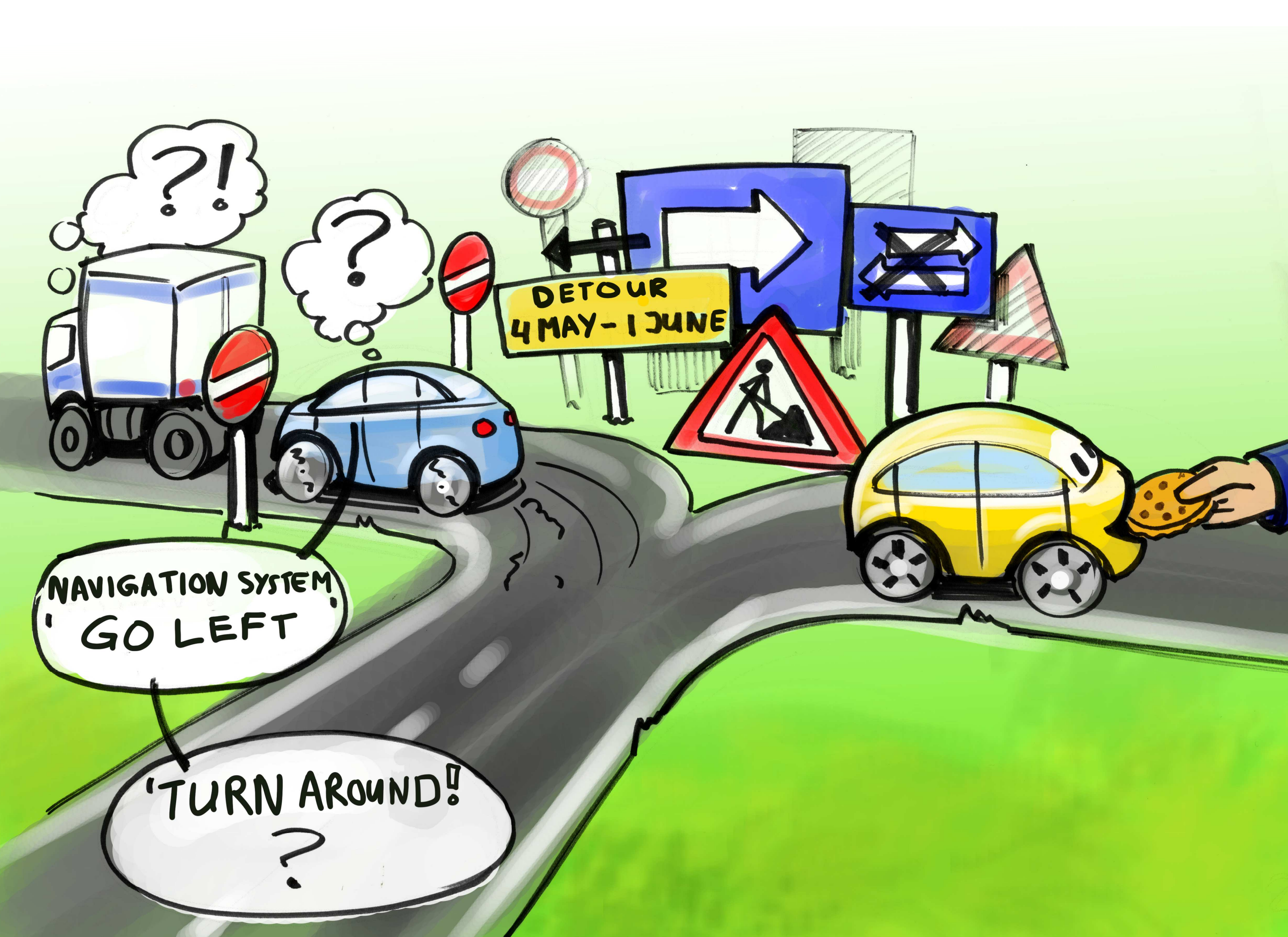
TrafficQuest report

Human Factors in Traffic Management

State-of-the-Art Background Document



Colophon

Authors	Hans Godthelp (ed.), with contributions of: Maartje de Goede, Jeroen Hogema, Richard van der Horst, Marieke Martens and Peter Rasker
Date	January 11th, 2012
Version	1.0
Published by	TrafficQuest Centre for Expertise on Traffic Management P.O. Box 5044 2600 GA DELFT, Netherlands
Information	Henk Taale
Telephone	+31 88 798 24 98

TrafficQuest is een samenwerkingsverband van

TNO innovation for life · TU Delft · Rijkswaterstaat Ministerie van Infrastructuur en Milieu

TrafficQuest

CENTRE FOR EXPERTISE ON TRAFFIC MANAGEMENT

Human Factors in Traffic Management

State-of-the-Art

Background document

11 January 2012

Table of contents

Foreword

TrafficQuest is constantly taking stock of the state of affairs in the field of traffic management and the direction being taken by developments. Traffic management is on the threshold of significant change. Countless new developments will make it possible to deploy traffic management more effectively and more proactively across the entire network, but further research is first necessary to achieve this. This is why the booklet "The future of traffic management" ["De toekomst van verkeersmanagement"] has been published with a research agenda. The booklet is available on the TrafficQuest website (www.traffic-quest.nl).

While writing this booklet, TrafficQuest collected a huge amount of background material on a wide range of traffic management aspects. This material is being published in a series of reports, all of which have the following structure:

- What is it about?
- What is the State-of-the-Practice in the Netherlands?
- What is the State-of-the-Practice in other countries?
- What is the benefit?
- What is the perspective for the future?

This report focuses on the above questions in relation to the subject of *Human Factors in Traffic Management*. However, the question 'What is the State-of-the-Practice?' is not discussed in this report, but it will be discussed at a later date.

1. Human Factors: what is it about?

1.1. Background

Good traffic management requires a clear understanding of traffic situations now and in the future. The current situation is characterised by a high-quality network of sensors and data systems, which together supply an assessment of the traffic situation at a particular time. Based on this assessment and the expected effects of specific measures, we can predict how traffic will behave in the near future. This enables us to choose the best measures, based on predefined criteria for traffic flow, safety and/or environmental effects. In order to make traffic predictions on the basis of the current traffic situation and the assumed effects of particular measures, it is essential to have a good understanding of traffic behaviour. This chapter presents a brief description of traffic behaviour and the existing knowledge and knowledge to be developed in that area in the coming years. It does this from a Human Factors perspective – that is, from the perspective of the scientific discipline that focuses on understanding the interaction between human beings and their surroundings and the various processes and objects in those surroundings. In the domain of Human Factors Traffic Behaviour, these principles are applied to the interaction between human beings and the transport system, with the aim of optimising human well-being and the performance of the system with respect to human behaviour.

