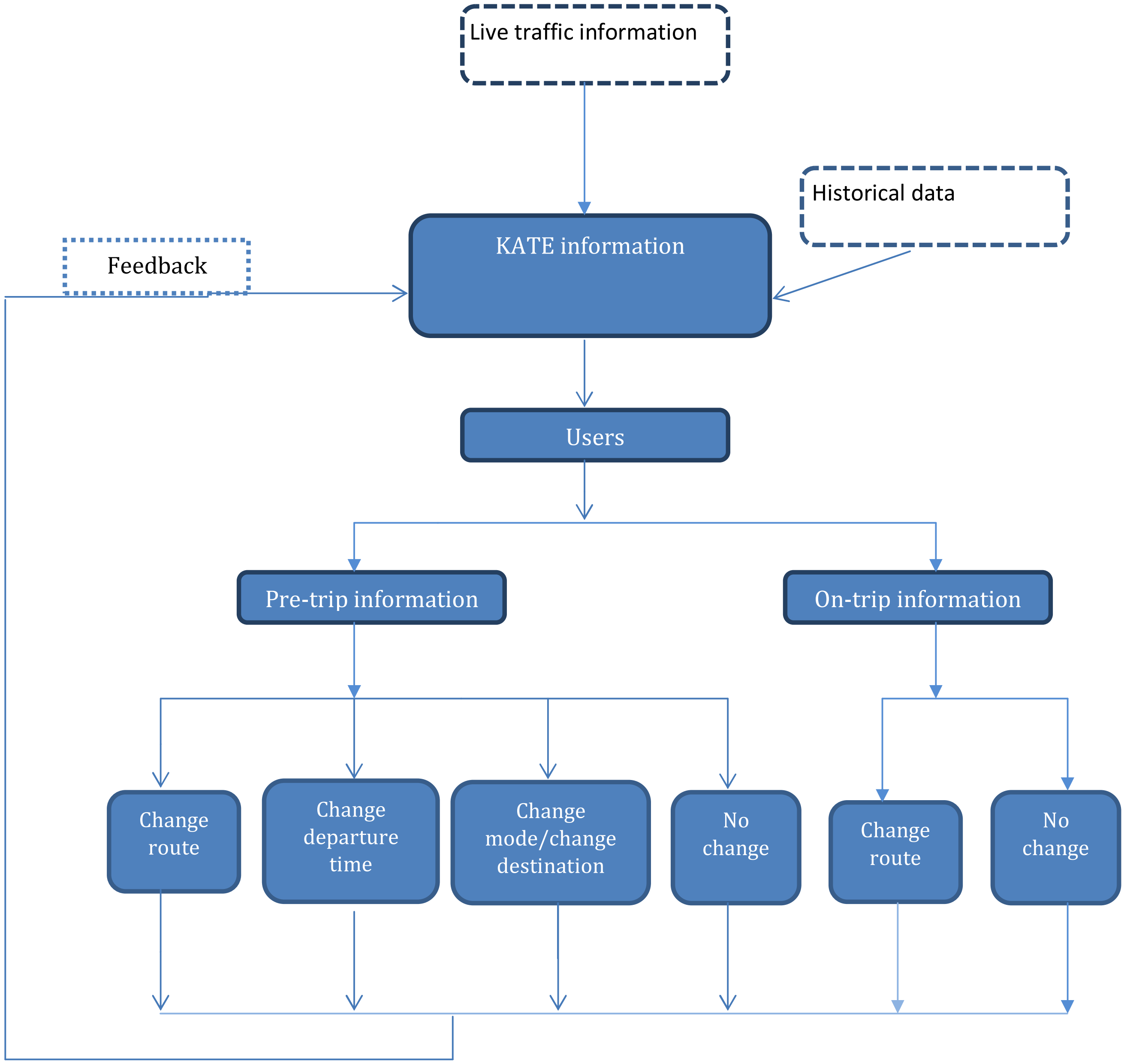


Figure 5: Flow diagram showing the conceptual framework for KATE Information

From the on-going discussion the choice of the form of the information to be modelled was made. For pre-trip information the choice was to model it similar to the implementation going on in that no real-time traffic data is used only historical data. This was also due to the implementation of departure time choice in ITS Modeller, the departure time is determined before the simulation starts and therefore any real-time update cannot be incorporated in the current form of the model.

For the on-trip type of information real-time data was used but as opposed to the proposed implementation feedback was not included as well as travel time prediction. For feedback the drivers in the ITS Modeller would have to be modelled with learning ability, that is information on previous choices and for travel time prediction an appropriate algorithm would be needed to do the prediction. These two would require more time and testing before implementation and therefore as a first step that can be built upon it was decided to incorporate real-time travel time update based on prevailing conditions only.

4.3 THE CASE STUDY AREA

The case network consists of the Ring road Amsterdam and six of the major entry/exit points for the city of Amsterdam, the highways and the associated on/off ramps. The traffic is for two hours of the morning peak. The morning peak is approximately three and half hours starting from 6.30 to 10.00 A.M, this research considers hours of the peak flow from 7.00 to 9.00 A.M. This is the duration which most of the congestion occurs and it is also because being a large network having a longer analysis period will mean even longer simulation periods (the size of the network and the demand slows down the simulation speed).

One of the problems experienced in the real life situation of the case study area as mentioned in the section 2 on the research problem is recurrent congestion that is congestion during the morning and evening peaks caused by the regular traffic. To study in detail this problem and obtain the exact location on the network and the quantity of the problem, the network was set up in the ITS Modeller.

SETTING UP AND TESTING OF THE NETWORK

The set-up of the network involved importing the physical network and the associated O-D matrix from the Omnitrans simulation tool. The primary and secondary roads that feed the highways were not part of the network and their traffic flows were aggregated into flows in/out of the highways through the ramps. The decision as to which primary/secondary road traffic flows in/out through which ramp was done by visually inspecting the network. This was not very accurate but was considered sufficient to set up the case study because the focus of the research was the relation between the input variables and the output and how changing that affects the performance of the network therefore the accuracy of the network was considered less important. The imported network was based on the 2012 network and traffic demand as set up in Omnitrans.

The network before being imported was first reduced in Omnitrans by getting rid of the smaller roads (provincial and local). The demand from these roads was aggregated into the nearest exit or entry point in the form of a ramp. This way the consideration of the travel time between the actual origin and the associated ramp, either to it or from it was not considered. This is because the point of interest was the presence of the driver of the highway part and how long they remain on it. Each on/off ramp had a small extension to it (a few meters) to allow the vehicle to get in or out of the highway. This limits the results obtained on the network because it is possible that part of the route changes in reality may include a secondary and primary road or even traffic from the local roads could use part of the highway in their trips.

In the case that the information improves the situation and therefore drivers initially using the secondary and primary roads are attracted to the highway part then it would mean the gains if any indicated by the test of the research would in reality be lower. Considering the effect of the two kinds of behaviour the net effect was assumed not to alter the results significantly but this would be noted when analyzing the effect in the end.

The O-D matrix was imported from Omnitrans tool by translating the O-D matrix using a Matlab script that reads the O-D matrix from Omnitrans and translates it into a form that can be read by the ITS Modeller. The script translated the demand into 15 minute interval flows by assuming an appropriate departure fraction and dividing the matrix into the required number of time intervals which in this case was 8 for the two hours). This worked by considering a static traffic load for the peak period, the script then translated that static load to a dynamic load by splitting it into 8 15 minute interval demand using a departure fraction. The departure fractions were used to make the peak profile for the network and were based on observed data (traffic counts).

The reason for splitting into departure intervals was to later cater for the implementation of pre-trip information especially a case where change in departure time is expected, it is easier to alter departure time in that case than where the demand is split into hour long intervals or more.

For the O-D relations that were removed and those that were aggregated, the imported O-D matrix was manually changed to reflect the changes. For the relations that did not include the highway part they were deleted and those that did include the highway were added to make one entry/exit point through the most suitable ramp. In the end there were a total of 610 O-D relations, this in ITS Modeller were further divided by departure time of 15 minutes interval for the two hour into 8 different relations, this led to a total of 4880. The total numbers of vehicles overall and per departure time are given in the Table 2 below

Departure interval (seconds)	Number of vehicles (actors)
0-900	13,462
901-1800	19,046
1801-2700	23,823
2701-3600	27,977
3601-4500	32,663
4501-5400	37,084
5401-6300	41,406
6301-7200	46,129
Total	241,590

Table 2: Total number of actors/drivers in the ITS Modeller.

As much as the accuracy of the network was not considered that important on the other hand the network had to be realistic in terms of the traffic flows and the problems experienced and their location. To test how realistic it was, a test of the assignment was done. The test was done by performing an assignment on the network in Omnitrans and doing simulation runs in the ITS Modeller. Selected links were then chosen and the traffic flow at 10 minute intervals was recorded and compared with traffic flows recorded by the assignment in Omnitrans. The areas chosen were all around the A10 ring road. The comparison was expanded to also include the real- world values that were obtained for the chosen areas from recordings in the autumn of 2012 because the Omnitrans model was also based on the 2012 network autumn season.

For the ITS Modeller, the test for assignment was also expanded to include the effect of updating the route choice model by incorporating historical travel time for the drivers that were deemed to be familiar with the network and therefore aware of the real travel times experienced (explained more in section 4.4). The percentages used for the familiar drivers (and therefore use historical time in route assignment) were also varied (73 and 100% were used). The links chosen for carrying out the assignment test are marked in the Figure 6 below that shows the study area network.

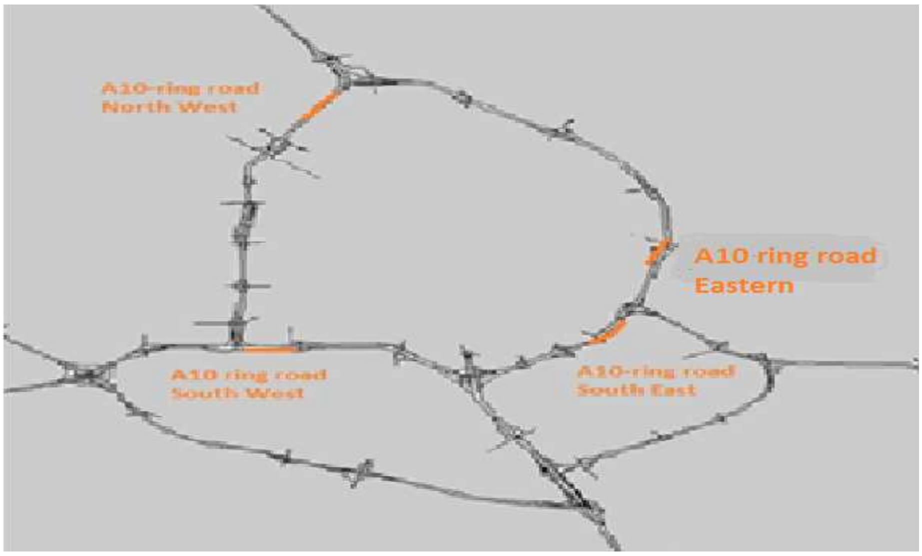


Figure 6: The case study network showing position of links used for assignment testing

Figure 7: Case study area from Omnitrans showing delays experienced.

By running 10 simulations with the set up network, from the output and for the areas shown in the figure above the rate of vehicle flow for each 10 minute was calculated. The values were initially compared to the Omnitrans values only. The initial comparison showed that the ITS Modeller values were in all the cases about half the values in Omnitrans. The ITS Modeller demand was then increased by 40% and a second comparison was made, this time the real-world values were also incorporated and the results are presented in the figures 8 to 11 below.

From the Figures 8 to 11 it can be seen that there are still variations in the rates, first the variation is in the start of the simulation, this was caused by the fact that the assignment in ITS Modeller starts with an empty network at 7.00 which is the start of the simulation period unlike the two. The other variation is in the values obtained, the Omnitrans has the highest values, higher than even the real-world case. The variations could be attributed to the fact that the Omnitrans model that was used in this case was not validated for the 2012 case and therefore it possibly has its own errors and other variations caused by factors inherent in the Omnitrans model. The second reason for the variation also is the way in which the O-D matrix in the ITS modeller was set up. The assumptions involved and the manual way in which the set up was done have impact on the outcome.

The values for the ITS Modeller however do seem despite the not so accurate way in which the O-D matrix was created to compare well with the real-world values. In the figures there are three different ITS Modeller values, original is or the case where nothing was done, ht for the case where the route choice model was updated to use historical time (73% percentage of the drivers) and ht 100 is where all the drivers (100%) were assigned routes based on historical travel time.

PERFORMANCE OF THE ITS MODELLER DURING SIMULATION

During running of the simulations one of the things noted was how the ITS Modeller performed. For the initial case where the network was run in its original state and later with the incorporation of the historical travel time and with 2 hours of simulation, the total time taken to complete one simulation ranged from six to eight hours. Later however with the introduction of information and especially the real-time information and logging of more output data the period of one simulation increased to between 12 to 18 hours.

DISCUSSION OF RESULTS

From the results presented in the figures 8 to 11 there are differences between the values and in most of the cases, the differences are quite big. The differences can be explained by a number of factors:

- The way in which the network was reduced and the manual way of assigning the flows from the cut out section to create the O-D matrix for the ITS Modeller case was inaccurate as earlier mentioned.
- The way of assignment in the Omnitrans model that used the INDY software, in this assignment Capacity of the links is only implicitly modeled meaning that when there are more vehicles entering the network, travel times will increase but it will not prevent vehicles from entering the link. This means that no queues are formed explicitly.
- The other factor is that for the ITS Modeller the network starts with zero at the 7.00 A.M. point at which point the Omnitrans Model is already having traffic flowing.
- The assignment in ITS Modeller and the flow of traffic is subject to capacity constraints, therefore when a link is at capacity at the origin it is blocked and therefore no more vehicles can enter the network, in the end therefore the flows are not indicative of the demand that was set. This was also noted later when analysis of incomplete trips showed that a big percentage of the vehicles tried to access the network but could not. This problem was also partly due to the shorter duration of the simulation, extending the simulation period would have enabled more vehicles to access the network and in the end the flows may have been more than what was experienced.

- Looking at figure 7 that shows the delays experienced on the network as given by the Omnitrans output, it can be seen that the areas in the North Western and Eastern regions (figures 8 and 11) experience more delays that the South East and West (figures 9 and 10). This explains why the results of the areas in Figures 8 and 9 are all below capacity even for the Omnitrans case, these areas do not experience the delays on average.

- The results of the T test performed for the different types of assignments that were compared showed negative results despite it being clear for the figures that the differences are quite big. The reason for the negative T test result would be that the variations among the individual data are too much, this was especially so for the ITS Modeller. The variations in the 10 minute flow for the links tested between the different runs was big.

- Out of all these the final decision was to use the ITS Modeller with the updated historical travel time as the base case (ITS Modeller –ht from the figures). This showed a more stable flow and one that was closer to the real-world values.

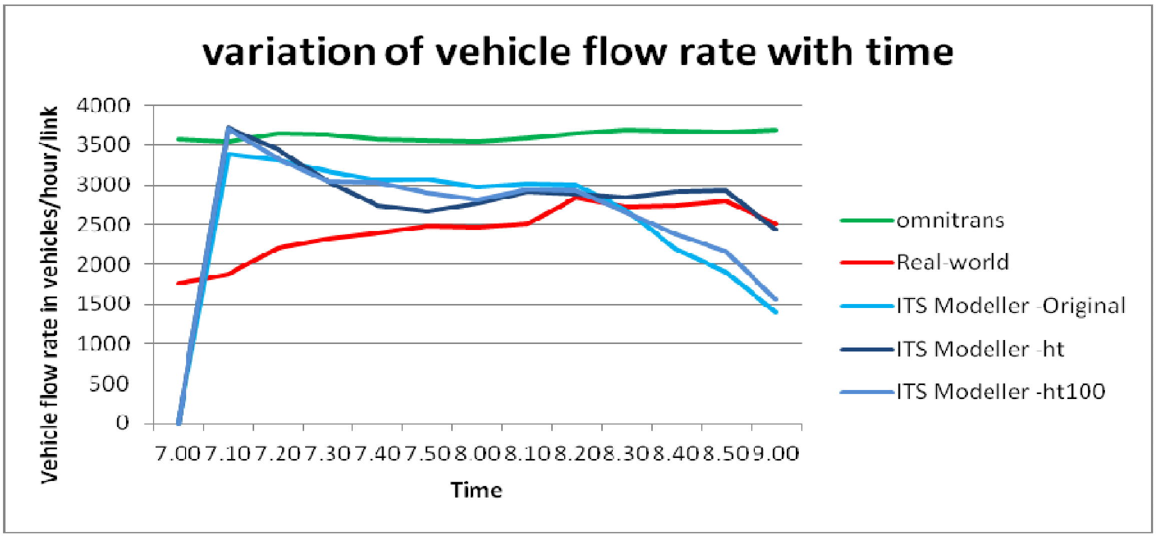


Figure 8: The variation of vehicle flow rate for the A10 ring road North West section (2 lanes)

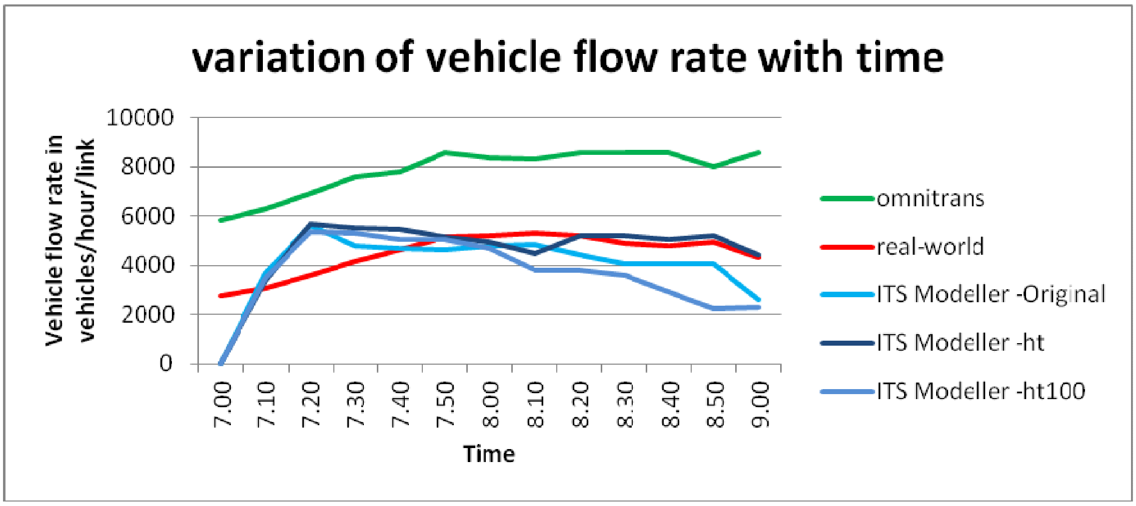


Figure 9: The variation of vehicle flow rate for the A10 ring road south west section (4 lanes)

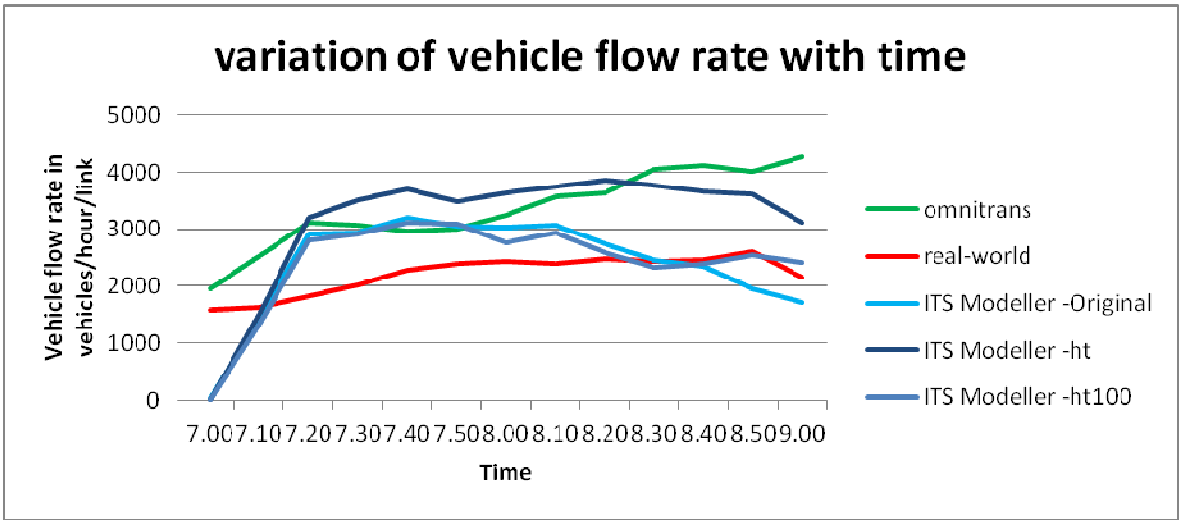


Figure 10: The variation of vehicle flow rate for the A10 south east section (3 lanes)

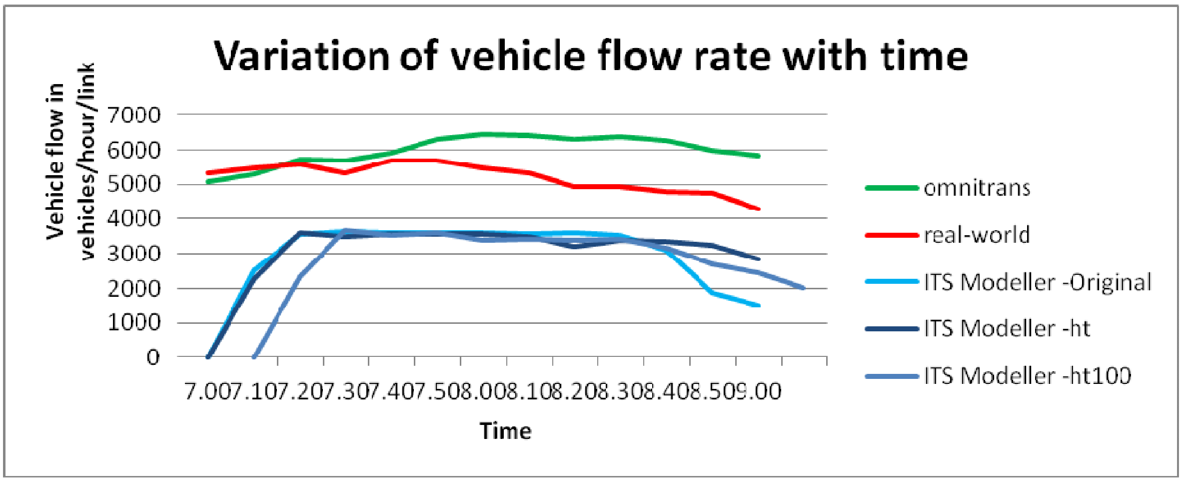


Figure 11: The variation of vehicle flow rate for the A10 Eastern section (3 lanes)

4.4 CONCEPTUAL SET UP

4.4.1 REFRENCE CASE

In the previous sections details of the original conditions are given as well as set up of the test case network. This section gives the process involved in preparing the network to collect data for testing and also implement the information. First was the determination of the number of simulation runs that would be required to give statistically significant results.

NUMBER OF SIMULATIONS

To determine the number of simulations required to give statistically significant results, six simulations were run, each with a different random seed. Area average speed was used as a determinant by calculating the variance and the number of runs that would give speeds within an allowable error of margin in this case within 1 m/s. The formula used is give below;

$$n_r \geq \frac{s^2 z^2_{\alpha/2}}{\varepsilon^2}$$

s^2 = variance (based on trial runs)
$z_{\alpha/2}$ = threshold value for a 100(1-α) percent confidence interval
n_r = number of runs required
ε = maximum error of the estimate

(Lindgren & Tantinyagulchai)

From the calculations, the required number of runs to produce results with a maximum error of 1m/s for speed and with a confidence level of 95% varies for different areas between 2 and 8. A rounded off value of 10 runs was therefore adopted. These numbers of runs were also done for assignment testing that is recorded in the previous section.

UPDATING ROUTE CHOICE MODEL

In section 4.1 the default route choice model used in ITS Modeller was described and it was noted that the only consideration in the route choice was free flow travel time. From the literature studies and also considering what is expected in real life cases, that is not realistic, there are other determinants of route choice behaviour and even for the travel time there are drivers in the network who are familiar with the network because of using it over and over and therefore are aware of the approximate travel times on their routes. The route choice model was therefore updated, there are various options for the update but for this initial case, the first option was to update the travel time used by the familiar drivers in route selection from free flow travel time to historical travel time. This was done because from the literature review travel time was noted as the key factor in determination of route choice behaviour and using the right estimate for the travel time was therefore considered a more suitable way to represent the behaviour. In addition this would also incorporate another factor, which is familiarity with network/experience. This way the link cost function mentioned in section 4.1 now becomes for the familiar drivers,

$$C = a*T_{ht} + b*D + c*M$$

Where: T_{ht} - travel time from historical data for the familiar drivers

The historical travel times used here were obtained by running 10 simulations prior (pre-runs) and using the average travel times (per link) from these runs as the travel time factor in the link cost function given in the formula above used for determination of the route choice. To determine what percentage of the drivers use the historical travel time in their route choice. A distribution of the traffic in the Amsterdam region by trip purpose was used. According to the report (Amsterdam, 2009)that gives the trip distribution per purpose and for day long traffic average for the years 2005-2008 summing the values gives 73% for familiar drivers and 27 % for those who can be considered as visitors.

With these figures the travel time was updated for the familiar drivers and 10 simulations were then run with the new travel times. To test the sensitivity of the model to the various percentage values used, a variation of the percentage values was done for 100% where all drivers are assumed to have knowledge of the travel times. The results can be seen from the Figures 8 to 11 above where the values are compared to the real world case and also the Omnitrans case.

From the Figures 8 to 11, it can be seen that the differences in the version of the ITS Modeller values is evident at the point of the start of the congestion, the first twenty minutes are for all the four cases similar but the variations increase as the time progresses and congestion sets in. The variation for the original case and the case with the assumption that 100% of the drivers have knowledge of historical travel times are similar even after the congestion starts.

The case where a percentage of the travelers have knowledge of historical time (73% for this case) indicates intensities with lesser variations and is similar to the intensities for the real-world case. The variations among the four different versions however are not statistically significant as the T test results for 95% confidence level shows that the difference in the means is not statistically significant (T test results table in Appendix 1). The case with 73% historical time update was adopted to be used as the base case for this research.

4.4.2 INFORMATION

The description of what the information does and how the drivers respond to it was used to come up with a conceptual plan for the implementation of this information in the ITS Modeller. The two kinds of information and the conceptual plan for each of them are described below.

PRE-TRIP INFORMATION

Pre-trip information as discussed in chapter three on literature review is information provided before the start of the trip and could for example take the form of the most appropriate departure time, the presence and location of congestion on the network, the expected travel time on route and/or the alternative routes. In this research the pre-trip information was given in terms of travel time, that is the expected travel time on route and alternative routes and also the travel time per departure time.

The response to the provided pre-trip information also varies and depends on the kind of information provided as was discussed in the section on literature review. The most common of these responses are changing departure time, changing the route, changing the mode, changing the destination and or cancelling the trip altogether. These are the responses also modeled in this research. The actual response of a particular driver to the information is also in itself a process that depends on a number of factors mentioned earlier like the age, gender, social/economic status and trip purpose. In this research the logit model used for route choice modeling is also used in driver response to information represent the process involved in choosing the action taken by the recipient of the information (mainly for the change in route option).

The first issue in design of the pre- trip implementation plan was to determine the source of the information. Because this is information before departure the most suitable source was taken to be the historical data. Historical data could be data from a few minutes before, to days, months and even years before. For the sake of this implementation, historical data was taken as the data obtained during the pre-simulation runs. The data of interest being the average speeds recorded for each link when the random seed is varied to cater for daily variations in traffic.

This historical data is similar to the one used to update the route choice model previously described. The difference comes in especially during implementation of different incident scenarios where the travel times in the base case also change. In that case the familiar drivers use the old historical time (does not change) while the drivers with the pre-trip information have historical time that is based on the recent past and is changed whenever there is a change in the network that leads to change in demand or the travel times experienced.

The driver response to the information as obtained from literature studies can take different forms, the ones of concern that were considered were; change of departure time, cancellation of trip which includes departure time changes outside of the peak period and any changes in mode and lastly the change in route. With this in mind the conceptual plan for the pre-trip information is shown in the figure 12 below.

To implement this information a few assumptions and design choices were made including:

- Penetration rates and percentages of compliance: it was not possible to test all probable values of penetration rate and therefore assumptions were made on reasonably expected rates of market penetration of the information should it be implemented. In the same way the percentages of drivers who respond in a certain way to the information were also assumed by considering logically which response would be most common to which would be least common

- Compliance to information- because the O-D matrix in the ITS Modeller is not dynamic the responses to the information that were modeled assumed total compliance. That is if the information was to change the departure time, the change was effected. The only difference was in change in route because the route choice was still done by the logit model of the route choice model.

- Driver responses that would involve mode change, cancellation of trip or shift to a time outside of the peak period was all considered under trip cancellation.

The translation of this conceptual diagram to the actual implementation in ITS Modeller is described in section 5.1

Pre-trip information

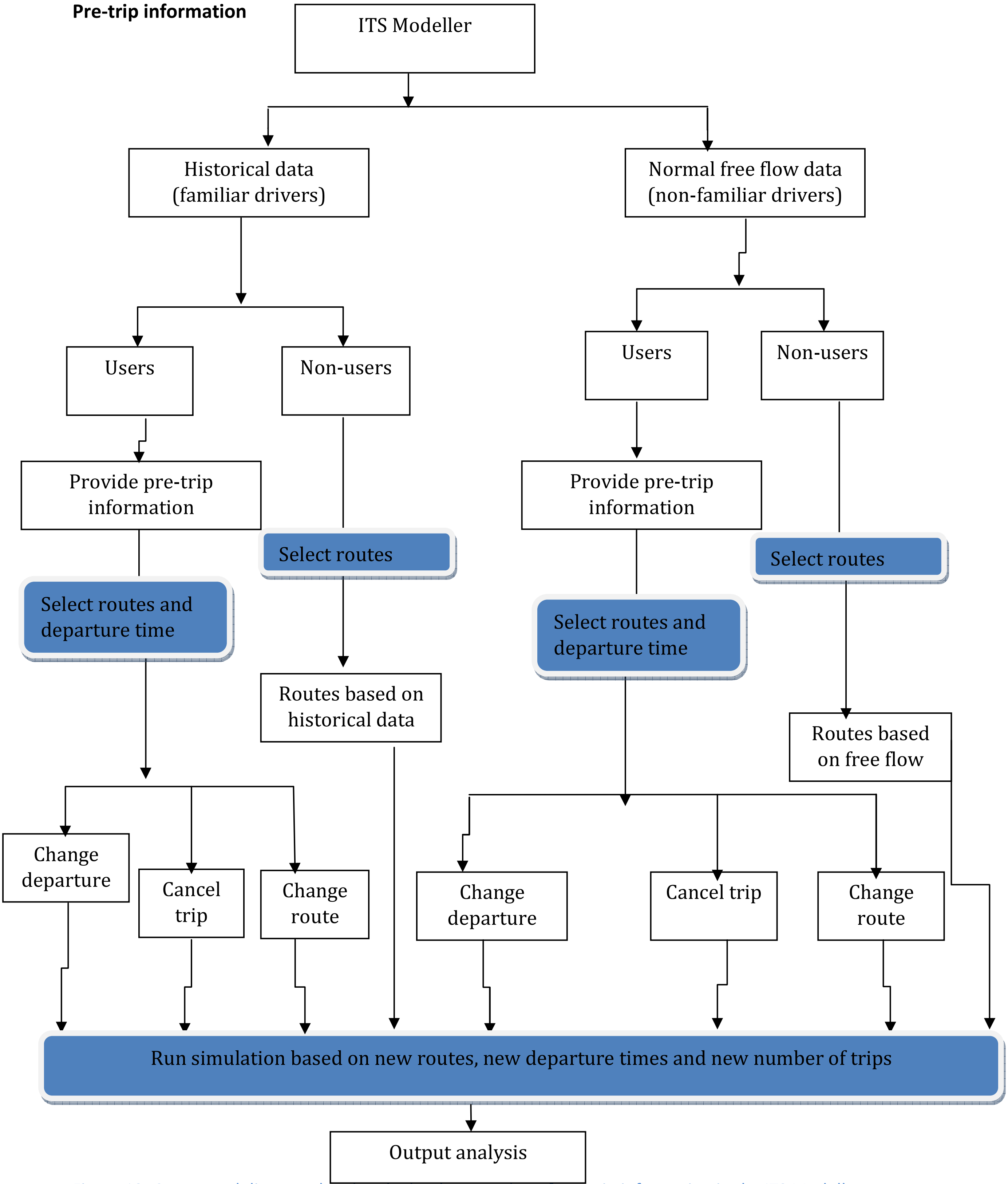


Figure 12: Conceptual diagram showing the implementation of pre-trip information in the ITS Modeller

On-trip information and its expected impact are also discussed in the section three on literature review. This information is provided in the course of the trip. The information can take various forms also like travel time on route and on alternative routes, location and extent of congestion, occurrence of incidences and or accidents. The most common of the information is on travel time and the response of the drivers is an appropriate change of the route.

For this research the on-trip information, descriptive travel time information is provided. It is considered descriptive because it gives in real-time the travel time of the driver for the remaining part of the trip on different route (if there are any). It therefore gives (describes) the current condition of the network. The source of the information in this case was a combination of the historical travel time with the real-time travel time by using appropriate weighting criteria (discussed in section 5.2). The use of the historical time is meant to cater for any unrealistic variations in the real-time travel time that may lead to unnecessary changes in route as response to the variations. The historical travel time used in this case was similar in definition to the one used in preparation of the base case.

With this information being updated at certain time intervals (between 120 and 300 seconds), the users use the updated travel times on the routes to select the best routes, in this case of the ITS Modeller the selection is done by the route choice Logit model. The conceptual flow diagram in Figure 14 below gives a description of the planned implementation of the on-trip information.

For the on-trip information to work, the source of the historical data was already set as the pre-simulation runs. For the real-time data however thee was need to come up with a way to collect the data while the simulation was running. This was done by use of areas, in ITS Modeller the areas act like sensors (loop detectors) and can therefore be used to collect data on speed and intensity among others. For this case the speed was considered most suitable because with the speed and with knowledge (stored in the ITS Modeller network characteristics) of the link length then it is possible to get the travel time which is the factor that was required to give the information.

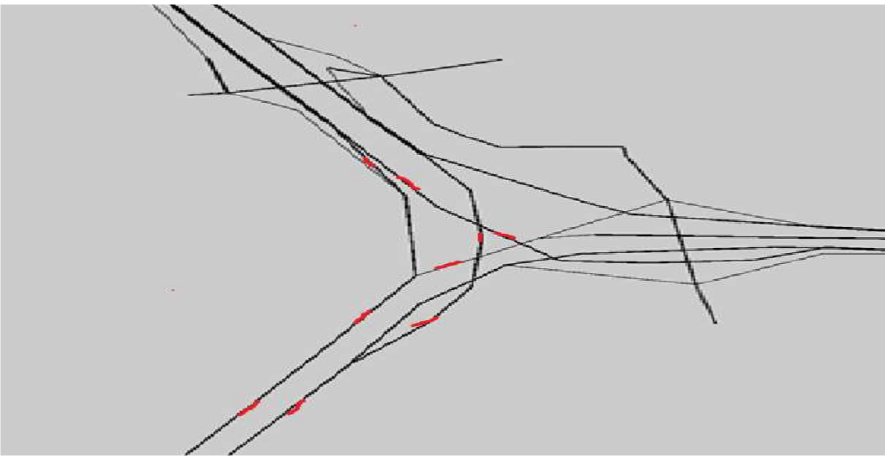


Figure 13: Snap shot of the North West region of the A10 ring road part of the test network showing location of areas

The areas needed to make this collection of data possible were also quite a number and the approach of average distance of 500m between the loop detectors that is used for the Dutch highway was adopted. Above in figure 13 is a snap shot a section of the test network showing the location of some of the areas.