The specialist subject of Human Factors and human behaviour developed after the Second World War into a central theme in a number of social domains. At that time, everyday jobs for humans were shifting from heavy physical tasks to functions in which the emphasis is on supervision, information processing and decision-making. These are often complex tasks involving high risks: the commander of a navy frigate, the operator of a power station or the traffic manager at a traffic management centre. More operational tasks also changed in the same direction: the captain of a commercial aircraft or a helicopter pilot are also operating in a complex information environment in which the question is raised more and more which sub-tasks should be carried out automatically or under human supervision. Motorists are also operating more and more in relatively complex information surroundings. It is therefore vitally important to now also develop and apply the relevant knowledge of Human Factors in the traffic domain.

The nature of the demand for knowledge and application of knowledge has changed throughout the years. In the 1970s it was about visibility at night and the size of the letters on signposts, for example. Nowadays it is about the behavioural effects of integrated route-finding and navigation systems, both in the car and at the roadside. In the traffic management centre at that time, the focus was mainly on the physical layout, while the question now is how the information flows and organisational structure can be combined into an effective tool for traffic management*. It is therefore increasingly important when designing systems to involve the Human Factors expert from the start*.

In the context of these developments, completely new human-factor challenges are now emerging. The information resources surrounding the road user and the traffic manager can increasingly be characterised as a self-thinking partner. Navigation systems and cruise control warn motorists about undesirable deviations from the speed limit and the following distance, or sometimes even take over certain tasks. The dialogue between the supporting system and the user now takes the user's wishes into account and can therefore also optimise the user's workload. Traffic simulations provide the traffic manager with a preview of the expected effects of specific measures over a number of years. In order to effectively design these innovations and combine them as a system, there is a need for more knowledge about behaviour in relation to modern media and information systems.

1.2. Behavioural levels

Traffic behaviour is a wide-ranging concept. [Knippenberg et al., 1989] include a comprehensive description of traffic behaviour in their Handbook of Social Traffic Engineering [in Dutch: Handboek Sociale Verkeerkunde]. The task of traffic can be better understood when we make a distinction between behavioural levels:

Strategic level

Transport choice:	Will I go out or not? Where to, when?
Modality choice:	Which mode of transport will I choose, will I change at the P&R?
Route choice:	Which route will I choose?

Tactical level

Speed choice:	How fast am I driving?
Lane choice:	In which lane am I driving, will I make a turn, will I merge?
Crossing behaviour:	Behaviour at traffic lights, gap acceptance
Overtaking behaviour:	Can I overtake?

Operational level

Staying on course:	Position in traffic lane
Following:	Position with respect to vehicle in front
Speed:	Maintaining the desired speed

Measures in the area of traffic management are usually intended to influence one or more levels of behaviour in different ways. To achieve this, traffic measures can have more or less of a mandatory character. They can inform, guide and control.

1.3. Inform

In many situations and traffic tasks, road users themselves are free to decide how they will behave. To support those decisions, we provide road users with a wide range of information sources: public transport information, route signs, traffic signs, navigation systems, signalling systems, and so on. The effectiveness of the information – that is, the extent to which it influences behaviour – depends on three primary aspects: the information content, the decision criteria and the practicability of the information.

In the first place, information should be *accessible* and *understandable*. If information carriers are not visible due to fog, they will not function. [Van Norren, 1981] has written a handbook about the visibility of roadside information carriers. Information can also be inaccessible because it is simply not available. Not everybody is able to use a personal information device during a trip, and therefore not every road user can use internet services, such as public transport information. Thus there are many aspects that determine the accessibility of information. Furthermore, information should be user-friendly and understandable. We call this 'information ergonomics'. In its 10 golden rules, [Rijkswaterstaat, 2008], Rijkswaterstaat clearly describes and illustrates these aspects. We now know a great deal about information ergonomics in a traditional traffic context. However, more attention needs to be paid to this subject when new media and intelligent support systems are being developed.

When information reaches road users in an understandable format, the crucial question is then what people do with it. Decision criteria are the result of a combination of economic, psychological and social motives: costs, time saved, habitual behaviour, working hours, enforcement. When traffic measures are being designed, this multi-dimensional palette of choice criteria should be taken into account, and traffic models should represent them in a valid way. We are already familiar with the basics of decision-making behaviour related to mode of transport, routes, speed and manoeuvres, but the current traffic models are often still one-dimensional and can therefore only predict the effects of modern traffic management measures in a limited way.

Finally, when road users want to perform the necessary traffic tasks, the question is whether they are practicable. Different road users have very different skills. Experience and age are important, of course, but so are the effects of fatigue, alcohol and drugs. The combination of new and traditional traffic systems – in-car and en-route, such as in the area of navigation – can also increase the workload, thus posing a safety risk. This can greatly reduce perceived traffic comfort and lead to consequences in decision-making behaviour on all task levels.

1.4. Guide and control

Actual guidance or control of traffic with some obligation only occurs on a limited scale in the Netherlands. Traffic is diverted in the case of incidents and road maintenance. Access to motorways is sometimes regulated. In peak hours, an extra lane is sometimes provided (the shoulder lane or a dedicated lane that is closed outside peak hours) [Ministry of Transport, Public Works and Water Management, 2005]. At some locations and /or times, heavy vehicles are prohibited from overtaking. Sometimes there are traffic-free Sundays. Traffic lights can also be regarded as a means of control, as they regulate access to intersections (and help prevent dangerous conflicts). [Steg, 2009] and [Theeuwes, 2009] indicate that control is often more effective than the provision of information. [Taale and Hoogendoorn, 2009] calculated that a considerable potential capacity benefit can be achieved by managing route and departure times for an evacuation. However, not a great deal is known about actual behaviour in the case of large-scale buffering and metering or rerouting – for example, in the case of evacuation or as a regular traffic management measure. For an evacuation, it is known that people tend to choose known routes.

1.5. Enforcement

Enforcement is also a means of controlling behaviour directly or indirectly. It can generally be said that it cannot be that a mandatory maximum speed is displayed but not enforced [Martens & Tertoolen, 2010]. We now know a good deal about the effects of enforcement. Section control – for example, in 80 km/h zones on motorways – has been found to be effective (this involves continuous strict enforcement by means of section control). It is also known that publicity greatly strengthens the effects of enforcement [Rothengatter, 1991]. However, section control can also lead to even higher speeds on adjacent road sections. It is important that people realise there is a reasonable probability of detection. Enforcement is particularly necessary in those cases in which no plausible (for the road user) speed limits are being displayed. Then enforcement is necessary.

In addition, a penalty works best if there is a direct link between the displayed behaviour and the penalty. Therefore, a tit-for-tat policy is more effective than a fine that is only received days or weeks later. However, a fine is increasingly regarded as an administrative transaction. People simply factor in a particular amount of fines per year as extra transport costs. The danger then is that fines will have hardly any corrective effect; the probability of detection remains low and the punishment is indirect. And this does not apply just to speed violations; the possible devaluation of red crosses (displayed above traffic lanes on the motorway, indicating a lane closure) is also the subject of research [Martens et al., 2010]. Sometimes reward works better than punishment. In the case of speed behaviour, positive feedback could have the desired effect. However, it is never a good idea to start rewarding standard behaviour.