On-trip information

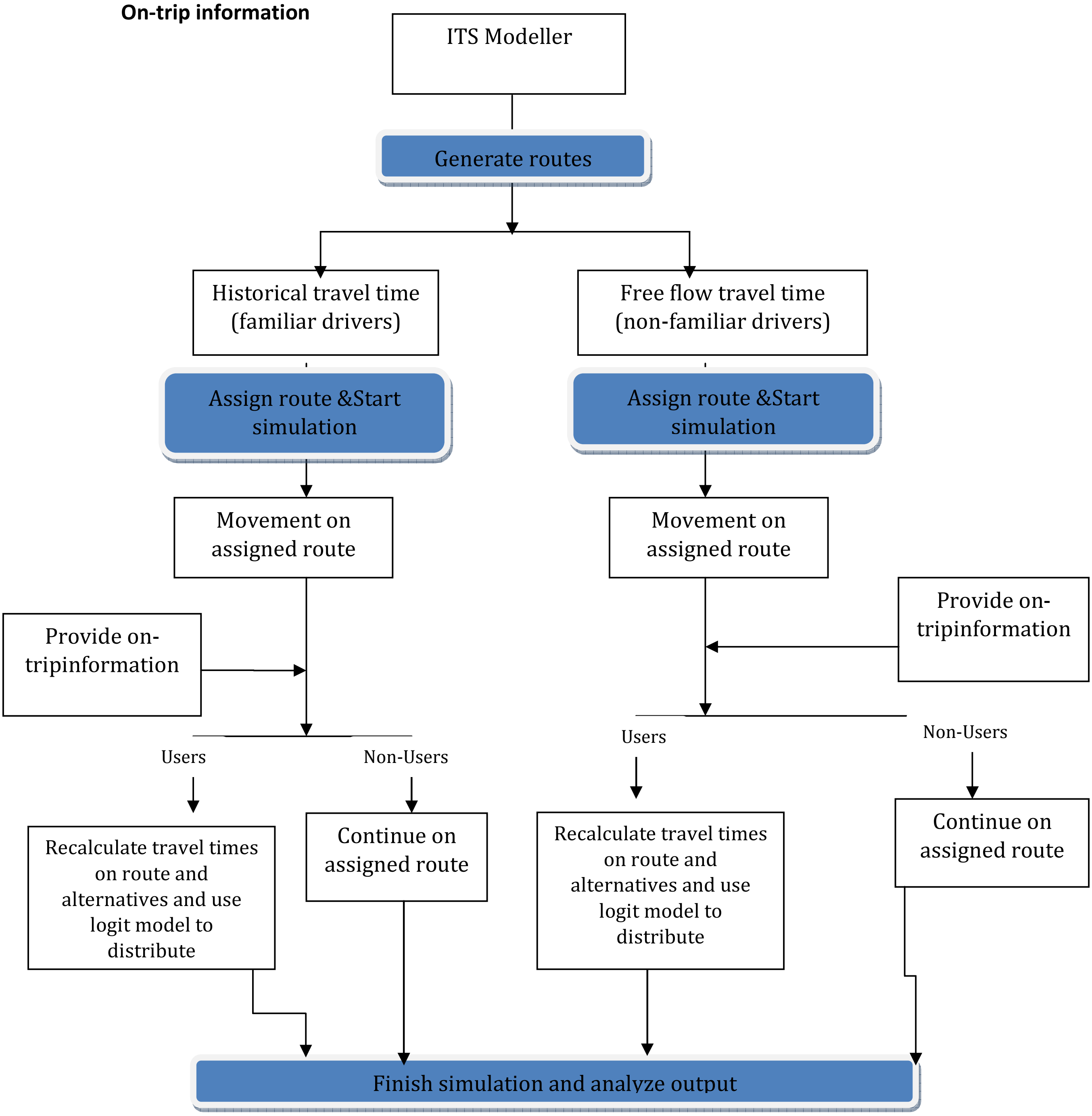


Figure 14: A conceptual diagram showing the implementation of on-trip information in the ITS Modeller

The actual implementation of this in the ITS Modeler is described in section 5.

For this information the assumptions of penetration rates mentioned in the section on pre-trip information were also applied. Because the information was based on the route choice model, compliance was not assumed. The response to the information was determined by the logit model.

4.4.3 SET UP FOR DATA COLLECTION

This section gives a description of the experimental set up required to collect data from the network that will be analyzed to answer the main research question. This includes setting up the base case and the scenarios necessary to get the required data

BASE CASE

The base scenario is the case before any information is implemented on the network. This was based on the network after the initial update of the route choice model to include the historical travel time. The specific case for the base case is where 73% of the drivers were considered to be familiar with the travel times and the congestion already in the network. The cases after the implementation were then compared with this case to determine the impact the information.

Since there are often cases where the traffic demand on the network can be more than normal due to traffic disturbances for example when bad weather like snow storms or rainfall is experienced or where there is an accident on the road or road works being carried. Therefore there was need to test the information and see how it would perform when these special conditions occur. These special conditions are discussed below.

INFORMATION SCENARIOS

To test the impact of information a number of scenarios had to be defined and set up. The scenarios also looked into different prevailing traffic conditions and what impact information will have in the different cases. The scenarios considered were the accident/incident scenario and the growth scenario. The choice of the scenarios to test was based on the most occurring cases that could make the state of the network be worse than the normal case due to extra traffic demand and therefore reduced network performance. The growth scenario was especially picked because of the need to see if the information can be expected to perform well even in the future case when the traffic grows.

The accident/incident scenario refers to a case where in the course of a normal simulation an incident occurs blocking the affected section of the road network. As a result that affected area is expected to experienced higher delays than usual and more than other sections on the same network. The blockage could also be caused by regular maintenance works that necessitate lane closures for the works to be performed. In this case only part of the road section say 3 out 5 lanes could be closed to allow for some minimal traffic usage. The blockage of a section of the network lowers the capacity of the network in the affected area. This leads to queues forming on the affected part and when these spill back to other sections the network is affected because of reduced travel times and delays that are experienced. This lowers the capacity of the

To simulate the occurrence of the incidence/accident in the ITS Modeller, traffic lights were used, where traffic lights were set on the links affected and using traffic light controllers the start and duration of the incidence/accident and the number of lanes affected was set. This is explained more giving the exact location for the lane closure in section 5. Below in figures 15 and 16 are snap shots of the network showing a closed lane and the resulting build up in congestion.

The growth scenario is the case where assumption was made that there is a growth in the traffic using the network by a certain percentage and determining how that would affect network performance with and without information. The scenario looks at what might happen in future if there is growth in traffic or just growth in seasonal traffic caused by certain events that would attract large number of drivers to use the network. To implement this, the original O-D matrix was increased by a certain percentage under consideration given in section 5 on implementation of scenarios.

In this scenario there is additional traffic on the network, part of it or the whole depending on the nature of the event. The additional demand lowers the capacity of the network and therefore congestion sets in faster and the congestion rates go higher leading to increased delays and travel times that are experienced by the users.

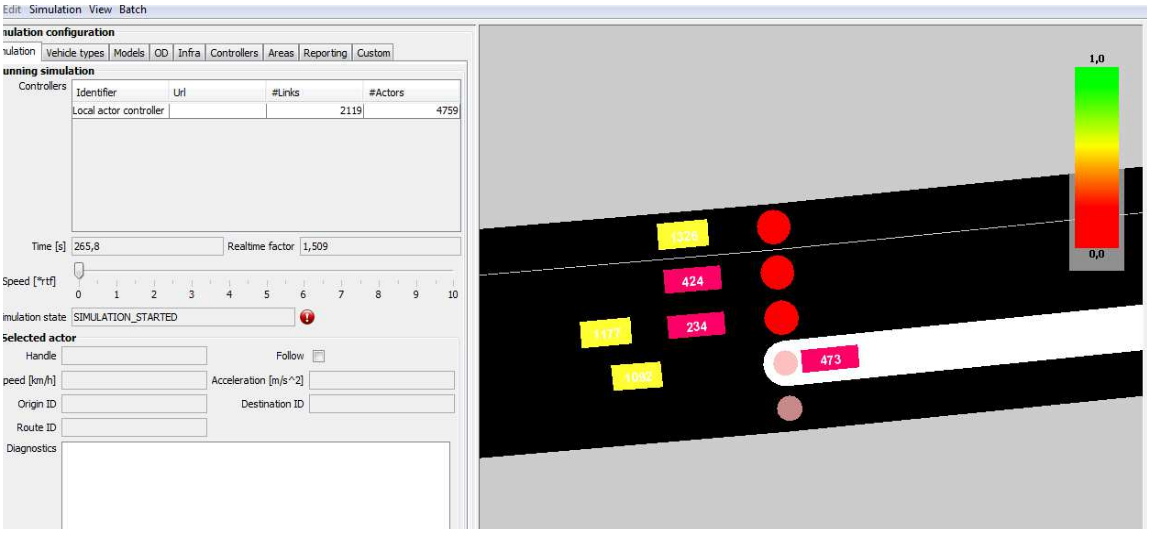


Figure 15: Snap shot of network showing closed lane

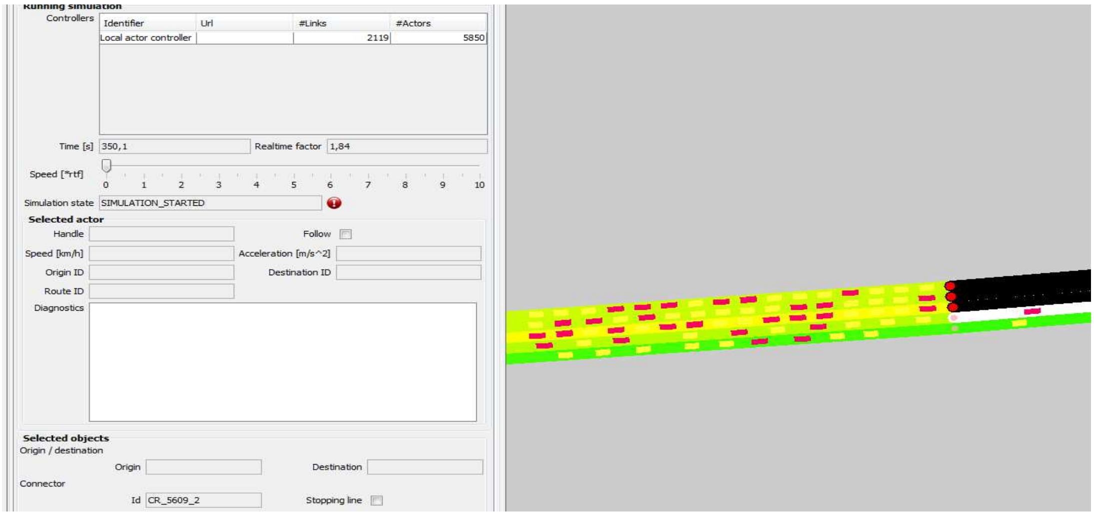


Figure 16: Snap shot of network showing congestion due to closed lane

5.0 IMPLEMENTATION OF INFORMATON IN THE ITS MODELLER

This chapter describes the implementation of information services and information scenarios in the ITS Modeller. The information services implemented are pre-trip and on-trip information.

5.1 IMPLEMENTATION OF PRE-TRIP INFORMATION

The conceptual design of how this kind of information works was given in section 4. In this section a description of how that was implemented in the ITS Modeller is given. First the pre-trip information is based on historical data; this is because this kind of information is given at the point of departure. The definition for historical data in this set up was the data obtained by doing pre-simulation runs as already mentioned. It was also mentioned that the O-D matrix in the ITS Modeller is not dynamic and therefore cannot be altered in the course of a simulation. This meant that to implement this kind of information, especially the part on the driver response to information and therefore modify the O-D matrix, the modification had to be done before the simulation starts.

The modification was done by implementing an O-D matrix builder in Java. By running a Java code that applies percentages to the O-D matrix and splits it into groups as desired (based on driver response) the O-D matrix was split into groups. The other possibility with the O-D matrix builder was to use it to modify the departure time, that is by application of percentages it was possible to split the O-D matrix into different departure times and therefore possible to shift vehicles from one departure interval to another.

From the conceptual diagram Figure12 the first step of implementing the pre-trip information involved splitting the drivers into familiar and non-familiar. This was done at the point of setting up the base case by incorporating historical travel time for the familiar drivers, the percentages used for this are 73% familiar and 27% non-familiar as already explained.

The second step of the implementation involved dividing the O-D matrix into users and non-users of the information. The users could either be familiar or non-familiar. The percentages used in the second split are based on assumptions about the possible penetration rates of the information. These are further explained below in the section on penetration rates.

For the non-users of the system, normal behaviour is assumed, that is if they are familiar they use historical travel time for the determination of the route and if non-familiar they use the free flow travel time. For the users of the system this step involved further modification of the O-D matrix to reflect the different kinds of responses that were possible. The division into the different response types was again done by use of percentages. The percentages at this level were obtained from the penetration rates by assuming that logically there are expected to be more route changes as compared to change in departure time and trip cancellation.

For the response of change in departure time, more distinction was made because there are different values by which the departure time can be changed. It was not possible to explore all of them because they could be as numerous as the number of drivers involved. It was therefore decided to test two in this research. The two that were tested are 5 and 10 minutes. The decision to do this came from initial analysis of the link delays that showed average delay values of not more than 15 minutes (per link) in the severe cases. The link delays were obtained by calculating the free flow travel time on a link and comparing that with the experienced travel time from the recorded mean speed in the output. The delay values obtained showed on average what delays were experienced per chosen link; the links were chosen for the parts of the network that were seen to experience the most congestion. Further it was assumed that 5 and 10 minute changes are small enough in the real case of information implementation and therefore the willingness to leave 5 or 10 minutes early is something that can be reasonably expected of a number of people with the information.

For the two shifts of departure time, different penetration rates were tested and therefore a variety of data was collected. The initial analysis also indicated that the congestion in the network started about 30 to 45 minutes into the simulation period (because of starting from zero network demand) and therefore the shift in O-D matrix was implemented starting from 45 minutes into the simulation. The first 30 minutes of the simulation remained the same throughout.

With the ability to shift the O-D matrix, it was also possible to shift the O-D such that drivers leave later by 5 or 10 minutes again depending on the conditions. But in this case only the shifting backward that is leaving earlier than planned was tested because it was deemed to be the best for the network as per the results of the initial analysis. The shifting ahead was considered to change to a time after the peak period and was partly taken care by the percentage for trip cancellation. By shifting the O-D and splitting into different groups using appropriate percentages modified O-D matrices were created and these were then used to run simulations.

PENETRATION RATES AND PERCENTAGES

As mentioned above different percentages were used in modification of the O-D matrix in the process of implementing pre-trip information. The percentages used to split familiar and non-familiar drivers (73 to27). For the penetration rates different percentages were tested, these were based on results from previous studies that are recorded in literature. (Levinson, 2002) for example looked into the effect of compliance rate of the information on network performance and the results indicated that beyond 30% the effect of the information becomes negative. That coupled with assumptions of possible penetration rates because the information is based on smartphone app and will have therefore to be paid for the penetration rates tested of 10 to 25% were considered reasonable.

Splitting the percentages into the different forms of responses that can be expected from the pre-trip information was done as earlier mentioned by splitting the penetration rate being tested into different percentages as long as the values were in a descending order from route change, departure time change to trip cancellation. The values used are summarized in the Table 3 below.

5.2 IMPLEMENTING ON-TRIP INFORMATION IN THE ITS MODELLER

The actual implementation of this information in the ITS Modeller started by determining how the travel times used in route selection are obtained. These are obtained by using the speed on associated links and combining that with the link length which is known, the travel time is then determined. The total travel time on all the links that make up a route are then summed up to give the route travel time. The travel time obtained this way is used in the link cost function to calculate the cost associated with each link and using the logit model the best route is selected and drivers assigned to them.

Penetration rate (%)	Familiar: 73%			Non- familiar: 27%		
	Familiar and Users		Familiar and Non-users	Non-familiar and Users		Non-familiar Non-users
	Cancel trip (%)	*Change departure (%)*		*Cancel trip (%)*	*Change departure (%)*	
10	1	7	65	1	1	25
15	2	8	63	2	3	22
20	4	10	59	2	4	21
25	3	15	55	1	6	20

Table 3: Percentages for pre-trip information

To provide this information therefore, an update of the link travel time during simulation was required. In real-life cases, the source of the information used to calculate real-time travel time and used in travel time prediction algorithms is obtained from among other sources loop detection data. In the ITS Modeller areas created act as sensors therefore they can record the number of vehicles passing through and their speeds. Using these created areas and getting these speeds and linking the area speeds to the associated links, the link speeds can be updated. The updated speeds can then be used to calculate updated travel times.

To create the areas and use them for route travel time updating, the piece-wise linear trajectory algorithm principle (Lint, 2004)) was used. The key to the functioning of the algorithm principle is to assume that speeds remain constant over a certain region and during a certain time of measurement. It works in such a way that, assuming there are two loop detectors on section of a road, over the upstream half of the section vehicles are assumed to travel with the speed given by the upstream detector. The downstream half then uses the speed of the downstream loop detector. The speed remains constant on the section covered by the respective detector.

A number of issues arose during this implementation process for this information;

- ***Default speed*** – default speed was set to the free flow speed; for loop detectors (areas in the case of the ITS Modeller) where no speed is available the free flow speed applies. This was found to be an issue where there is congestion and vehicles are standing still, the zero speed is recorded as no speed and therefore updated to free flow speed and instead of drivers being rerouted away from such a route they are instead assigned to the route. This would be an issue especially in implementation of test scenarios where a section is closed/blocked, drivers would be assigned to the section and in the end the travel times experienced will be high and the case would be even worse as even other drivers not of the route could be assigned to it due to the 'high' speeds experienced.

Solution- this was solved by setting a minimum speed and a time threshold. The minimum speed was set as the speed by which no further reduction in speed can be done and so the updated speed will be the previous recorded speed. The time threshold was used to set the maximum duration over which a speed substitution will be effected if there are no speeds recorded, that is if for example in 180 seconds there are no speed records for an area, the speed for the area is set to the previous recorded speed.

The concern with this solution is that it still requires there to be an initial speed on the areas, so that if an area is blocked from the start of the simulation, there is no gradual speed reduction and would still go back to the free flow. To go about this, the plan was for the test scenarios to be set up such that any incidents/accidents blocking a section start in the course of the simulation and not at the beginning or block only part of the link allowing for some traffic to flow through ensuring that speed is recorded.

The other solution which would have been to sense the occupancy of the areas, so that if there is no speed recorded because no vehicles but there are vehicles on area, then the default speed is not used but rather a set minimum (close to zero for example). This would give more accurate speeds and the point at which a section is blocked would not affect its accuracy. This however was not implemented this time due to time constraints.

- ***Unnecessary route changes***: these are like route changes where a change is made to a route that was not originally in the route set

Solution: For the route changes overlapping routes were not included in the route selection such that if there are overlapping routes only one is added to the selection of routes used for rerouting.

Incorporating historical travel time means a criterion was needed to combine the two values and get one that can then be used to update the travel times on the routes. The criteria used was assigning weights to the two values, that is saying 30% for the historical and the rest of the 70% for the real-time and combining them to give the travel time on the route. The value for assigning weight to the two instances of time can vary in, literature the common ones are 50% and 30 to 70% where the real-time instance is given more weight (Tatomir, 2009). For this research 30% to 70% was used for the normal congestion case and 20% to 80% for the information scenarios (lane closure and growth). More weight was given to the real-time data because in the simulation environment the variation in speed experienced are not extreme and the possibility of something detector failure or some other factor that would give erroneous data are less likely to occur.

With these updated travel times, the drivers who are users of the Smartphone app and therefore the information will get the information (real-time travel time on alternative routes) and using the logit model in the ITS Modeller appropriate route changes are made (rerouting if necessary). The percentages used in spitting the O-D matrix in the pre-trip information implementation are used here also to divide the O-D into familiar and non-familiar as well users and non-users. The Table 4 of percentages below gives the values considered. The percentages used for the penetration rate are similar to those used in the pre-trip information and the reason behind them is similar.

The information given here is generated based on the real-time speeds that are updated every set number of seconds. It however does not include prediction of the travel time into any time in the future

IMPLEMENTATION OF SCENARIOS

The scenarios designed as part of this research were mentioned in section 4. In this section the actual implementation of the scenarios in the ITS Modeller is discussed. The normal case does not need special mention because it is the case of the current state of the network.

The lane closure/incident case was implemented as mentioned by executing traffic lights and making them red for an hour of the simulation period. The closure started at the beginning of the simulation period. The area chosen was the south western part of the network. From analysis and inspection of the network during simulation, this is one of the areas that were seen to experience congestion. Further the area falls within the SAA (Schiphol, Amsterdam, and Almere) project also as well as the PPA and was therefore seen as a choice that has potential to give answer to both projects. Below a snap shot of the network showing areas that are congested and among them is the south of the A10 ring road.

Penetration rate (%)	**Familiar: 73%**		**Not familiar: 27%**	
	Familiar and Users Recalculate route travel time (%)	***Familiar and Non-users***	***Non-familiar and Users*** Recalculate route travel time (%)	***Non-familiar and Non-users***
10	8	65	2	25
25	18	55	7	20

Table 4: Splitting percentages and penetration rate percentages for the on-trip information

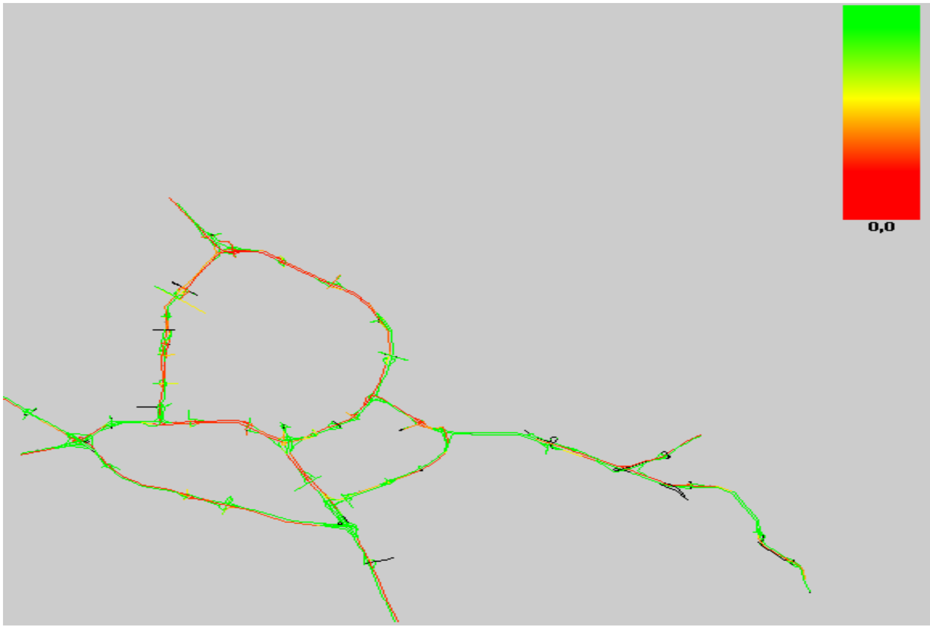


Figure17: Snap shot of case network showing congested areas

From the figure the legend shows the lane statistics (the speed ratio, ratio of speed experienced to free flow speed). The areas in red have the lowest ratio and the ones in green have the highest. It can be seen from the figure that the A10 ring road experiences a lot of the congestion.

The growth was implemented by doubling the network demand. The scenario looks at what might happen in future if there is growth in traffic or just growth in seasonal traffic caused by certain events that would attract large number of drivers to use the network. To implement this, the O-D matrix builder mentioned earlier (in the implementation of pre-trip information) was used to factor the original O-D matrix by doubling it.

The table below gives a summary of all the simulations that were run in this research for both the pre-trip and on-trip information under the different assumed penetration rates. For the lane closure and growth scenarios the pre-trip information considered only a 10 minute shift in departure time because a 5 minute shift was to not have such a big impact considering the increased intensity and also due to time constraints because the simulations were taking quite a large amount of time to complete.

Penetration rate / **Traffic condition**	**Information type**	**10%**	**15%**	**20%**	**25%**
Normal	Pre-trip (300)	Scenario1.1	Scenario1.2	Scenario1.3	Scenario1.4
	Pre-trip (600)	Scenario2.1	Scenario2.2	Scenario2.3	Scenario2.4
	On-trip	Scenario3.1			Scenario 3.2
Incident/lane closure	Pre-trip 600	Scenario4.1			Scenario4.2
	On-trip	Scenario5.1			Scenario 5.2
Growth / event	Pre-trip 600	Scenario6.1			Scenario6.2
	On-trip	Scenario7.1			Scenario 7.2

Table 5: Overview of experiments and scenarios

6.0 DATA ANALYSIS

6.1 INTRODUCTION

This section deals with analysis of the ITS Modeller output data to answer the main research questions. The questions addressed are:

- What is the impact of pre-trip and on-trip information on the efficiency of the Amsterdam network
- How does that impact vary under different traffic conditions and penetration rates

This section is structured this way; first the performance indicators used to define the road network efficiency and analyzed in this section are discussed. The second section gives the results of the actual data analysis including the discussion of the results.

6.2 PERFORMANCE INDICATORS

The efficiency of a traffic network can be looked at in different forms depending on what definition of the performance is under consideration at a specific time. The efficiency could be measured by some of the following performance indicators;

- Travel time, traffic volume, density, speed
- The network throughput
- Amount of congestion experienced
- Amount of pollution caused by traffic demand
- Safety level like number and/or severity of accidents.

In this research the problem that was identified was congestion and therefore the solution implemented (information) was aimed at reducing that congestion. In literature there are different indicators that have been used for this kind of problems. In addition looking at the problem and target of the solution the performance indicators; the amount of congestion and throughput were chosen. The other indicator that would have worked was travel time (average for the network) but this was not used because according to the analysis, the simulation period used did not allow for emptying of the network giving rise to incomplete trips so instead average network speed was used. Speed is measured at an instant in time and therefore it is not dependent on the complete trips just the vehicle flow and their speeds at a given time

The incomplete trips would have made it hard to compare the travel times because the exact time of the vehicles that do not complete their trips cannot be known and the comparison would include unfinished trips making it inaccurate. There was however the possibility to consider the travel time per departure time and this was used to calculate the personal gain (if any) in travel time of having the information.

For the chosen indicators defining them to suit the data obtained from the ITS Modeller output was done. The values were also averaged over the 10 simulations run for each case. The specific indicators chosen were: congestion length, speed, throughput and percentage of incomplete trips and personal travel time gain, these are further explained below.

6.2.1 CONGESTION LENGTH

Congestion in traffic occurs when road users are not able to drive at their desired speed (while adhering to the speed limit) due to the presence of other road users. The Dutch national road authority Rijkswaterstaat defines congestion as a condition in which the driving speed falls below 50km/h (Paula Marchesini, 2010). There are also other different ways to measure congestion for example queue length, delay, travel time and volume to capacity ratio among others. One of the measures that has also been used by Rijkswaterstaat is the amount of congestion in kilometer minutes, that is the length of congestion in a given time interval (interval in minutes).

This definition by Rijkswaterstaat was used in this research by considering speed on the highway part of the network (where the speed limit is equal to greater than 100km/h). This was converted into a measure of performance by considering the length of congestion in Kilometers (km). By calculating for every five minute interval the total length of the highway network that is experiencing speeds under 50Km/h and summing up the lengths of the affected sections, the total length of congestion was obtained for the five minute interval and also for the two hour duration of the analysis period. Comparing of the congestion length before and after the implementation of the information was then used as a measure of the impact of the information. This definition is summarized by the formula below:

For every 5 minute interval; the total congestion (cl_i) is given by

$$Cl_i = 5\left(\sum_j^n lj\right)$$

Where cl_i- congestion length per 5 minutes (in km-minutes)

j-n- number of links where mean speed (u_j)<13.88ms/s (50km/h)

l_j-length of j^{th} link (in km)

For the total congestion (T_C) over the two hour simulation period is then given by

$$T_C = \sum_i^m cli$$

Where T_C- total congestion

i-m – number of five minute time steps

cl_i- 5 minute interval congestion from first equation.

6.2.2. THROUGHPUT

The second performance indicator used was throughput, the Federal Highway Authority (FHWA) lists throughput as one of the measures of effectiveness that can be used to measure network performance (US department of Transport, 2013). It goes on to define throughput as the number of distinct vehicles or people able to enter and exit the network system during a certain period (analysis period). The throughput for a certain road network is computed by calculating the number of vehicles that successfully entered the network and were able to exit by completing their trips. By comparing alternatives (in this case information vs. no information) the relative productivity of the system can be computed. The difference between the alternatives when all other things hold constant can then be attributed to the information of any other measured being tested. In general higher throughput values are desired and the aim of the information in this research was to increase the throughput and therefore the productivity of the network during the morning peak.

To calculate throughput, departure time was used, the O-D matrix was divided into 15 minute intervals (during the setting up of the network) therefore for each departure interval the number of vehicles that successfully completed their trips in the time period of the simulation was summed up and used as the throughput for that duration for the two hour analysis period that was 8 departure time intervals.

Along with the throughput FHWA also defines another indicator the percentage of incomplete trips. The percentage of incomplete trips is given by considering the total vehicles in the system;

i. Those at the start of the analysis period that completed their trips
ii. Those that were at the start but could not complete their trips
iii. Those that entered the system but did not exit,
iv. Those that tried to enter the system but could not
v. Those that entered the system and successfully completed trips.

The total of categories ii, iii and iv divided by the complete total gives the percentage of incomplete trips. For this specific case because the network is empty at the beginning, items i and ii are zero. Generally for desirable network performance high throughput values and lower values of percentage incomplete trips are targeted.

6.2.3 AVERAGE NETWORK SPEED

The third performance indicator chosen was average network speed. To obtain this a weighted average speed was calculated. The weighting was based on the number of vehicles on a link, this way links with more vehicles have more weight compared to less used ones. The calculation was done for the whole network including the roads that have speed limits lower than the 100km/h. The calculation was done for each five minute interval and also as an average for the whole duration of the simulation.

6.2.4 PERSONAL TRAVEL TIME GAIN

The fourth performance indicator that was considered was personal gain in terms of travel time. The information that was tested in the real-life case is to be provided via a smartphone app and for the users of the app personal gain from the information is important to encourage more use and trust in the information. This was obtained by comparing the travel time experiences by the drivers with the app as compared to those without the app but have a similar origin destination and the departure time is the same.

For the pre-trip information this was straightforward since the drivers that changed their departure time were known and could be traced to obtain the travel times. For on-trip information however the drivers were provided with information but the output does not indicate how they responded to that information. For this case therefore the driver having the information alone was used to analyze the gain in travel time if any irrespective of their response to the information.

For both cases the comparison was not made between the case with information and without because of the issue of incomplete trips. The comparison was made for only the cases with information considering same scenario, same conditions by comparing the travel of the drivers with and without the information for on-trip. For pre-trip leaving early was used, comparing the travel time experienced by drivers who left early as opposed to those who had no information and therefore left at the set departure time. Only departures within the first hour were used because most of the trips started in the second hour were not completed.

6.3 DATA ANALYSIS

All the results in this section were based on calculated average values over the 10 simulation runs done for each case**.**

6.3.1 THE IMPACT OF PRE-TRIP INFORMATION: THROUGHPUT, CONGESTION AND SPEED

To determine the impact of pre-trip information, two cases were considered as mentioned in the section on implementation of pre-trip information. The two cases were shifting a given percentage of the O-D matrix by 5 (300 seconds) and 10 (600 seconds) minutes respectively. The two cases were then tested under various penetration rates and the results are shown in the figures 18 to 20 below. The percentage shifted depended on the penetration rate being tested and in the figures the letters PR stand for penetration rate, while the 300 and 600 stands for the amount by which the O-D matrix was shifted. To give meaning to the results and show the different percentages used for trip cancellations and departure time change, the table 3 showing the different percentages is again shown below;

Penetration rate (%) -PR	**Familiar: 73%**			**Non- familiar: 27%**		
	Familiar and Users		**Familiar and Non-users**	**Non-familiar and Users**		**Non-familiar Non-users**
	Cancel trip (%)	*Change departure (%)*		*Cancel trip (%)*	*Change departure (%)*	
10%	1	7	65	1	1	25
15%	2	8	63	2	3	22
20%	4	10	59	2	4	21
25%	3	15	55	1	6	20

Table 3: Percentages for pre-trip information

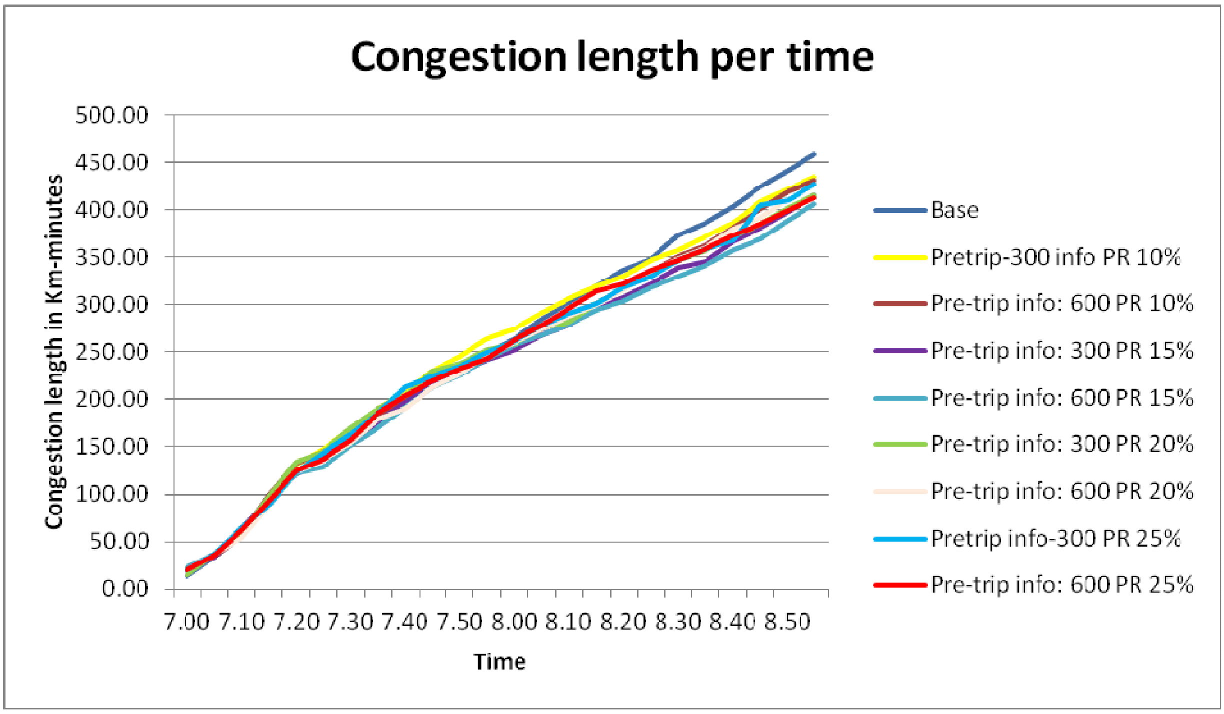


Figure 18: The impact of pre-trip information on network Congestion length

The total congestion level for the entire simulation period was summed up to give total congestion length and is presented in the figures 19 and 20 below.

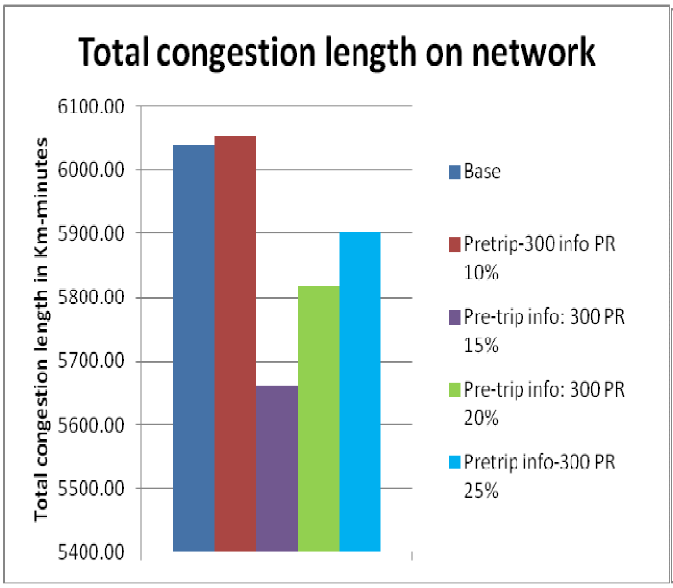


Figure 19: The impact of pre-trip (300) information

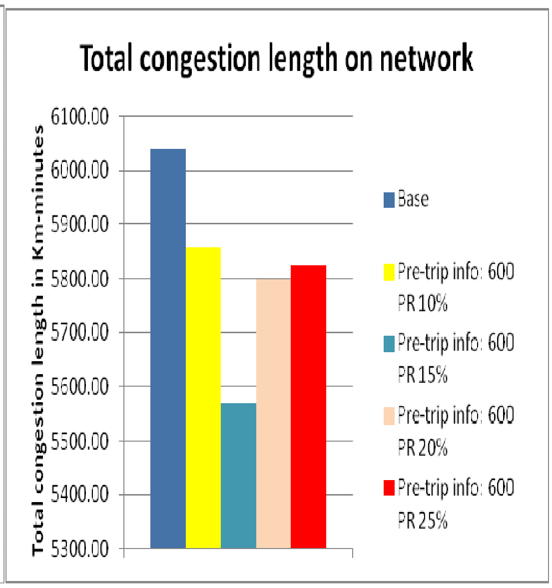


Figure 20: The impact of pre-trip (600) information

From the figures it can be seen that compared to the base case the implementation of pre-trip information with the penetration rates ranging from 10 to 25% has a positive impact on the congestion especially during the last 30 minutes of the analysis period (figure 18). In terms of total congestion the Figures 19 and 20 show the impact of the two different shifts in O-D matrix and what impact they have. From the figures it can be seen that a 15% penetration rate has the highest impact in terms of congestion reduction for both types of information. The 15% penetration rate has a difference of 8%

reduction in congestion length while the others range between 2 and 4%. The least reduction is for the penetration rate of 25% (300 info case) which is 2%.

In terms of throughput the results of the network throughput and the percentage of incomplete under the influence of information is shown in the figures 21 to 23 below.