1.6. Road users

When designing and estimating the effects of traffic measures it is important to realise that there is no such thing as 'the average road user'. Unlike the aviation and shipping sectors, roads are used by a very varied group of users with a great diversity of characteristics, varying considerably in age and traffic experience (as mentioned above). Those users often have their own objectives, they are sometimes in a hurry and sometimes not, and they often interpret and understand rules and messages in an unexpected way. Their capacity to observe is almost unlimited, but not perfect. They can multi-task, but they still cannot do everything at the same time. They have particular expectations in particular circumstances. In that sense, road users often include people who are susceptible to 'human error'. The traffic system should therefore be fail-safe and should be geared to the weakest link. The system should be consistent, uniform and more or less self-explanatory – under all circumstances, including at night and in foggy conditions. [Rijkswaterstaat, 2008] illustrates these characteristics on the basis of 10 golden rules (see Table 1 below).

Table 1: 10 golden rules [Ministry of Transport, Public Works and Water Management, 2008]

Characteristics and idiosyncrasies of road users Rule 1: Road users are quite selfish Rule 2: Road users cannot do everything at the same time Rule 3: You can tell road users to do something, but will they actually do it?
How road users view traffic and traffic measures Rule 4: Road users only accept measures that they think are meaningful
How road users react to conditions on the road Rule 5: Road users are full of surprises Rule 6: Road users have expectations and behave accordingly Rule 7: What happens if the system or the road user goes wrong?
What road users demand from the information that you give them Rule 8: Tell road users what is really important Rule 9: Do not confuse road users
The requirements to be met by the information Rule 10: Information must be visible, clear and understandable for road users.

Over the past 50 years, traffic psychonomic studies have recorded the skills of road users for many situations in quantitative relationships; see for example [Van Norren, 1981] and [Van Knippenberg et al., 1989]. This data can be used for design and evaluation purposes.

2. State-of-the-Practice in the Netherlands

2.1. General

Due to the increasing pressure on our mobility system, it is important not only to optimise existing travel needs, but also to be able to manage those needs. This requires an understanding of the behavioural mechanisms on all the behavioural levels listed in the previous chapter. *Behavioural influencing* is therefore a frequently-used term in discussions about tackling problems in our mobility system related to congestion, safety and the environment. Particularly in relation to decision processes on a strategic level, the approach involving desired behavioural changes is still often a process of trial and error. The behavioural models are often still one-dimensional and do not adequately take into account the complexity and diversity of the various contexts in which measures are being implemented.

This chapter includes a short description of the latest developments on the various behavioural levels.

2.2. Decision processes on a strategic level

Habitual behaviour
On this level, the focus is on choices related to the travel purpose, time of travel, modality and route. Decisions about the first three aspects are usually taken before starting a journey. People's transport behaviour is primarily determined by the purpose of the journey: work, work appointments, leisure, family visit, etc. The Government wants to promote multimodal travel. To this end, P+R locations are often linked to information systems aimed at helping to decide during the journey, to transfer from the car to the train, for example. In addition, the choice of a particular route can be determined either before or during the journey.

Dutch people are generally very consistent in the use of a modality and are reasonably happy with it. Little or no attention is paid to alternatives, with the result that approximately 92% of our travel behaviour is predictable [Gonzalez et al., 2008]. In other words, we display little flexibility in behaviour. To a large extent, travel choices are the result of habitual behaviour. Especially when people often make the same journey, an initially well-considered choice of a particular time, route or means of transport can become a habit in the course of time. With this type of behavioural pattern, the advantages and disadvantages are no longer weighed against each other, while the reasons for such a choice may indeed change. This happens with commuter traffic, for example. Frequent and consistent decision-making behaviour with the same goal leads to a strong association between the behaviour and the goal, thus giving rise to a habit [Aarts & Dijksterhuis, 2000]. More flexibility in our travel choices could result in a more balanced distribution of travellers over the available infrastructure, leading to better traffic flow and lower emissions.

One way of breaking down habitual behaviour is to 'decondition' the behaviour – that is, to break the habit. The most obvious way to do this is to replace the existing behaviour with an alternative so that the habitual behaviour is diminished, as it were. One example of this is the use of a reward to get car users to use public transport. [Fuij & Kitamura, 2003] studied the effect of this type of temporary 'incentive' on bus travel in Kyoto. For one month, a free bus ticket was offered to 23 car users in the experimental group of participants but not to a control group of 20 car users. The results show that by providing a free bus ticket people's attitude to the bus became more positive, people used the bus more frequently and their habit of using the car diminished. This was still the case one month after the experiment had ended. These results suggest that a temporary intervention, such as offering a free public transport ticket, can be an effective means of reducing car use and stimulating people to use public transport more. One drawback of this study is that there is no data related to the longer-term effects. Recent Dutch research into the effect of cash incentives for driving outside the rush-hour shows that after car users stopped receiving payments in the course of time they returned in their old travel behaviour – that is, driving during the rush-hour [Ben-Elia & Ettema, 2010].

Costs: money and time

Money is an important decision criterion for much of our behaviour. Even if the need for comfortable transport still offsets the high costs of driving a car, specific measures can nevertheless ensure that we will meet our needs (partially) in another way. We know that higher petrol prices do not necessarily lead to reduced car use. Experts expect that the introduction of kilometre pricing, with the highest price in the rush-hour, will stimulate people to use the car less during these 'expensive hours'. However, such measures will lead to hardly any increase in the use of public transport. On the other hand, the active promotion of public transport by (temporarily) offering free transport has had positive effects (for example, [Thøgersen, 2009]).

Travellers prefer travel information to be expressed in travelling time (see the following section). Time-saving not only benefits the individual, it also implies a general reduction in the number of vehicle hours, which can have positive effects on the traffic situation. Despite the fact that various studies produce estimates of the degree of delay that leads to alternative route choices (for example, see [Taale & Schuurman, 2012]), there are major differences between the various estimates. These differences are probably caused by specific contextual, environmental and personal factors.

The distance of a route is directly related to time. Although this is an important factor that determines the attractiveness of a travel choice, in most cases knowledge about distance will be combined with knowledge about the type of route in order to ultimately come to an evaluation of a particular route in terms of time. Nonetheless, the perceived time and distance of a route often differ from the actual values. Factors that influence the perception of the time and distance of a route include route complexity and the motive for travelling [Crompton, 2006].

Travel information
Another way to break through habitual behaviour is to provide travellers with up-to-date personalised information. Travel information can make the traveller aware of the available choices and in that way remove any uncertainty about unknown routes and means of transport, *and about the related costs in time and money*.