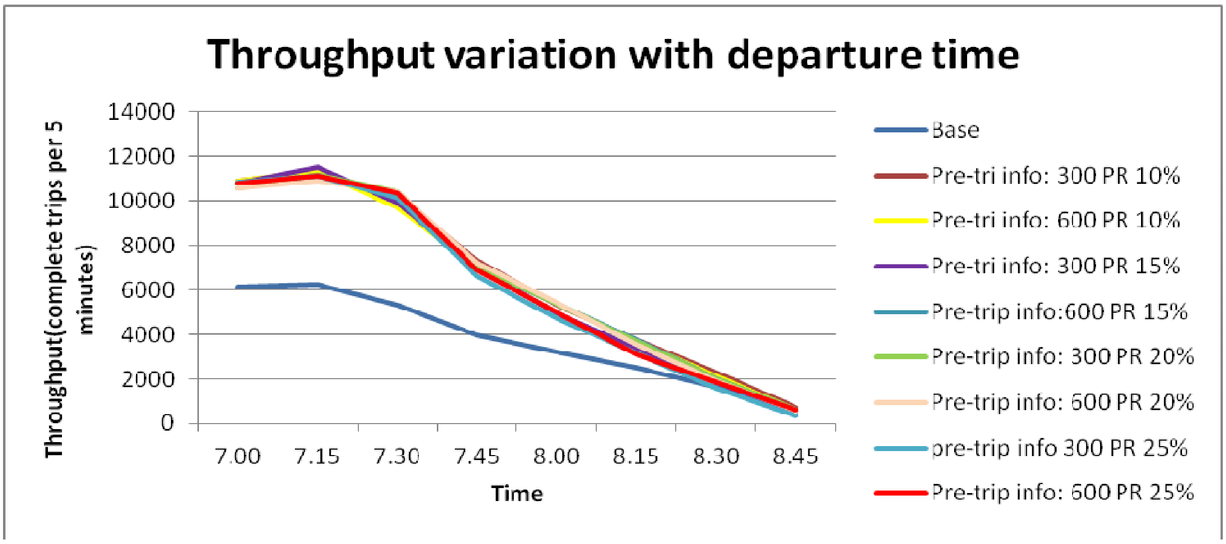


Figure 21: Network throughput variation

The total network throughput for the simulation period (summation of the values in figure 21 above) is presented below. The figure 22 below highlights the differences between the penetration rates which is only just slight and is not clear from figure 21.

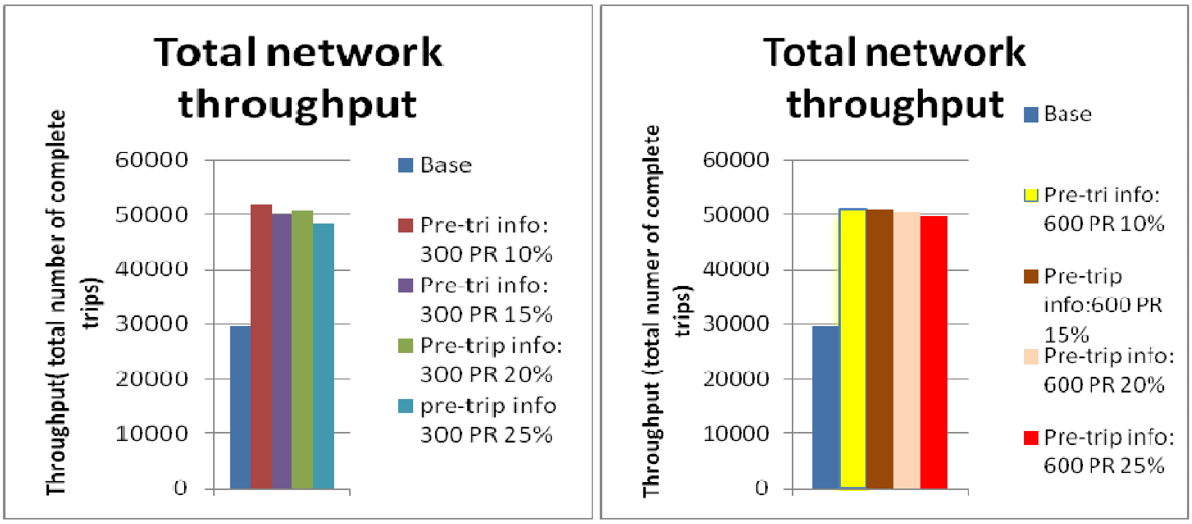


Figure22: Total network throughput for on-trip information

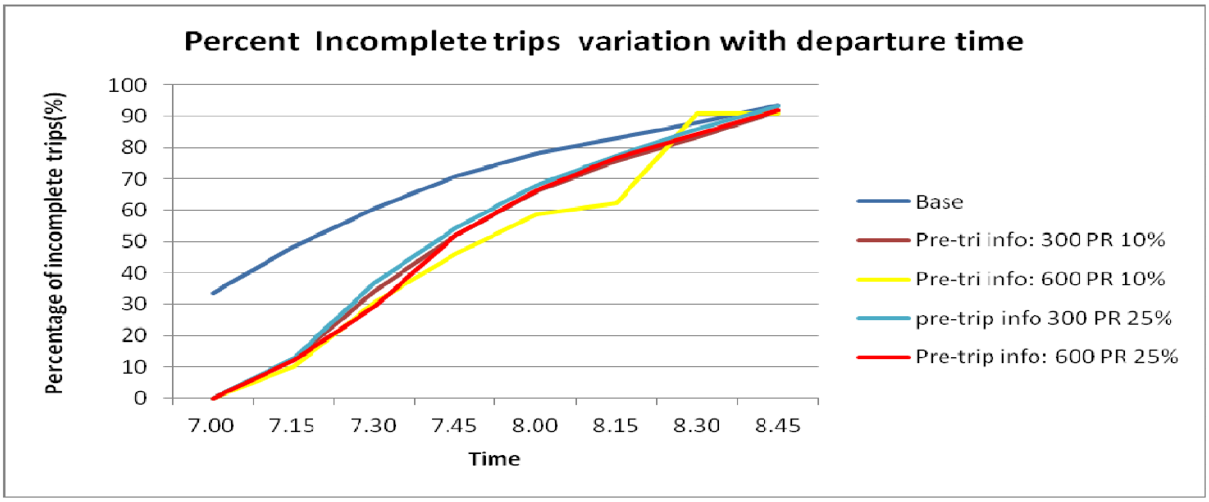
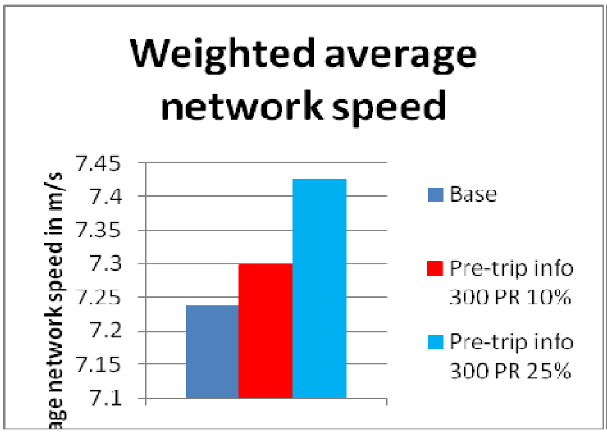


Figure 23: Percentage of incomplete trips

The figures 21 to 23 show that the throughput increases with the implementation of information and especially during the first hour of the analysis period and in the same way the percentage of incomplete trips decreases. The throughput increases on average over time with a percentage ranging from 60 to 70%, the least being with the 25% penetration rate and the highest at the 10% penetration rate. All the differences are however not statistically significant as shown by the negative results of the T test (actual results presented in appendix 1) done to determine if the mean of the different values are significantly different. The differences between the penetration rates are only slight in this case and this is due to the short simulation period, as can be seen from figure 21 the differences decrease as the departure time increases.

In terms of congestion length and throughput pre-trip information achieved a positive impact. The redistribution of traffic in time due to departure time shift and space due to route changes led to improved network speeds. This reduced congestion and increased throughput. The results for throughput showed a rather high percentage increase after implementation of the information. The reason for this is the increase in speed that was brought about by the information, the redistribution enabled the average network speeds to go up and therefore more vehicles were able to complete their trips within the simulation period.

In terms of the network speed, the results are presented in the figure 24 and 25 below. The figure shows the average weighted network speed for the entire simulation period and also the five minute interval.



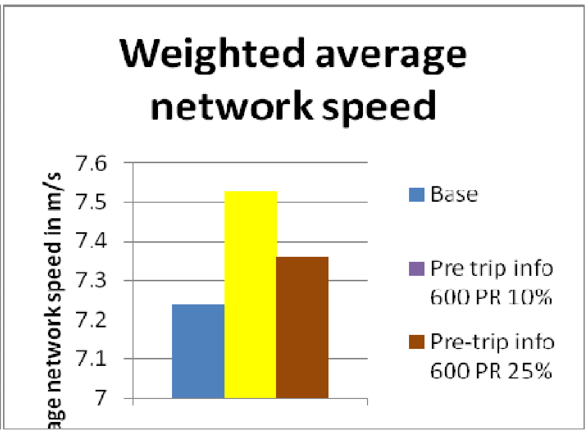


Figure24: Average network speeds with pre-trip information

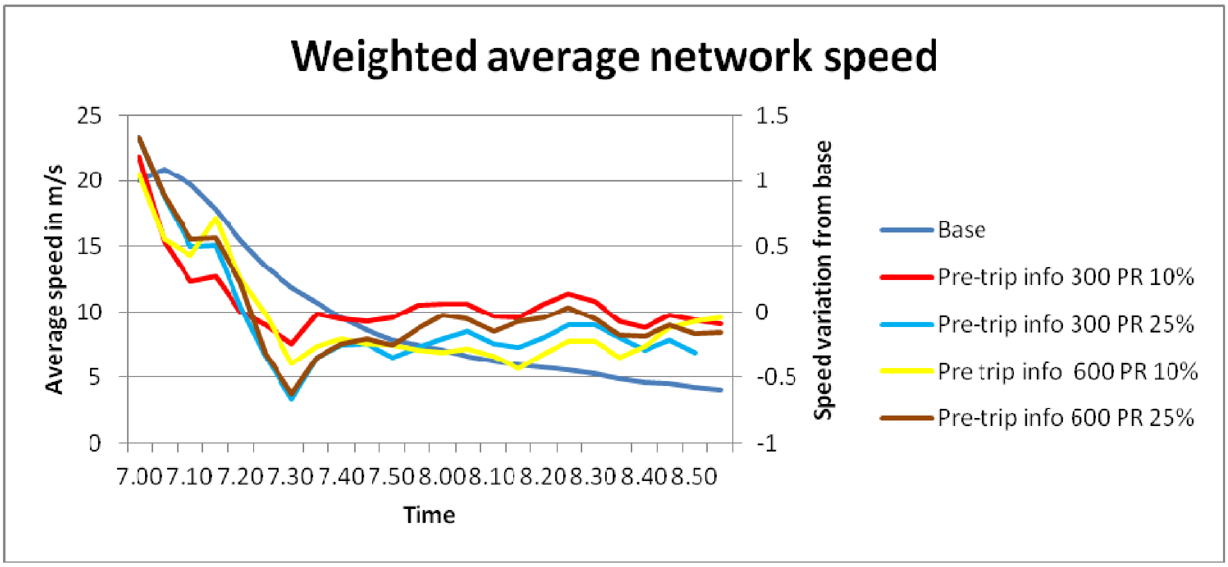


Figure 25: weighted average network speed for pre-trip information normal case

From the figures 24 and 25 it can be seen that implementation of pre-trip information helps to increase the average network speed. From figure 25 that shows the five minute interval variation, in the first 20 minutes the speed with information is lower than the base case speed. 30 minutes into the simulation the speed variation shows that the information case has higher speeds as compared to the base case. Overall the effect is positive, the pre-trip 300 information shows a 1.7% increase in speed and the 600 has a 2.8% increase in speed.

The variation in speed indicates that during the first 30 minutes of the simulation, which is before congestion starts information does not have such a positive impact that is why the speeds are lower than for the base case. As the congestion starts information provides opportunity to change route or departure time and the gain can be seen as the speeds recorded for information are higher than the base case. As simulation period moves and congestions increases the quantity of the speed variation also decreases, as can be seen from figure 25, the variation approaches zero towards the end. This is because when congestion sets in there are fewer opportunities for change and even with information these opportunities are reduced and as such the impact of information also reduces. Similar trends were observed by (Levinson,2002) who noted in their findings that information gain is most significant at the precipice of congestion, that is when traffic flows average 95% of the capacity flows.

To further understand the influence of the penetration rate, congestion length for all the penetration rates that is 10 to 25% were calculated and the outcome is shown in the figure 26 below. From the figure 26 the congestion levels experienced reduce with increase in penetration levels but up to a certain extent. Congestion reduces for 10 and 15% and the effect starts to decrease at the 20% penetration level. Once again the differences between the congestion values of the various penetration rates were not found to be significantly different at both 90 and 95% confidence levels.

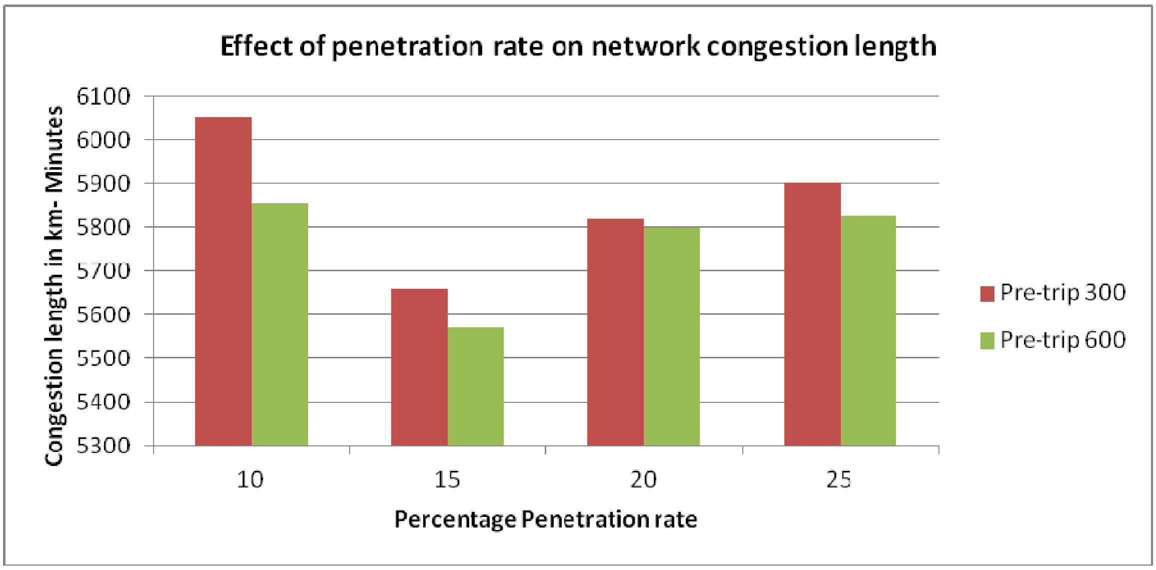


Figure 26: The effect of penetration rate on impact of pre-trip information

From the figure for both variations of pre-trip information the 15% rate of penetration is the one that gives the best results in terms of congestion. These results are similar to results obtained by (Emmerink, Axhausen, Nijkamp, & Rietveld, 1994) and (Mahmassami & Jayakrishnan, 1991). In the case of Emmerink et al however they used a hypothetical network and found that the best results were obtained for penetration rates lower than 20%. The reason for this is that increasing the share of people with information reduces opportunities that can be exploited and therefore when the share of informed people goes up a limit is reached where the effect becomes negative.

(Hall, 1996) looked specifically into this issue for decrease in benefits beyond a certain percentage of drivers with information. In their findings they noted that, it is not necessarily the increased penetration rates that affect the impact of information but also the accuracy of the information and the network configuration. They found out that for a simple parallel network increasing penetration rate of accurate information did not harm network performance but harm was noted when the same information was based only on instantaneous travel time estimates. This could also be the explanation for the behaviour noted here because the information was indeed based on mainly historical travel times and neither real-time updates nor predictions were used. In addition the exclusion of secondary and local roads in the network structure reduced the possible number of possible alternative routes.

DISCUSSION OF RESULTS

From the data analysis and results presented above, it can be see that pre-trip information does have a positive impact on network performance. It reduces the average total congestion, increases the average network speeds and increases the throughput. The results as presented were expected because part of the pre-trip information response involves cancellation of trips and or change of departure time to a time slot outside of the peak period. The shift in departure time was expected to reduce especially the congestion in the second hour of the simulation and as can be seen from figures 18 to20 the reduction in congestion is especially visible in the last 45 minutes of the simulation period. This implies that the time shift of either 5 or 10 minutes does have the desired effect of spreading the congestion through time.

The influence of the quantity of the departure time change, that is whether it is 5 or 10 minutes can also be seen where the 10(600 seconds) minutes change shows higher impact rates as compared to the 5 (300 seconds)minutes case. The other factor that influences the impact is the penetration rate of the information. The highest impact was obtained at a penetration rate of 15% and any further increase reduces the impact. This applied to both cases as can be seen from the figure 26.

The effect of the penetration rate in this case also showed the compliance rate because the pre-trip information was modeled in such a way that having the information implied complying with it for departure time shift. The effect would be expected to be different if for example the driver response to the information was modeled separately using a kind of utility model with other factors being used in the choice process to determine driver response. The reason for the trend with the penetration rate could also be explained by considering other factors like overreaction, where a high number of drivers respond to the information by changing their route and this leads to increased congestion in the areas where the drivers change to and in overall the network congestion levels go up. Another reason is that when higher compliance rates are experienced the chances within the network for the drivers with information to explore by changing departure or route become reduced and the overall effect of the information reduces thus.

From checks on network behaviour and performance of the information during the simulation it was noted that the network performed well and that the modeling of the information worked. The departure time shifts and the cancellations were effected and the change in route was also noted by checking the O-D matrix before start of the simulation. The O-D matrix showed for the same O-D pair that for the drivers with information some of their route choices and alternatives were different from those of non-users of the information. In general therefore the implementation of the information as modeled and its functioning was successful. The outcome of the information obtained therefore is a result of individual driver interactions and traffic behaviour under information and not inaccurate information modeling.

6.3.2 THE IMPACT OF ON-TRIP INFORMATION: THROUGHPUT, CONGESTION AND SPEED

On-trip information was implemented as described in section 5, to determine what impact this information had on network performance different penetration rates were tested for the normal case of congestion experienced. The rates tested were 10 and 25% and in both cases the impact on network congestion and throughput was calculated and the results are presented in the figures 27 to 30 below. In running simulations for this information, it was realized from previous simulations that the duration was not enough for the vehicles released later in the system to complete their trips. The analysis period was therefore extended by 30 minutes but still this was not enough to completely clear the network dues to the high demand and the inherent properties of ITS Modeller that when there is congestion at the origin vehicle release is delayed.