At the moment, just a small percentage of travellers adapt their decision to use a particular means of transport on the basis of (journey) information. The reasons for this may be that in 90% of cases public transport cannot compete with the car in terms of travelling time [Bakker & Zwaneveld, 2009] and that the trains are overcrowded during the rush-hour [Vaessens, Van Hagen & Exel, 2008].

In the Netherlands, pre-trip information about delays in public transport and queues is widely available on the internet or videotext. Around 40% of travellers use these information sources to change their departure time or adapt their route. Modelling studies indicate that when there is regular congestion travellers have the flexibility to leave 30 minutes earlier. This can reduce travel time delays by 30% [Van Arem et al., 2008].

To influence route choices, Dynamic Route Information Panels (DRIPs) and navigation systems would seem to be the ideal applications, with personal navigation systems having the greatest effects (as indicated by research). According to a summary report of evaluations [Taale en Schuurman, 2012], 14% of road users in the Netherlands change their route as a consequence of relevant information displayed on a personal navigation system, while just 6% of road users do this when general information is displayed. The city of Rotterdam estimates the effect of DRIPs to be 2% to 2.5% [AGV, 2004]. In addition to the small scale, reported effects therefore also show considerable variation. The effects often depend on the circumstances, such as the driver's knowledge of the surroundings, the extent of congestion, the available route alternatives and the predictability of the situation [De Goede et al., 2010]. According to [Chorus, 2010], the possible effects of travel information are therefore more limited than is often assumed. He states that usually only alert travellers use travel information, while non-alert travellers (with established travel habits) are much less inclined to actively search for information. This would mean that the further development of information systems has little value, given that alert travellers are already quite well informed, while the travellers that display strong habitual behaviour are not receptive to information.

According to [Van den Berg et al., under preparation], however, this reasoning is too simplistic. [Chorus, 2010] focuses on the effects of existing information systems. The intelligence and personalisation of new systems could indeed be suitable for stimulating more flexible travel behaviour (for example, more multimodal trips). [Grotenhuis et al., 2007] state, for example, that the parallel presentation of travel alternatives stimulates people to compare and combine travel options. In addition, [Steg, 2009] shows that tailoring – that is, focusing information on the individual level – is effective. However, this does require the availability of integrated dynamic multimodal information services that anticipate – online – changing traffic circumstances and personal preferences and planning schedules, both on the road and in public transport. Such systems are indeed available, but the supply of dynamic multimodal and personalised information during a journey is still really in its infancy. Put another way, although the need for multimodal travel is increasing rapidly, travellers are still discouraged by the complexity of such a journey and the lack of personally relevant information. In addition, the way information is presented is also important. Research by [Brookhuis et al., 2008], for example, shows that auditive information or information supplied on a PDA are experienced as more useful and require less mental effort while driving than text messages.

Developments

The above shows that we should take the habitual behaviour of travellers into account when developing new measures and the related personalised information systems. The more established those habits are, the less effect any measures will have [Verplanken & Aarts, 1997]. Precisely for that group, therefore, the challenge is to develop a smart combination of measures – for example, price incentives and personal information.

The travel demand is also diminishing due to people working at home, video conferencing, shopping on-line, etc. The current social-economic processes are still just partially geared to the New World of Work (Het Nieuwe Werken). Our society is largely based on fixed time and location patterns, both inside and outside the work context (shops, care institutions, child care, etc.). Companies are becoming increasingly aware of the fact that greater flexibility in working hours and locations is needed to reduce the pressure on our mobility system. However, developments in this area are still in their infancy. And there are therefore still major effects to be achieved in the area of (knowledge about) more flexible travel patterns among individuals and companies. For that reason, travel demand management can still contribute significantly to traffic management – a few percent less traffic on some roads can have a considerable effect on congestion. However, particular measures and developments can have both advantageous and disadvantageous effects. Shopping on-line is an example of the kind of development that can result in possible counter-effects: the resulting flow of goods is actually generating new traffic. Therefore, the question is always whether, on balance, the advantages offset the disadvantages.

The next generation of travel information systems will greatly strengthen behavioural flexibility. They will enable travellers to make strategic choices not just before but also during the journey that match their personal calendar, circumstances and preferences. Intelligent Transport Systems offer greater reliability and user-friendliness of information and in that way improve the quality of public transport. This can help to increase the number of travellers that adapt their choice of transport. The personalisation of information increases the chance of breaking down habitual behaviour (see also [Van den Berg et al., under preparation]). This will result in greater comfort and less uncertainty for travellers.

In 2011, just a limited number of navigation systems provided dynamic traffic information. So there are still many opportunities in this area too. The effects of DRIPs are generally limited and depend greatly on the situation and the location. The ultimate effects of information systems depend on aspects such as the user's knowledge of the area, the congestion level, the available route alternatives and the predictability of the situation (recurrent or non-recurrent congestion) [De Goede et al., 2010]. A greater density of dynamic navigation systems should result in more varied advice (adapted to individual preferences and situations) to ensure that congestion does not 'relocate' to elsewhere in the traffic network.

Behavioural change processes are often a question of common sense. However, in many situations we need to take counter-intuitive aspects into account. Behaviour is complex and can depend on many interacting factors. Therefore, behavioural change cannot usually be realised by taking just one measure (for example, a price incentive), but must involve a process of divergent measures on different behavioural levels. The disadvantage of a single intervention is that its effect can be counteracted by factors that remain unchanged. Furthermore, behaviour is context-specific. A measure that works in one case can be completely off the mark in another case. This is often forgotten when a seemingly successful intervention is copied exactly to a new situation or surroundings and then turns out to have a totally different (or no) effect. Moreover, human beings are emotional decision-makers, with the result that, depending on personal characteristics and experiences, there can be considerable individual (or group) differences in reaction to particular measures.

Interventions aimed at behavioural change therefore demand both a thorough analysis of the determinants of the behaviour to be changed and an analysis of the best possible ways of realising the intended effect. The ultimate success of an intervention depends on a number of factors. To optimise an intervention, it is important to determine in advance what the ideal result should be and whether and under which circumstances it can be achieved. In the case of travel choices, for example, it is important to determine which type of habitual behaviour is involved in addition to evaluating available travel alternatives. The intensity of the habitual behaviour, the specific character of the behaviour and the motivation on which that behaviour is based are all important. Such an analysis of the relevant behavioural processes can also prevent antagonistic reactions in the longer term, such as rebound effects, adaptation and avoidance [Heijs, 1999]. Another important aspect is the duration of the effect of the intervention. As specified above, effects that are successful in the short term can disappear in the longer term and people can revert to the original behaviour. Finally, it is important to realise that some interventions are successful under ideal circumstances (in an experimental setting, for example), but that these circumstances are often not the same in daily life. One example of this is that desirable behaviour (for example, not smoking) can be realised under normal circumstances, but as soon as there is a stress situation people revert to their old behaviour. It is therefore important that the effects of interventions are evaluated in everyday circumstances, preferably 'real life'. Moreover, more knowledge must be gained about relevant behavioural determinants and the relationships between those determinants that are crucial for mobility behaviour. More knowledge about the determinants of behaviour ensures that we can more accurately determine which combination of possible behavioural change can be applied in which specific situations for concrete mobility issues. The aim of the Enabling Technology Program: Behaviour & Innovation at TNO is to further develop this knowledge in the years to come.