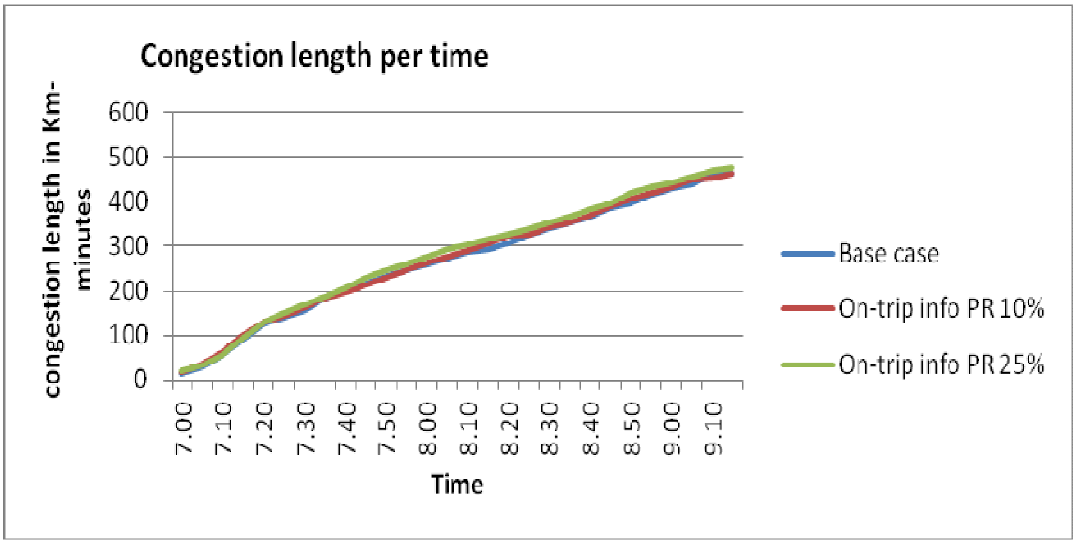


Figure 27: The impact of on-trip information on congestion length

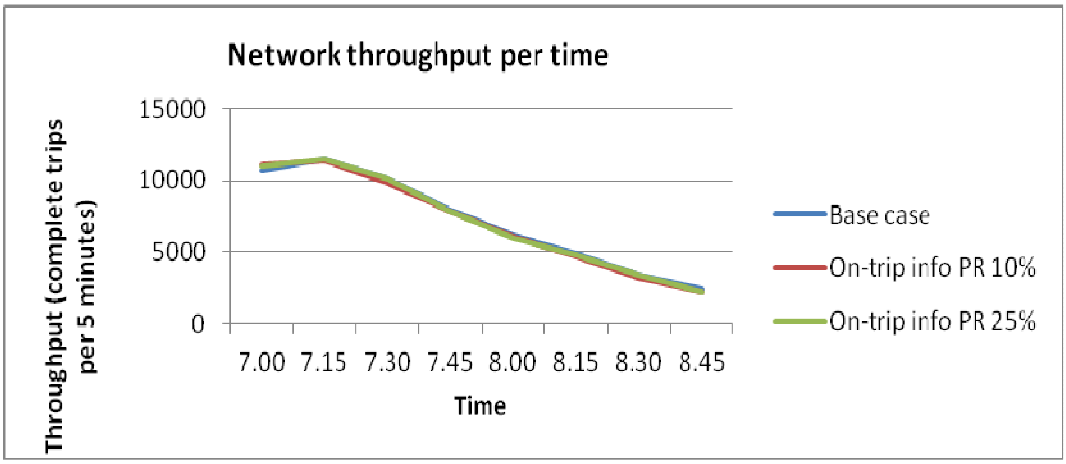


Figure 28: The impact of on-trip information on network throughput

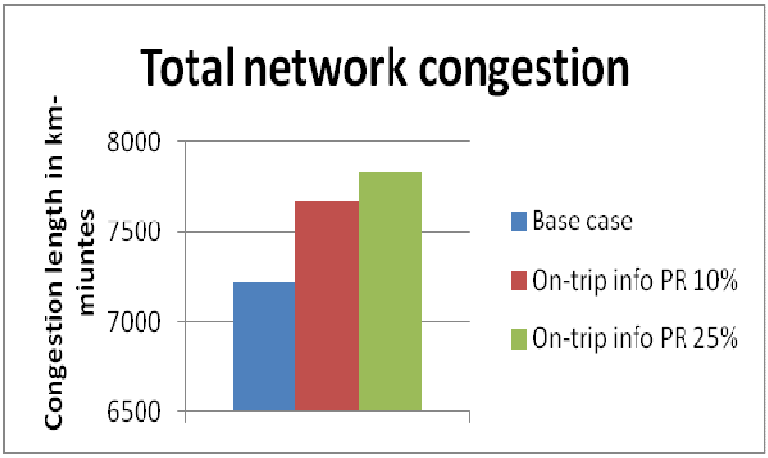


Figure 29: Total network congestion under on-trip information

From the figures 27 and 29 it can be seen that the impact of on-trip information on network congestion is negative, that is the congestion goes up by 6 to 8% when the on-trip information is implemented. For throughput and the percentage of incomplete trips the effect is also negative, the throughput decreases and the percentage of incomplete trips goes up. The differences in all the cases still did not show statistical significant according to the results of the T test at both 90 and 95% confidence levels.

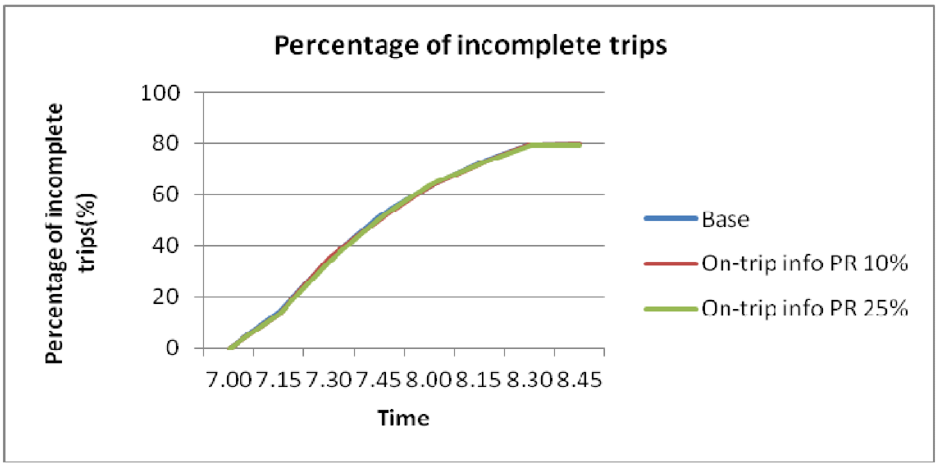


Figure 30: The impact of on-trip information on percentage of incomplete trips

The negative impact of this information was unexpected and undesired because it made the network even worse than it was before. This could have been caused by network structure, state of the network and type of information. For the state of the network, during the first hour of the simulation, minimum to no congestion levels are experienced in that time, giving information in such cases has been found to not be of value and even in some cases made the sitaution worse because changing routes at that point provides no gain and if those route changes are increased due to overreaction to the information the network performance could worsen. The type o information also affects, this information was based on instantaneous updates of link travel times, no predictions were involved, this could have led to less than optimun route changes and this could worsen the situation. The network configuration comes in because of the exclusion of the secondary and local roads, this meant that any route changes had to be done at only intersection points,after that the number of alternative routes reduced and `in most cases provided no alternatives. All these therefore would have caused the network conditions to deteriorate under information. These also could explain why the 10% case performed better that 25% that had more drivers with information.

The impact of the information on average network speed was also obtained and is shown in the figures 31 and 32 below.

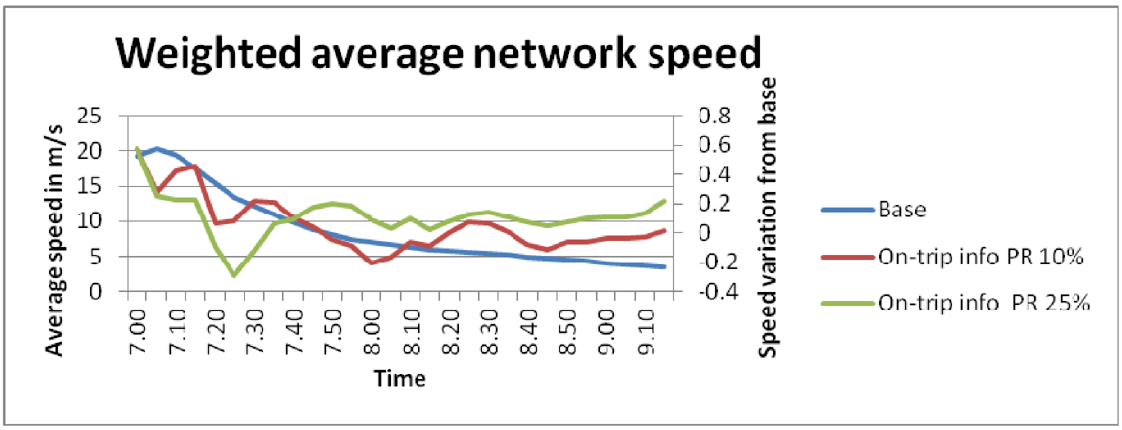


Figure 31: impact of on-trip information on average network speed

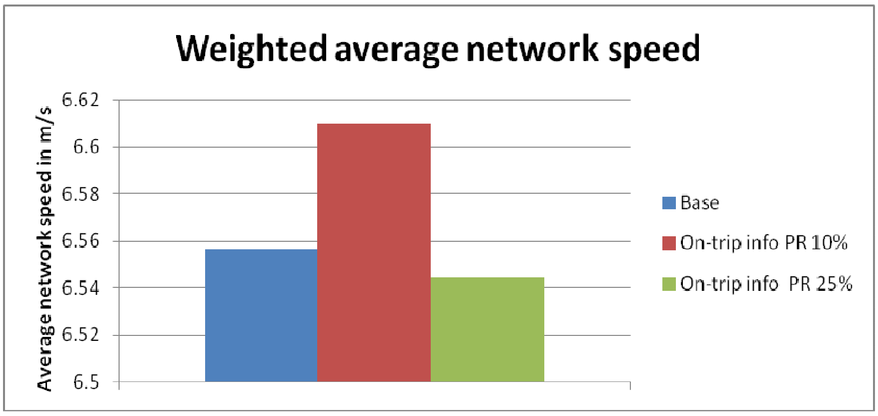


Figure 32: the impact of on-trip information on network speed

From the figures 31 and 32 it can be seen that the effect on on-trip information on the average network speed is somewhat mixed. The average speed increased for the 10% penetration rate yet reduces for the 25% case. From the figure 31 that shows the variation in speed compared with the base case, the effect of information in the first half hour of the simulation is negative with the average speed in most cases lower than the base case. That changes at the half hour mark and the average speed with information is higher and as the simulation continues and the network goes into the congestion zone variation reduces to almost zero for the 10% penetration rate and for the 25% case the variation even becomes positive showing the base case speeds as higher.

The variation in the first minutes (about 20) can be explained by the lack of congestion and therefore not much gain to be obtained by the information. As the network starts to get congestion information becomes useful and the drivers with information are aware of the opportunities to change route and therefore there is gain in speed. As the total congestion sets in the information becomes less significant because even with the information the opportunities that a route change would give faster travel times are reduced. In the end the overall effect is less that 1% gain in travel time.

DISCUSSION OF RESULTS

The impact of on-trip information as was presented above had some unexpected results. For the network congestion the results indicate that the congestion gets worse with the implementation of this kind of information. The effect on the average network speeds for the same case is somewhat different where the 10% penetration rate shows on average an improvement in speed while for the 25% rate the effect is negative.

The reasons for the poor performance of this kind of information can be explained by the network configuration and the type of information that was give as also discussed in the findings of Hall, 1996 mentioned earlier. The exclusion of the secondary and primary roads from the network mean that any route changes on the highway are done only at the intersection points, once past that even with the information, there is a limit to the route changes that can be effected. In the research by (Yao, Zhan, Lu, & Yang, 2012) that looked into different network structures and how that affects the impact of information, they showed that network structure does affect. For a parallel network which is similar to the test network in this research the impact was the least and the impact of penetration rate was indicated by the fact that after 30% rate the recorded gains due to information went down. The other two network structures grid and ring had different results where increase in the penetration rate of the information gave better results.

In addition the information given was based on instantaneous travel time updates, no predictions were involved. This kind of information as reported by (Hall 1996) has the potential to harm the performance of the network because it is prone to overreaction from the drivers, where a large number of drivers respond to the information by changing their route. This in essence shifts the congestion from one area to another without necessarily improving the performance of the network and in the end could even make things worse.

The implementation of this information and the performance of the network during simulation were also observed. From the observations it was seen that the information was relayed to the drivers, this was indicated by the observable route changes during the course of a simulation (the drivers implementing route changes were set to have their vehicles turn colour for about 30 seconds during the change). From this it can be deduced that the information was generated and relayed and that it worked. The negative effect observed therefore cannot be attributed to failure of the implementation or functioning of the information but rather to the other factors like reaction to the information and individual driver interaction that were discussed above.

6.3.4 THE IMPACT OF INFORMATION FOR THE LANE CLOSURE/INCIDENT SCENARIO

In this scenario a lane was closed by implementing traffic light controllers and for the first one hour of the simulation period the lights were red blocking any vehicles from using the lanes. The simulations were then run for the base case (without information) and the cases with information, both on-trip and pre-trip (separately) and the results are presented in the figures 33 and 34 below. For the pre-trip information the historical data used was obtained from the base scenario where the incident had already been simulated and the resulting responses were therefore with knowledge of the occurrence of the incident and its impact.

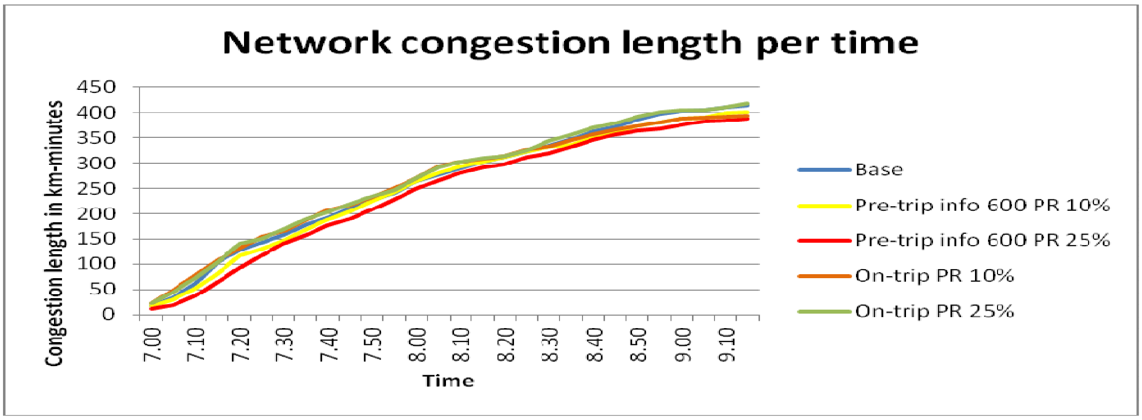


Figure 33: The impact of information on congestion

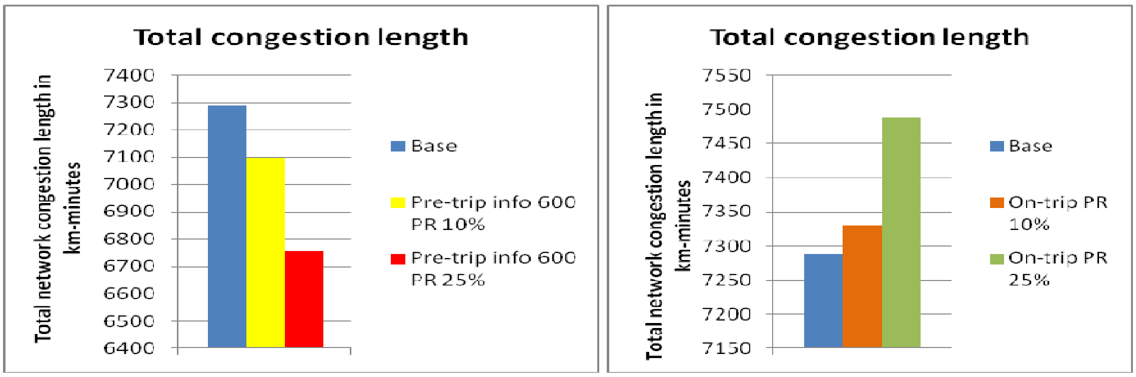


Figure 34: Impact of information (pre-trip: left and on-trip: right)

From the figures 33 and 34 above for congestion the pre-trip information reduces congestion while under the on-trip information the congestion increases once again. For the effect of this information on throughput the results are shown in the figures 35 and 36 below. From these figures the effect of the pre-trip information in terms on throughput and percentage of complete trips can be seen to be slightly higher than for the on-trip information, for both cases however the difference is minimal ranging from 1 to 3%. In this scenario, the pre-trip information tested was the 600(shift of O-D by 5 minutes) the only variation being in the penetration rates.