2.3. Decision processes on tactical and operational level

Once traffic arrives on a road section, the challenge is to process it as quickly and safely as possible. On the main roads, exercising influence on a tactical and operational level mainly relates to speed behaviour, lane choice, overtaking behaviour and following behaviour.

Speed behaviour

Amongst other things, speed choice depends on personal motives, the speed limit, the plausibility of the limit, the pressure of enforcement, weather conditions and the amount of traffic. In the context of traffic management, there are currently four ways of influencing speed in the Netherlands (see also Figure 1):

a) Automatic speeds prompted by the Automatic Incident Detection system (AID). This relates to so-called queue tail monitoring, which is indicated with speed limits of 70 or 50, displayed on overhead matrix signs, where the reduced speeds are displayed with flashers. 90 is only displayed automatically on a lane bordering a lane on which 70 is displayed. The 90 speed limit is not displayed with flashers, however.

b) Dynamic and/or electronic speed limits, displayed as 90 or 70 but without flashers. For example, this format is used: (1) for road-works, in order to support fixed limits placed temporarily at the roadside or (2) for particular traffic volumes, in order to improve traffic flow. The 90 speed limit is never displayed with flashers.

c) Dynamic and/or electronic speed limits with a red border. These were first used for environmental reasons in Rotterdam-Overschie, and later also at other locations and for other reasons. This type of speed guidance was also tested in 2009 at pilot locations in the frame-work of the 'dynamic maximum speeds' campaign (Dynamax). Reasons for adjusting speed limits include traffic volumes, environmental considerations or to reduce shockwaves. In Dynamax, the speeds of 100, 80 or 60 were displayed [Burgmeijer et al, 2010]. In principle, this is the same measure as under b), but then with a red border.

d) Dynamic non-electronic speed limits, such as those displayed on changeable signs along the road. These speed limits always have a red border. This might include the new tests with a 130 km/h speed limit. However, when the speeds are displayed on the matrix signs, they fall under category c).

(a) Automatic Incident Detection | (b) Dynamic speed limit (no red border) | (c) Dynamic speed limit with red border | (d) Changeable speed limit signs

Figure 1: Dynamic speed limit signs on motorways in the Netherlands

The Dynamax programme symbolises a move towards more flexible signalling, where traffic management can be adapted to the prevailing and/or local objectives and traffic and weather conditions. The Government wants to work towards an unambiguous display of speed limits, where all the dynamic limits are displayed with a red border. The only reason for not yet displaying speed limits with a red border is because the older type of matrix signs cannot do this. In practice, this means that road users are confronted with different interpretations of the same measure. As a result, people may feel that speed limit signs without a red border are "less mandatory", and so do not observe speed limits as conscientiously.

In the past, there was a debate about the formal meaning of speeds on the matrix signs. In the early days of the AID, this was a recommended speed but was later converted to a speed limit. Many road users still think or would like to think that it is a recommended speed. However, given that the AID mainly has a warning function and is not deactivated if road users strictly adhere the speed limit, this is not regarded as a problem. It fulfils its function, namely as a warning system in the case of queues or incidents. The AID concept works well, it increases safety, and road users now know it very well. When people see flashers displayed next to speeds, they associate it strongly with a queue. From a Human Factors perspective, it is important to maintain the AID in its current format.

As far as dynamic maximum speeds are concerned, to ensure that those speeds are observed it is also important that the limit is plausible, or rather that people understand why the speed limit is being displayed and that they also see that it makes sense. The more plausible the speed limit, the more people will observe it. When it is snowing, people will tend to reduce speed, even without a restriction from traffic management. However, when people are confronted with a restriction and they do not understand the reason for it (for example, 80 km/h on a motorway without a specific visible reason), they will be less inclined to adapt their behaviour. To explain these limits, RWS has introduced "argumentation" signs. In Dynamax, for example, it was specified that a limit of 80 was introduced for environmental reasons. If road users still do not consider this limit to be plausible, there will only be a minimal change in their behaviour. Worse still, it may even reduce the plausibility of other measures.

Enforcement is ultimately an effective way of compelling people to observe the speed limit. One disadvantage of this, however, is that it does not increase the plausibility of the measure itself, and speeds are often lower than intended (under the limit, as was found, for example, on the A13 at Overschie due to the strict enforcement with section control) or are only reduced at the location of the speed control measure itself. In addition, when there is section control the traffic flow sometimes becomes less dynamic (less variation in speed), and therefore also becomes less flexible, and this can cause weaving and merging problems (this happened, for example, on the A12 at Voorburg), thus resulting in more queues.

Choice of traffic lanes

Besides speed behaviour, traffic management also often focuses on making extra traffic lanes available (peak hour lanes) or, the opposite, on closing traffic lanes. At the moment, a red cross is used for the following situations:

- Indicating that a peak hour lane has been closed.
- Closing a traffic lane in order to regulate traffic (improve traffic flow).
- Closing a traffic lane because of road works.
- Closing a traffic lane because of an incident (for example, an accident, a stranded vehicle, an object on the road).
- Closing a traffic lane for special services (for example, urgent ambulance transport, motorcade for dignitaries).

The legal basis for the red cross on overhead matrix signs is stipulated in Article 73b of the Traffic Rules and Signs Regulations [RVV, 1990], which states that the traffic lane may not be used in such cases. A red cross is always preceded by a white arrow with flashers (directing traffic to an adjacent lane). For road works, the speed is often also reduced (but no flashers are displayed), and for incidents the AID often switches on. For closed peak hour lanes and for traffic regulation, in most cases no information is displayed over the normal traffic lanes (unless the AID is activated). The red cross is formally ended by displaying the symbol 'end of all restrictions' (F9). The use of a red cross for incidents is described in the *Guideline for Initial Safety Measures during Incidents* (Richtlijn Eerste Veiligheidsmaatregelen bij Incidenten) [REVI, 2010], for road works in [CROW, 2005] and for peak hour lanes in the *National protocol for operating peak hour lanes* (Landelijk protocol voor bediening spits- en plusstroken).

There are strong indications that in the past few years more and more road users have been ignoring red crosses and that the red cross has been devalued because road users are frequently confronted with peak hour lanes that are closed for no obvious reason. Internally, there is a debate in the Government about whether it might be better to use a symbol other than the red cross for traffic regulation. Then, when the red cross is again associated more with danger, compliance would improve and therefore also safety when reacting to accidents and road-works. The signal issued to the road user should be: "You really must not drive here because if you do you will get into trouble". Certainly when a car with mechanical problems stops on a peak hour lane there will be a problem if traffic upstream ignores the red cross. At the moment, when red crosses are displayed over peak hour lanes no distinction can be made between a 'Standard closed traffic lane' and 'Danger: physical obstruction on this traffic lane'. The dynamic use of the 'Closed with explanation' sign (white sign, red border) is being considered for such lanes, as is also customary for dedicated lanes (see also [Martens et al., 2010]).

Overtaking behaviour

An overtaking ban for heavy goods vehicles is one of the measures aimed at improving the flow of traffic. On approximately 800 km of motorway in the Netherlands, an overtaking ban for heavy goods vehicles is applied during the peak hour. From the perspective of traffic safety, the measure is working as expected. The number of very short time intervals of less than 1 second on the left-hand lane is diminishing appreciably. It looks as though there are fewer critical situations and fewer discernible dangerous and faulty manoeuvres. Up to now, no problems have been observed when changing lanes. The risk of accidents is diminishing and therefore also the chance of incidental queues. The effects on traffic flow are very location-specific. This is causing the capacity effect to be diffuse (-4% to + 4%, according to [Taale and Schuurman, 2012]). The overtaking ban for heavy vehicles usually applies at specific times – for example, during the peak hour. Dynamic traffic management could make the deployment of this regulation more flexible – for example, as a function of traffic volume.

In other countries, the Keep Your Lane principle is used and is aimed at calming traffic. Whether such a philosophy could also work in the Netherlands however still is subject for discussion [Schuurman, 2011b].

Following behaviour
At the moment, traffic management does not exert direct control over following behaviour. Road users are not told to drive closer to each other (shorter following distance or time interval) or to increase the following distance (longer time interval and following distance).

By influencing speed, following distances and time intervals are also indirectly regulated. At lower speeds, motorists can safely drive closer to each other and that is exactly what they do. When traffic management also has an in-vehicle component (and can be tailored more to individual motorists), there will be more opportunities to influence following behaviour. ACC systems regulate the time interval, which can usually be defined by drivers themselves in a number of steps. Here, the driver will still have some room to manoeuvre, because some people prefer a shorter following distance than others. Safety is a priority here: the road manager cannot advise people to start driving closer to the preceding vehicle because it is still not clear how this would affect safety. In addition, an alert driver with a short reaction time with ABS on a dry road section can maintain a shorter following distance with the same safety margin than a less alert driver without ABS on a wet road surface. We do not know enough about the effects of this type of behavioural influence on a large scale to enable road managers to control it. However, we expect that the road capacity can be increased if some cars are equipped with, for example, ACC [Van Arem et al., 2008].

Developments
Since the 1980s, the Netherlands has led the way in the development of modern traffic signalling on motorways. From a network of traffic management centres, traffic managers have control over speed messages, the availability of traffic lanes (whether to open them or not) and regulating access to motorways (using ramp metering systems). Traffic guidance is aimed at stimulating road users to display behaviour that benefits traffic flow, safety and the environment the most. Traffic guidance systems have become better in the course of time. This is linked to the steady improvement in quality of traffic monitoring and traffic modelling.
However, optimal use of the road network requires more innovation and more adaptive and flexible traffic guidance – that is, traffic guidance that adapts to the prevailing traffic and weather conditions, light-dark situations, the current traffic volume, incidents, and so on. This development

requires intelligent sensor networks and smart traffic predictions that are based on traffic models in which behaviour is represented in a valid way.

One important step forward will be made with the interaction between the intelligent road and the intelligent vehicle. This interaction is still limited, but it is now starting to emerge. Navigation systems can develop into an integrated traffic information system with information about the local speed limit, for example. Adaptive cruise control systems can already help to homogenise traffic flow now by keeping vehicles at a safe distance. In the more distant future, cooperative ACC will be able to anticipate traffic flow disruptions that are far beyond the direct perception of road users. The development in the direction of cooperative systems and information opens up great opportunities, but there is also the danger of inconsistencies in information. When the infrastructure displays a speed limit that does not match the limit displayed inside the vehicle, road users will not hesitate to use the limit that suits them best. In that sense, the system cannot yet be described as intelligent. The aim of Human Factors is to develop a system that provides the right information for the particular time and place and is also tailored to the individual, where possible. For example, a heavy goods vehicle should be presented with a different speed limit than a car, and in the future individual destinations can be taken into account when lane choices are being made. It has enormous advantages, for example, when through traffic is advised to keep left in order to distribute traffic more evenly. There are already plans to apply these types of principles on ring roads, but the information will still be displayed on dynamic signs above the road, so by definition it will not be tailored to individuals.

2.4. Integrated approach of behavioural influence

There is an enormous amount of empirical knowledge available for the various behavioural levels. In terms of traffic management, however, this knowledge still needs to be structured and translated to the practical situation. Above all, it is important to link up the behavioural knowledge about the various levels or to develop new knowledge on the interface between the behavioural levels. This is because modern traffic influencing measures do not usually focus on a specific behavioural level. The real challenge is to utilise the interaction between the levels. Personalised information could be based, for example, on an available space at a P&R location at a specific time. With knowledge of the traffic situation at a particular time, the route system could display the optimal route and departure time, based on the current speed limit/constraint. In that way, future traffic guidance could use the various behavioural levels as a behaviour-based chain.

3. What are the benefits?

The notion that Human Factors knowledge as described in this document often has a qualitatively and relatively abstract character is inaccurate. Many results of research into human performance and behaviour are rooted in quantitative data and relationships. Just as *design vehicles* are used when designing roads, data about human performance can be translated into a *"design road user"* (a road user with certain characteristics and capabilities which should be taken into account when designing traffic management measures). And for many years that has already been taking place in numerous areas. [Godthelp & Tenkink, 1990], for example, developed sighting criteria (overtaking sight distance, driving sight distance, stopping sight distance) on the basis of representative reaction times and accepted acceleration and delays. These are often based on 85-percentile values that take into account the perception and locomotory skills of young, middle-aged and elderly people. In this way, most of the design standards on the Dutch roads and the positioning of information carriers are based on data about the design road user, although this methodology is never described as such.

The 'classic' design road user mainly describes the human skills – that is, what are people able to do? Reaction times, accepted delays, night vision, and so on. A more contemporary design road user should also include more cognitive data. This relates to a diversity of quantitative relation-ships, as described in the sections 2.1 and 2.2. On a tactical behavioural level, it might include descriptions of following behaviour, gap acceptance, speed behaviour and overtaking behaviour. But also the workload restrictions to be defined. On a strategic level, factors such as costs and time can be translated into quantitative models. Examples of these are also available, but a more systematic approach is necessary.

The following section includes a short description of the tools that Human Factors offers for design, evaluation and prediction.