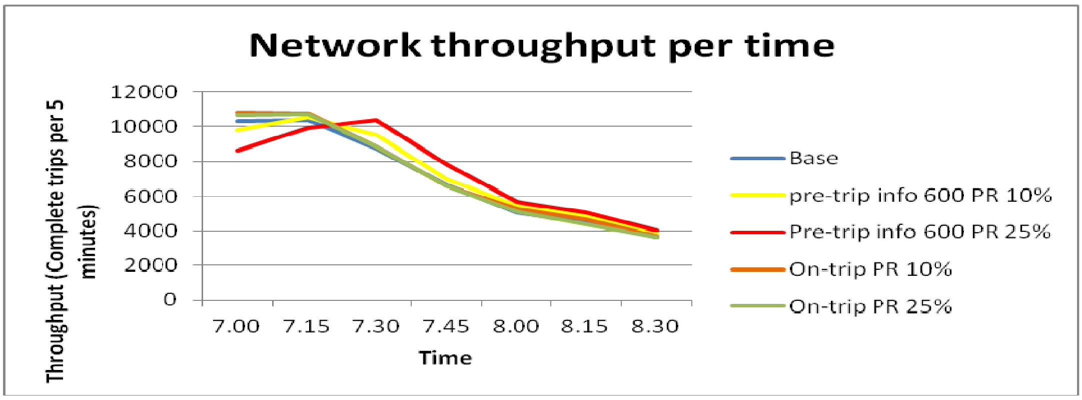


Figure 35: The impact of information on throughput

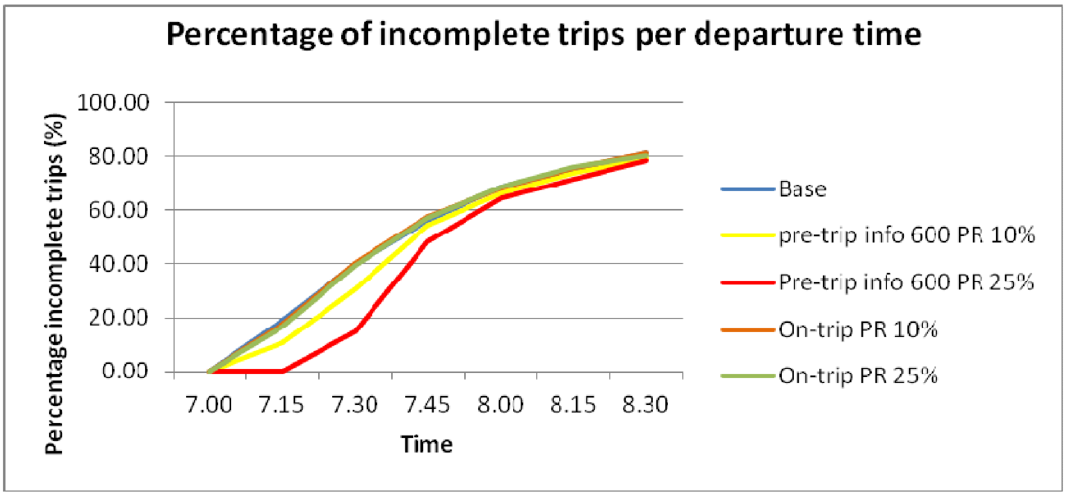


Figure 36: The impact of information of percentage of complete trips

The average network speeds were also calculated for this incidence for the two kinds of information and the results are shown in the figures 37 and 38 below. From these figures it can be seen that the pre-trip information has higher impact than the on-trip information. From the variations figure 37, the highest difference can be seen in the first half hour of the simulation, it is also during the occurrence of the incident. The reason for the difference between the information types can be due to the fact that for pre-trip using the base case data that assumes the incident has occurred and uses that give more accurate information (averaged over the entire period). For the on-trip information, it's updated every two minutes and also it takes longer for the effect of the incident to be felt and recorded by the areas, by the time that happens some drivers have already been assigned to those areas and in the end therefore the impact of information is reduced.

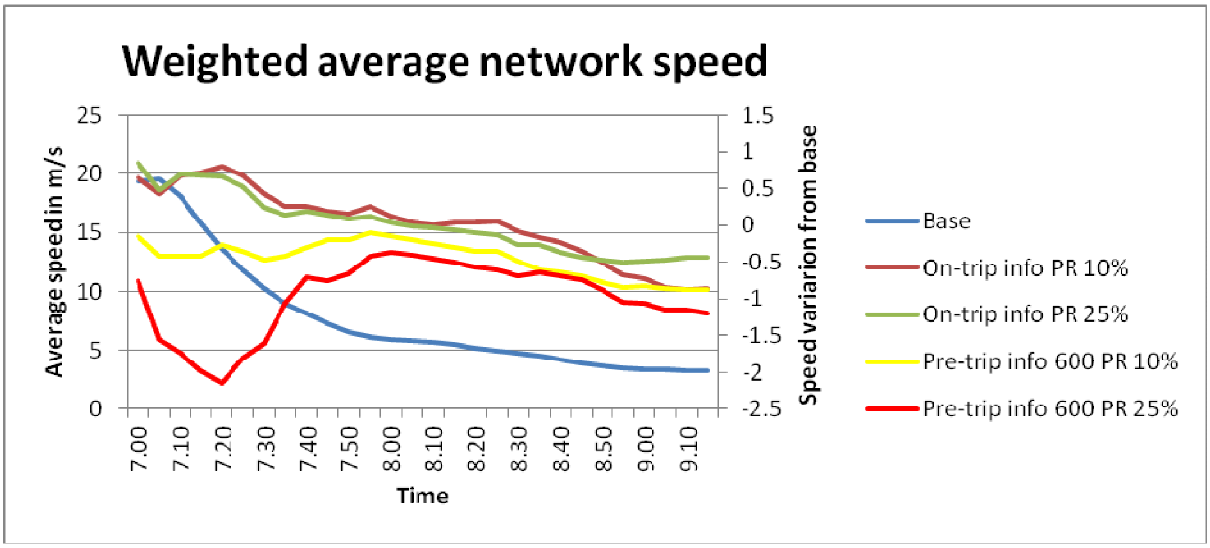


Figure 37: The effect of information on average network speeds per time interval.

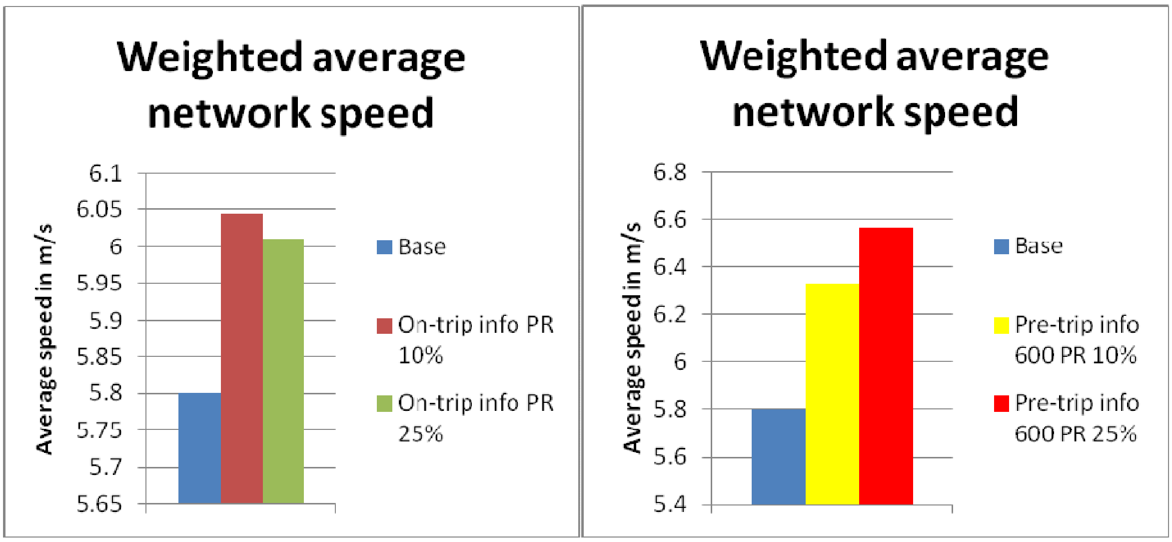


Figure 38: Average network speeds for on-trip and pre-trip information

Analysis was done for some specific link areas especially the link on which the incident occurred showing the local effect on the information provision on the average link speed. The results are presented in appendix 2 and show for all the links considered that use of information leads to higher speeds on average for the considered links.

DISCUSSION OF RESULTS

For the on-trip information in this case again the congestion length went up while the percentage incomplete went down and throughput as was the case also during the normal congestion. Average speed comparison shown in figure 38 indicates that on average there is an improvement in speed although by a really small margin. The improved speeds in this situation can attributed to the occurrence of the incident, the increased congestion due to the incident was recorded by the appropriate loops and this was passed to the drivers with information and therefore they were able to avoid the area. Why the margin is small is because the duration it took for the effect of the incident to be felt in the network may have been long and therefore the resulting route changes were also not of such great value because at that point the congestion was already spread to even more areas.

The results of the on-trip information in this case were in general more positive than those recorded for the normal congestion case. This goes to support the general idea that has also been recorded in past studies that information is of greater value under traffic disturbances. Because in this case even though the quality of the information is similar to the one used in the base case (based on instantaneous updates) its impact was more positive.

Considering pre-trip information, for the lane closure/incident scenario the differences in throughput are less than 10% whereas for the normal congestion it was over 60%. The reason for the big differences experienced in the normal case could be due to the simulation period, in the normal case the period is just 2 hours, this period was not enough for the drivers to complete their trip. For the other two cases the simulation period was extended by 30 minutes for the base case and the information cases allowing more drivers to complete their trips. This meant that even without information most of the drivers in the first half hour of the simulation were able to complete their trips. With information this number did not go up because it would not exceed the demand for that duration. In fact the number was expected to reduce slightly because part of the response to information involved trip cancellation.

The impact of this pre-trip information on congestion length and average speed was positive and the values recorded were better than for the base case further strengthening the value of information during traffic disturbances.

6.3.5 THE IMPACT OF INFORMATION FOR THE GROWTH/EVENT SCENARIO

In this scenario the network demand was increased by double to test what impact the information would have in case of an event or future situation where the demand increases. The results of the information impact on the network congestion levels and throughput are shown in the figures below. For the pre-trip information in this scenario as for the lane closure the 600 seconds shift in the O-D matrix was tested under different penetration rates.

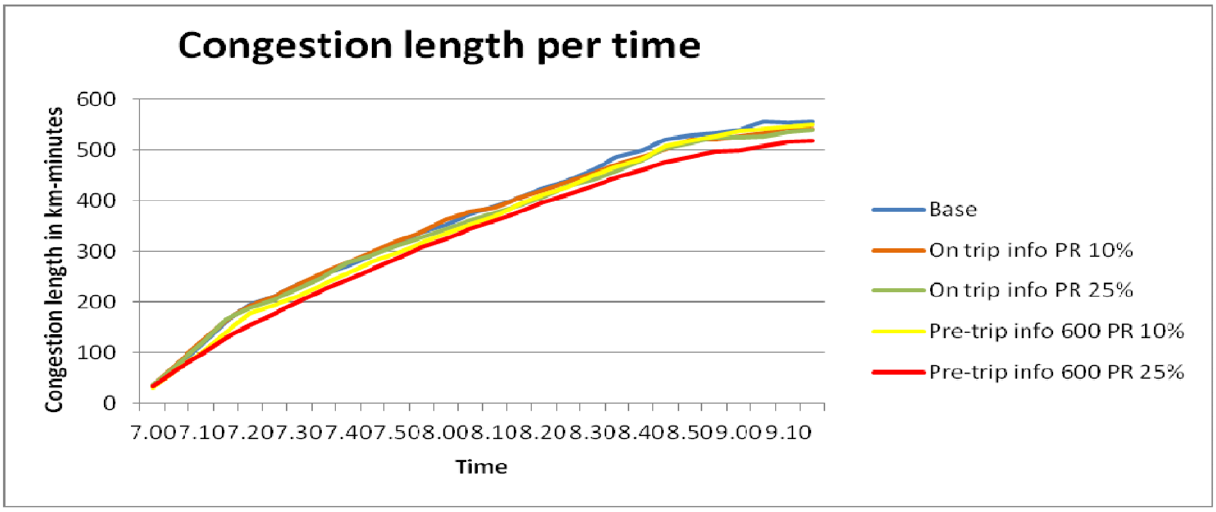
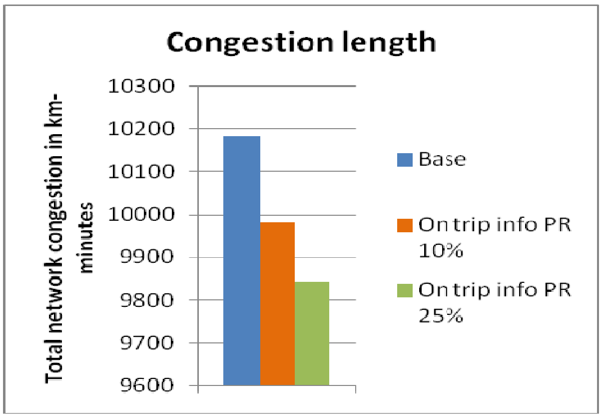


Figure 39: The impact of information on network congestion for the growth scenario



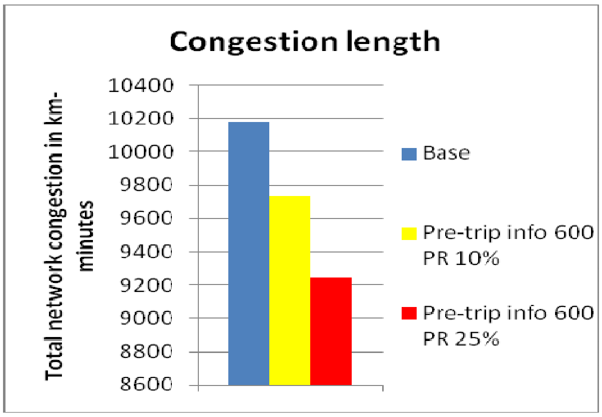


Figure 40: variation in impact of information with penetration rate (left: on-trip, right: pre-trip)

From the figures 39 and 40 above it can be seen that both information types have a positive impact on network congestion. The reduction in congestion length is again slightly more for the case of pre-trip information as compared to the on-trip information. Unlike the previous case under normal congestion cases, in this case the impact of on-trip information was positive in that on average it reduced the congestion. The effect of the penetration rate in both information cases can be seen where the higher the penetration rate had more positive impact. The impact of the information for the throughput indicator and the associated percentage of incomplete trips are shown in the figures 41 and 42 below.

For the throughput and the percentage of incomplete trips as can be seen from the figures 41 and 42 below, the throughput increases and the percentage of incomplete trips reduces however on average the margins of the reduction are low. The results of the T test for this case also indicate that the differences are not significantly different.

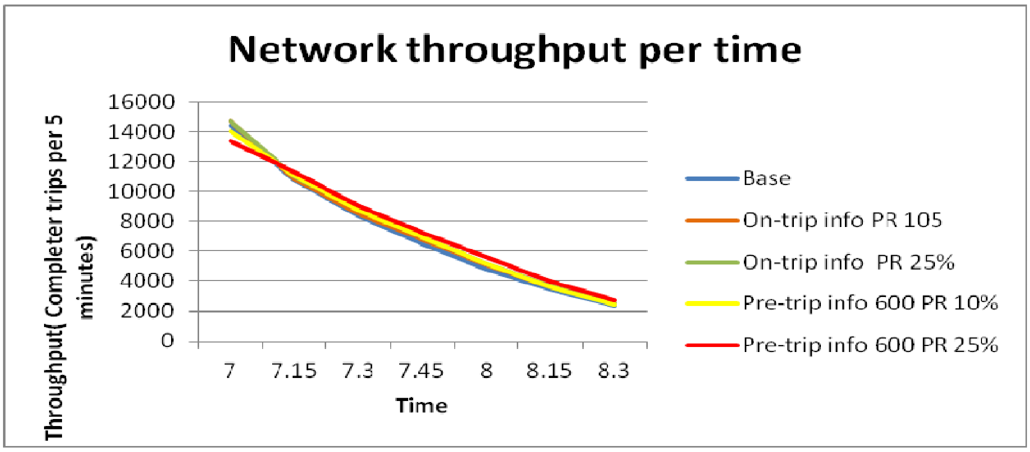


Figure 41: The impact of information on throughput

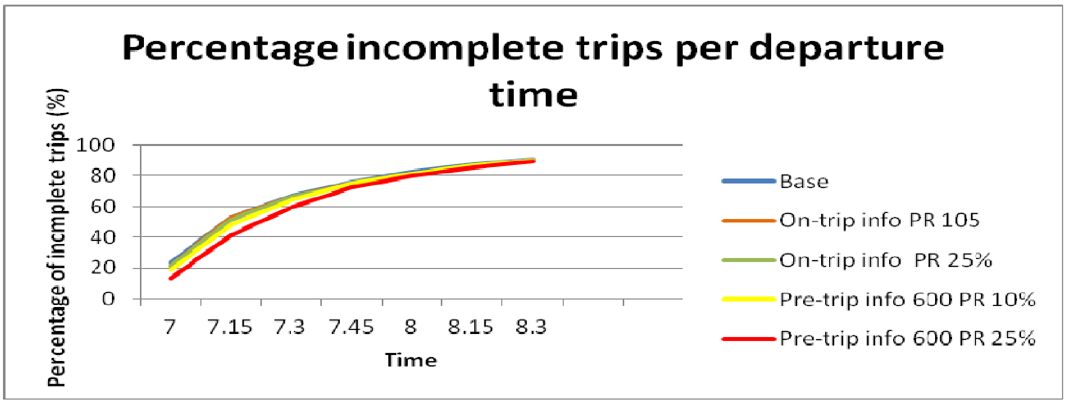


Figure 42: The impact of information on percentage of incomplete trips

For the same case analysis of the average network speed gave the results shown below in figures 43 and 44.

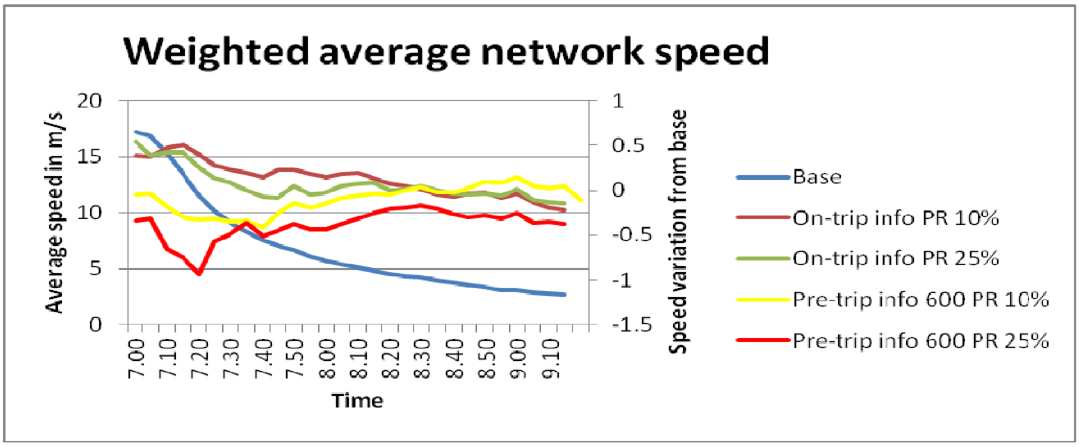
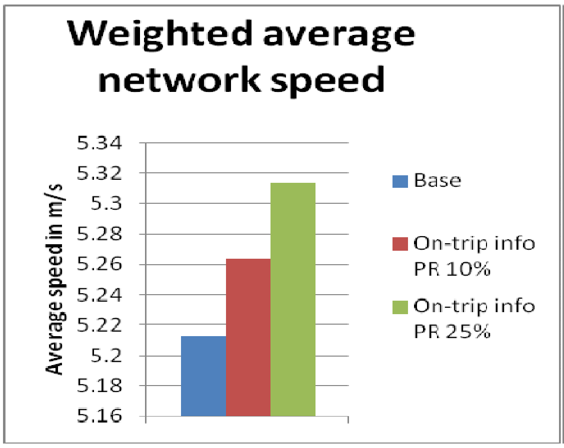


Figure 43: impact of information on network speeds per time interval



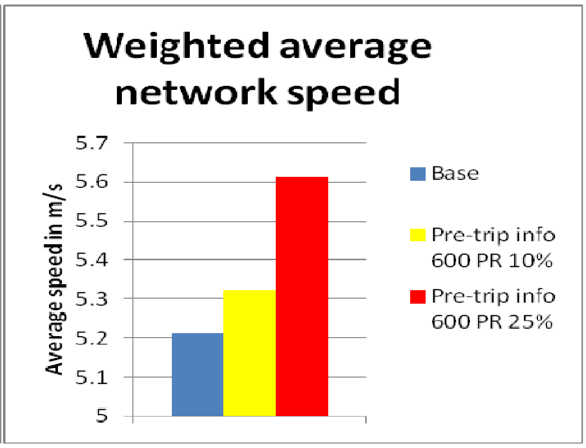


Figure 44: the impact of on-trip and pre-trip information on average network speed

From the figures 43 and 44 above on average the network speeds increase with the introduction of information. The increase is higher for the pre-trip information as compared to the on-trip. The reason is because pre-trip information includes trip cancellation meaning less traffic or push of traffic to outside peak period. In addition the data from the base case was used as the historical data for the pre-trip information. Therefore the pre-trip route assignmnent was based on the travel times with the factored growth. For both information types higher penetration rates gave better average speeds.