3.1. Methods and techniques

Like other scientific disciplines, the specialist area of Human Factors has a stratified system of research methods:

- Behaviour and performance can be observed *in the laboratory* under carefully defined conditions. For example, this is how the visibility of retro-reflecting traffic signs in foggy conditions is determined. Or the relationship between reading distances of traffic signs at night and the size of the letters.
- We measure actual driving behaviour in *driving simulators and instrumented vehicles*. To measure the workload, there are more or less standardised methods available – for example, the peripheral detection task (PDT). Time measurements such as TTC and TLC describe operational behaviour, and are also translated into criteria that can be used to test safety standards.

- Interaction in 'real' traffic can be observed using numerous sensors – for example, *loop detection and video observation*.
- Strategic choice behaviour (route, modality) can be determined by means of questionnaires and on the basis of registration number recognition with cameras or with Bluetooth sensors. Questionnaires can also be used to gain an insight into the motives underlying decision-making behaviour.

The *statistical method* is an important basis for all of these instruments. The Human Factors experts can use these methods to translate their findings into reliable relationships. Most of the results of performance and behavioural measurements can then be converted into quantitative relationships that can be used for design, evaluation and prediction purposes. Almost all aspects of human perception in traffic are recorded in quantitative relationships. There are also more or less standardised methods available for assessing the comprehensibility of traffic measures. A great deal is also known about human adaptation and decision-making behaviour, but the available knowledge about these aspects is less accessible for practical use. This knowledge is partly under development and still needs to be recorded more categorically in quantitative relationships and behavioural models. This approach should lead to a new version of the design road user.

3.2. Tool for design, evaluation and prediction

Human Factors knowledge can play an important role when designing and evaluating traffic systems and when making traffic predictions.

Design
A great deal of behavioural knowledge is translated into standards for design purposes. Most Dutch guidelines for the design of roads are based on knowledge about human skills. For ITS systems, the EU developed a Statement of Principles [EU, 2008] which stipulates requirements for the attributes of in-car systems. ISO committee TC22/SC13/WG8 Transport Information and Control Systems on-board Man Machine Interface [2010] defines criteria for in-vehicle ITS systems, but then in a broader sense.

More and more often, the Human Factors expert is involved in the design of components for traffic systems at an early stage. As part of this process, components of traffic management and ITS systems are now being tested and optimised by large groups of human test subjects in the prototype phase in driving simulators, concept vehicles and field evaluations. But the aspirations of the human engineer go further than that – the use of behavioural knowledge is also crucial for the development of the integrated traffic management system. Early system choices benefit from an understanding of the related behavioural effects. The development of traffic management centres (see section 3.5) is a good example of this.

Evaluation

The methodological tools supplied by the Human Factors expert are mainly necessary for large-scale evaluation studies. After the first versions of prototypes have been optimised in the laboratory, many modern traffic systems are then tested in the field. The contribution of the Human Factors expert can greatly help to ensure that the test produces data that is easy to interpret. A methodologically well-structured test produces clear findings − for example, when different variants of a system are compared. The methodological toolbox used by the Human Factors engineer is helpful and should be a requirement when setting up large-scale field tests [FESTA Consortium, 2008].

Traffic predictions

In the long term, traffic predictions will make up the basis of traffic management. Measures can then be chosen based on predictions of effects that we make with our traffic models. These types of predictions will only be usable, however, when the behavioural effects implemented in them are accurate. Traffic models must be supplied with valid behavioural models. Behavioural and performance models together make up the building blocks of the modern design road user.

3.3. Models of traffic and behaviour

In the end, we record our knowledge of traffic and behaviour in theories and explanatory models. Based on that information, we scientifically identify the relationships between, for example, behavioural characteristics and explanatory factors, and this in turn generates new research questions. This section presents a global description of this area of expertise. A quantitative translation of behavioural models should be included in the broader context of generic traffic models. After all, the validity of these models largely depends on the quality of the behaviour implemented in them. *Unlike the past, it is now no longer enough to consider the behavioural model as a black box.* And that is a good thing. After all, just as traffic behaviour can be differentiated into strategic, tactical and operational levels, traffic models also display a certain amount of stratification − we make a distinction between macro, meso and micro-simulations. Table 2 shows how the various behavioural levels are present in traffic models. It also shows that there are no traffic models that cover all the behavioural levels, and that we think (without thorough analysis) that some aspects of behaviour are clearly only modelled roughly.

Table 2: Modelling levels of behaviour in traffic models

		macro	meso	micro	sub-micro
Strategic level	decision to travel				
	destination choice				
	departure time choice	often only roughly		sometimes	
	mode of transport choice				
	willingness to change/transfer	approximately			

		macro	meso	micro	sub-micro
	route choice			sometimes	sometimes
Tactical level	speed choice	traffic flow	traffic flow	indiv. veh.	indiv. veh.
	lane choice (through-traffic)				
	lane choice (turning off)				
	lane choice (merging)				
Operational level	position in traffic lane (lateral)			usually not	
	Following behaviour				
	(degree of) maintaining desired speed		approximately		

Legend:

not modelled

modelled

Macroscopic models

The macroscopic models describe the distribution of traffic over the network. They characterise the traffic volumes in terms of quantity, origin and destination. Based on optimisation criteria, they differentiate the traffic according to modalities and links in the network. The models function on the level of traffic flows, speed, volume and density. They do not focus on individual behaviour. The criteria that are used are based on costs in terms of time and money. The assignment of traffic is ultimately such that every road user has an optimal (for the road user or for the system) route through the network. The utility concept underlying this method largely corresponds with the motives of strategic traffic behaviour described in section 3.1. The indicated psychological context is missing, however. The effects of habitual behaviour, the power of price incentives and the impact of personalised information need to be included in these models. That will give the allocation a more dynamic character, which can improve the quality of the road network design and of traffic management at that moment.

Mesoscopic models

On the mesoscopic level, the models describe the traffic flow over (parts of) the network. Given the traffic volumes derived on the macro level, the model calculates the characteristics of the traffic flow. The traffic flow consists of individual vehicles that behave in accordance with macroscopic relationships, which are based on assumptions about speed choice, time headway distribution and lane choice behaviour. Knowledge of the influencing mechanisms as indicated in section 3.2 is only partly represented there. However, the traffic models could be significantly improved in this area, but that will require better behavioural models than those currently available. Quite a good deal is known about traffic behaviour on the tactical level, but more knowledge is required to translate this into valid behavioural models. It will necessitate model-based interpretations of the relationships between speed, following and overtaking behaviour under the influence of psychological, infrastructural, and vehicle-linked characteristics in various traffic, lighting and weather conditions. This requires more detailed (microscopic) data.