DISCUSSION OF RESULTS

From the results presented above for this case, both information types had positive impact on the performance of the network. For the congestion length, both information types had the impact of reduction in the congestion experienced. The percentage reduction experienced for the pre- trip information (4% and 9% respectively for PR 10 and PR 25%) was however slightly higher than for the on-trip information (1.9% and 3.3% for PR 10 and PR 25% respectively).

In terms of throughput both information cases led to an increase in throughput, the increase was 2.5% and 5% for penetration rates 10 and 25% respectively for the pre-trip information. For the on-trip information the increase was 2.7% and 4.1% for PR 10% and PR 25%. For both cases the average speed also went up, the increase was with 2 and 7% for the pre-trip information and 1 and 2% for the on-trip information, in each case for the 10 and 25% penetration rates respectively. The positive results posted for both information types in this scenario also serve to further support the idea of information being more useful under traffic disturbances. The better performance of the pre-trip information can be attributed to the modeling of the information (assumption of compliance) and also in the source of the information. While pre-trip was based on average network historical data that had the influence of the disturbance factored in, the on-trip was based on real-time updates without any predictions. This therefore meant that for on-trip information the issue of overreaction was still present as well as it taking time for the effect of the disturbance to be recorded.

The influence of the penetration rate in this scenario is different from the normal congestion case. In this scenario higher penetration rates had a higher impact, this could mean as was also noted by (Emmerink et al 1994) and (Levinson 2002) that information is more important under non-recurrent congestion cases. Further in such incidents the more the percentage of drivers informed the better it is because then the informed drivers make better choices and this lead to better performance of the network.

6.3.6 IMPACT OF INFORMATION IN TERMS OF GAIN IN PERSONAL TRAVEL TIME

For this section the personal gain of having the smartphone app and therefore the information was tested by considering for pre-trip information the travel time experienced by leaving early and for on-trip information the travel time experienced by using the information. For the on-trip information it was not possible to tell if the recipient of the information actually responded by for example changing their route and therefore the analysis just considered that the drivers were provided with the information. The table 6 below summarizes the results

From the table it can be seen that there is some gain in personal travel time for the users of the information. The gain for pre-trip information that is leaving early has the higher gain in travel time too apart from the scenario where there is a lane closure. The on-trip information also presents some personal benefit as can be seen. The results are however not conclusive because they involve trips mainly in the first hour of the simulation period. Most of the trips started in the second hour do not get completed and therefore it's not possible to see in total the travel time benefits of the information considering that the first hour does not have as much congestion as experienced in the second hour.

Scenario	Information type	Travel time saved (seconds)	Driver response	Remarks
Normal congestion	Pre-trip 600 PR 25%	600	Change departure time	Driver response confirmed from output
		1200		
		590		
	Pre-trip 600 PR 10%	80		
		60		
Growth	On-trip info PR 10%	700	Route change	Driver response not confirmed from output
		1200		

Table 6: Summary of personal travel time gain results

Note: All the time values are in seconds.

DISCUSSION OF RESULTS

The results for personal gain in travel time were summarized table 6. From these results it should be noted that the drivers considered had their departure time within the first hour of the simulation, this was so because most of the trips started in the second hour of the simulation were not completed. From the results therefore there is indication of personal gain travel time by having the information for both the on-trip and pre-trip information. The results can however not be considered conclusive because during earlier analysis it was noted that the first hour had lower delays and lower congestion levels as opposed to the second.

DISCUSSION OF T TEST RESULTS

For all the results obtained and the comparison with the base cases, the differences were not statistically significant according to the results of the T test at 90 and 95% confidence levels. The only difference was obtained at the 60-70% level, where the results showed a statistical significance and average p values of 0.333 recorded. These can be attributed to the big variations experienced with the ITS Modeller output (the high variations were noted in the 5 minute link data for the different simulation runs). The variation of speeds per link for example for the different simulation runs (with different random seeds) was noted to be quite high. This would make the standard variation values for the data to be quite high leading to low T test values.

The results indicate therefore the difference between the values and therefore the impact of the information is due to random variation rather than due to the impact of the information. However because of the reason above and the fact that the T test merely tests whether the null hypothesis (that there is no difference) is true or false, the differences cannot be dismissed as being caused by just a random variation and not as result of the implemented information. There is still chance (70% probability) that the differences were brought about by the information and therefore carrying out more simulations would be required before that can be ascertained.

7.0 CONCLUSIONS AND RECCOMENDATIONS

7.1 CONCLUSIONS

The objective of this research as was outlined in section two of this report was to determine the impact of in-vehicle on-trip and pre-trip travel time information on network performance. The main research question that was addressed was:

> **What is the impact of pre-trip and on-trip information provision on the efficiency of the Amsterdam area network under different scenarios?**

7.1.1 IMPACT OF PRE-TRIP INFORMATION

Pre-trip information as modeled here assumed that the information provided would be accurate, since it is based on historical data that is possible in reality also. Further it was assumed that the drivers would respond by changing their departure time, changing their route or cancelling the trip altogether (includes departure time change to time period beyond the peak period). Therefore if the implementation of the information in reality would get drivers to do this, then the impact on network efficiency would be positive.

In terms of throughput, congestion length and average speeds the impact of the information was found to be positive. The percentage of information usage required to produce the effects that were recorded here was found to be dependent for this research on the traffic conditions considered. For the normal congestion (recurrent congestion) it was found that a rate of 15% would give the best results. For the lane closure and growth scenarios the 25% rate which was the highest rate tested showed better results as compared to the 10% case. This would indicate that maybe higher levels of penetration are required for out of the ordinary traffic conditions for better network performance.

For this kind of information it was also noted that the penetration rate tested was in essence a compliance rate because the driver response to the information did not use a choice model but rather assumed that the driver would comply with the information. In reality not all the drivers with information would comply, in that case then it would mean that to achieve the compliance rates that were tested in this research the actual penetration rates would be expected to be slightly higher.

7.1.2 IMPACT OF ON-TRIP INFORMATION

On-trip information was modelled based on the update of real-time travel time updated every 120/180 seconds for this research. With this update drivers equipped with the information were then able to evaluate their routes and alternatives and make a choice as to whether to change or not (based on the route choice logit model) this was done to replicate the real world choice where drivers provided with information have to decide whether to use it or ignore. The percentages of drivers with the information were assumed for testing purposes between 10 and 25%. In this case again the assumption of accuracy of the information was used. Considering the way of generating the information, it is something possible in reality also, therefore assumption of accuracy of information was considered logical.

With those assumptions the results of the analysis show that the impact of on-trip information here was mostly negative. For the normal congestion case, it was seen that congestion went up and throughput reduced although the average speeds were higher at least for the 10% penetration rate.

An exception to the impact of on-trip information was seen for the growth case in which the traffic was doubled. In this case the information had a positive effect, throughput was higher, average speeds were higher and the congestion went down and the higher penetration rate had higher impact. The reason for this could be as already mentioned in section 7.1.1 above that information has more impact under non-recurrent congestion cases; this could also explain why the effect of the lane closure case was also less severe compared to the normal case. The lane congestion case did not have as much effect though because the resulting increase in traffic flow was not as bad as the doubling experienced for the growth case. This would then go to support the idea that information is more important when adverse traffic conditions are experience. It can therefore be concluded that information is of most importance under traffic disturbances and in such disturbances irrespective of the type of information, having information is better than not having any information at all.

The influence of the penetration rate from the results of the network performance during the incidents shows that higher penetration rates are required to have more impact. Therefore for on-trip information as tested in this case, it was found to be of value only during incident cases (non-recurrent congestion)

For all the information types given the results of the T test, carrying out more studies with alterations to the network and the simulation period would be needed to obtain more conclusive results. The results of this study can therefore be used as a basis and improved upon to draw more firm conclusions on the impact of information.

7.1.3 USE OF THE ITS MODELLER

Application of the ITS Modeller in this research offered the possibility to model and implement the different information types in a way that was considered helpful. The tool was also able to handle the large network and even handled the implementation of information that made the network even heavier to deal with. The duration of the simulation which was 6-8 hours for the normal case and 12-18 hours for the cases where the information was incorporated can also be considered to be quite good, bearing in mind again the size of the network. To get better results especially in terms of travel time the simulation period needs to be extended, which would imply running one simulation for up to 24 hours.

7.2 RECOMENDATONS

From the discussion in the section above, the following recommendations are made to improve the results and carry out more studies to look at the impact of information on network performance:

- For pre-trip information compliance was assumed, using choice model to model driver response to information would give more realistic values especially for the penetration rates and the resulting impact on network performance.

- For pre-trip information, the departure time change was one sided, moving a certain percentage by a definite time interval. Updating that to incorporate drivers leaving later or shifting by another value of time depending on factors like work flexibility could give more realistic behaviour that would be a reflection of real-world behaviour.

- For on-trip information including an algorithm for travel time prediction would improve the quality of the information given and issues like overreaction to information could be avoided and this could be expected to give better and even more positive results for network performance.
- For on-trip information more penetration rates need to be tested to find out what rates would give optimum results for network performance especially during non-recurrent congestion.
- In terms of network congestion, performing simulations on the whole network including the secondary and primary roads may give more indicative results because then there are possibilities for more driver response choices and the effect on the secondary and primary roads would also be important to note because the information implanted should not adversely affect the other road sections/types. Because this would affect the speed of the simulations, using just a section of the entire network that is complete with all road types would be more appropriate.
- For all information sources, it would be important to test the impact of having both information types by different drivers and also the impact of multiple information sources. That would mean having both on-trip and pre-trip information in the same scenario and testing what impact that would have. Also incorporating other information sources like VMS in addition to the in-vehicles information and testing how that would affect network performance would be an interesting case for future studies.

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9.0 APPENDIX 1: T TEST RESULTS

The tables below give the results of various T test results done to determine if the results obtained were statistically significant. The tests done were two tailed test at 90% and 95% level of confidence. The null hypothesis for the tests is that the sets of values being compared are equal and the alternate hypothesis that they are not equal. If the obtained T test value is less that the critical value, then the null hypothesis the two sets are the same is accepted.

T -test results for lane closure: Throughout

T critical	90%	1.76
	95%	2.14
Information type		**T test value**
On-trip PR 10%		0.900487
On-trip PR 10%		0.952829
Pre-trip info 600 PR 10%		0.871321
Pre-trip info 600 PR 25%		0.82894

T-test results for lane closure: Congestion length

T critical	90%	1.67
	95%	2.00
Information type		**T test value**
On-trip PR 10%		0.962296
On-trip PR 10%		0.826928
Pre-trip info 600 PR 10%		0.832916
Pre-trip info 600 PR 25%		0.56151

T -test results for growth case: Congestion length

T critical	90%	1.67
	95%	2.00
Information type		**T test value**
On-trip PR 10%		0.933145
On-trip PR 10%		0.806546
Pre-trip info 600 PR 10%		0.744447
Pre-trip info 600 PR 25%		0.449031

T -test results for growth case: Throughout

T critical	90%	1.76
	95%	2.14
Information type		**T test value**
On-trip PR 10%		0.933289
On-trip PR 10%		0.897895
Pre-trip info 600 PR 10%		0.934986
Pre-trip info 600 PR 25%		0.870177

T -test results for normal case: Throughout

T critical	90%	1.76
	95%	2.14
Information type		**T test value**
Pre-trip info 600 PR 10%		0.13028
Pre-trip info 600 PR 15%		0.130898
Pre-trip info 600 PR 20%		0.137715
Pre-trip info 600 PR 25%		0.160559

T -test results for normal case: Throughout

T critical	90%	1.76
	95%	2.14
Information type		**T test value**
Pre-trip info 300 PR 10%		0.116969
Pre-trip info 300 PR 15%		0.1543
Pre-trip info 300 PR 20%		0.131556
Pre-trip info 300 PR 25%		0.188776

T -test results for assignment testing area North West

T test critical value	**90%**	**1.7**
	95%	2.0
Information type		**T test vale**
Real-world		1.40456E-08
ITS Modeller ht		0.00299247
ITS Modeller original		0.681593485
ITS Modeller ht 100		0.001695302

9.1 APPENDIX 2:

AVERAGE NETWORK SPEEDS FOR CHOSEN LINKS FOR THE LNE CLOSURE SCENARIO

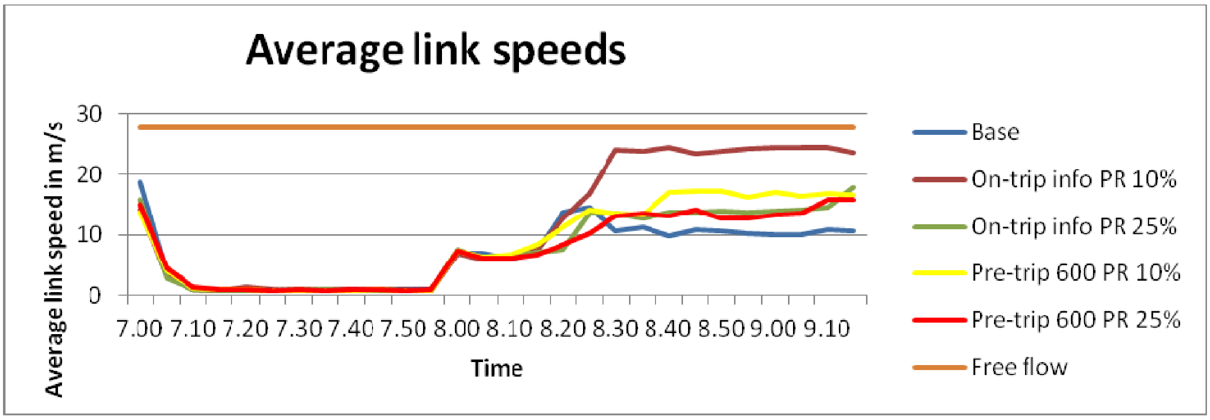

Figure 1: Average link speed for incident link (on A10 south)

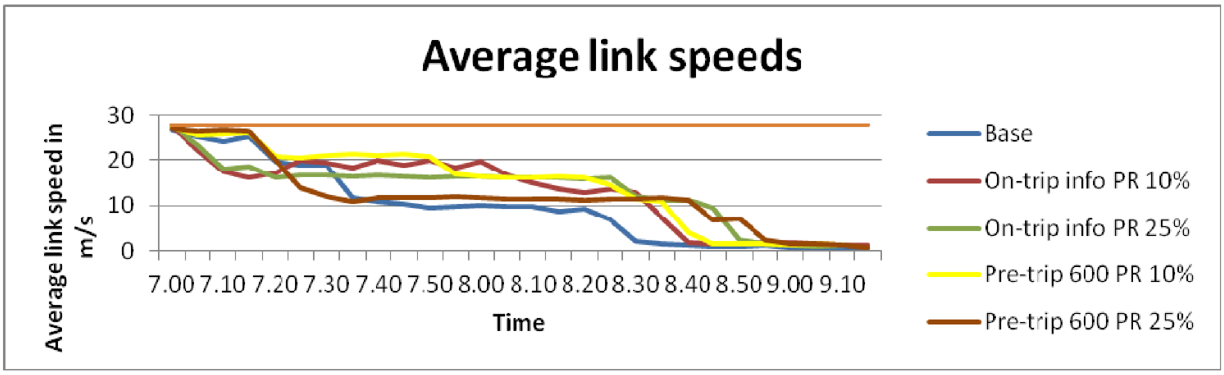

Figure2: Average link speeds for link on A2

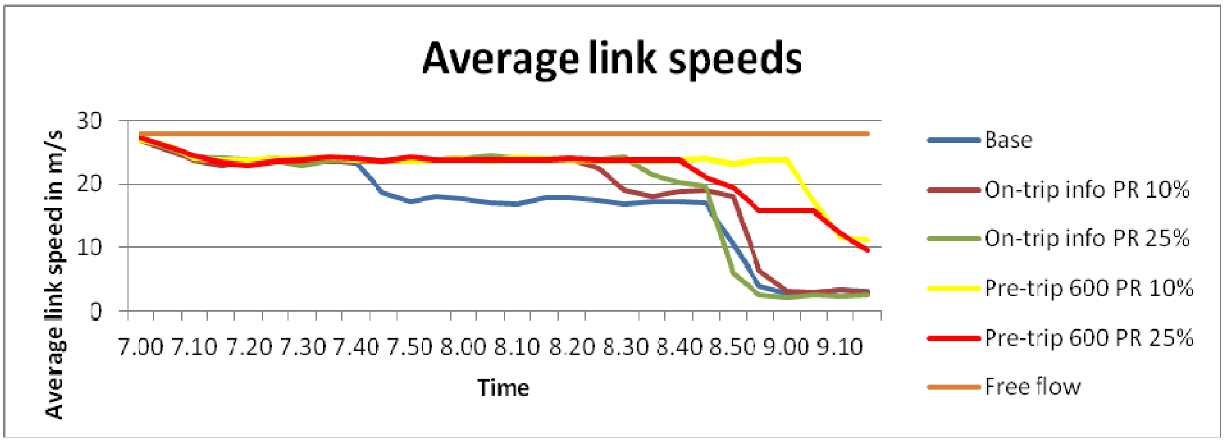

Figure 3: Average link speeds on link on A10 East