Micro and sub-microscopic models
Micro-simulations model the traffic on the individual driver/vehicle level. Based on relatively basic regulatory models and elementary if-then rules, the model describes the movements of vehicles that collectively generate a traffic flow on a particular road section or in a network. Micro-simulations can be used to rapidly evaluate all kinds of traffic management measures and traffic control mechanisms. More and more advanced versions of these models are now being developed and are being used, for example, to quantify the impact of incidents and the effects of ITS systems. Modern micro-simulation models are supplied with simple behavioural models that are used to describe behaviour in a relatively elementary way. Especially for innovative applications it is important to include the actual resulting behaviour (such as behavioural adaptation effects) in these models so that valid and reliable estimates can be made of the expected effects. In this context, the input of Field Operational Tests (FOT's) and naturalistic driving studies are essential. The developments related to a Driver Model Library (DML) are a good starting point for this [Absil et al., 2009].

Sub-micro-simulations are used to implement sensitivity analyses of the technical characteristics of ITS systems. On a local level − for example, for an intersection or a curve − these simulations calculate the flow of specific manoeuvres using detailed sub-models of sensors, actuators and advanced communication systems. However, they include hardly any reactions of drivers to the control characteristics of these systems. A link between a sub-microscopic model like PreScan and DML would be a good way of incorporating the behaviour of the drivers in a valid way.

3.4. Developments

When applying Human Factors knowledge to design, evaluation and traffic prediction, the following two developments are important:
a) the description of the design road user for traffic management, and
b) the implementation of behavioural models in generic traffic models.

The modern design road user provides an overview of human design criteria on a tactical and strategic behavioural level. Part of this knowledge is available, but not in a usable format. Other knowledge − for example, the influence of habitual behaviour – requires further interpretation and description. Behavioural models are a way of describing the design road user numerically. Further development in that particular direction is necessary in order to integrate the behavioural knowledge into traffic models.

Traffic models are a basic instrument in transport studies. When the traffic system is being designed, models provide estimates of the expected traffic distribution over the network and of the assumed traffic flows at specific locations. When calculating the effects of a new system or a new measure (ITS, ADAS, DVM, ...), the first question is how the system affects driving behaviour. When that is known – for example, based on driving simulator research – those behavioural effects should be taken into account in the traffic model.

In particular, traffic models are used as an instrument to calculate the effects of specific measures on traffic flow, safety and the environment. In the long term, (on-line versions of) traffic models will be used to support traffic managers in traffic management centres. The actual traffic flow can then be optimised using models by making real-time predictions of the expected traffic flows and simulating measures that are based on those predictions. This requires models that can predict the effects of measures many times faster than real-time.

The link between Human Factors knowledge and traffic management tools should ultimately mean that the traffic models can be filled on the macro, meso and micro level with empirically substantiated models of strategic, tactical and operational traffic behaviour. The various layers in these models can then also link up with each other. This approach reflects the integration into a behavioural chain as described in section 3.3. By linking this new generation of traffic models to effect models in the field of throughput, traffic safety and the environment, it will be possible to predict the effect of measures in a valid way. See for example [Wilmink & van der Horst, 2004] and [Absil et al., 2009].

3.5. Operational traffic management

Operational traffic management
In the Netherlands, operational traffic management is performed at traffic management centres. Operational traffic management includes:

- informing and warning traffic,
- guiding and controlling traffic flows,
- managing incidents,
- harmonising and supervising road-works,
- monitoring and controlling objects.

For traffic management on the national road network, Rijkswaterstaat has five regional control centres and one national control centre at its disposal. There are also a number of regional and municipal road traffic management centres.

Developments
Many developments are currently taking place in the field of operational traffic management for road traffic. Those developments are having a major effect on the work being done in traffic management centres and on the Human Factors used in that work. This relates to the following developments:

The traffic management centre is playing an increasingly important role in improving traffic flow and safety and in better utilisation of the road capacity. Partly due to the use of route information panels and dynamic reversible lanes, road traffic managers can now 'guide and control' the traffic and in that way improve the traffic situation. Whereas the work in the traffic management centre of the past consisted of monitoring and controlling objects on demand, the traffic management centre is now becoming more and more of a control centre with a network approach. As a result, the management and control of road traffic is now turning into a proactive management task.

The area over which traffic is being managed is expanding. The special act for widening motorways has resulted in an enormous increase in the number of kilometres of lanes on motorways, dynamic reversible lanes and route information panels. In addition, the number of tunnels to be operated and managed in the Netherlands is also increasing all the time.

Besides these infrastructural expansions that are increasing Rijkswaterstaat's operational traffic management tasks, developments are also taking place in response to the "mobility approach". The mobility approach was mend to better manage and control road traffic on the underlying (regional) road network. This included that both on governmental and on operational level parties are working together to manage road traffic on both the motorways and the underlying road network.

Operational traffic management has to cope with an enormous increase in the amount of information and the expansion of the networks in which information can be shared. The number of loop detectors, cameras and other sensors has already grown enormously. Traffic management centres are now responsible for large parts of the road network. In the future, it is expected that the information in the navigation equipment used by road users will also become available for traffic management and that in-car technology and roadside systems will also supply more and more information. Add to that the possibility (thanks to the standardisation of information technology, applications and software) of linking the traffic management centres to each other in a network, and this could result in *network-centric* traffic management.

A final development is that the demand for operational traffic management will increase, but for efficiency reasons it will not be possible to expand the required manpower unrestrained. In short, organisations will have to perform better with fewer people.

The above developments are having a major effect on the Human Factors aspects of the management and supervision of traffic and traffic management centres. The following three aspects are discussed below:

- Cross-organisational, multi-team cooperation in networks
- Workload, task integration, and adaptive automation
- Competencies and skills; proactive traffic management

Cross-organisational, multi-team cooperation in networks

For operational traffic management, the need to work together with different organisations and teams is increasing. Cross-organisational means that different organisations will be involved. For Rijkswaterstaat, this means that the multiregional approach will lead to greater cooperation between the administrative organisations (Rijkswaterstaat as the national road authority, provincial and regional road authorities). It is also likely that other parties will become players in the field of traffic management, such as the manufacturers of traffic management systems and service providers (using navigation equipment en route guidance).

Cross-organisational and multi-team cooperation require a good organisational structure. Firstly, the partners must be able to exchange information in networks. On top of that, mechanisms must be deployed to interpret that information in such a way that the various partners can actually use each other's information. The next step is that partners get to know each other well enough that they can support each other, if necessary, and they know which knowledge is available. On this basis, efficient and implicit coordination structures can be created in which the team members of the various organisations can find each other automatically. In cross-organisational working relationships, people also have to deal with conflicting (sub-)objectives. This and the difference in (corporate) culture can make the cooperative relationship more difficult if insufficient attention is paid to this in the organisational design.

For operational traffic management, the cooperative relationship must become operational on the work floor of the traffic management centre. The question is how to tackle this. Should there be far-reaching integration of the traffic management tasks for the motorways and the regional road network? Or should the tasks be separated and handled as specialist subjects by different desks or perhaps even in different traffic management centres? What can the different working methods result in, both on the service side and on the organisational side? Which coordination principles are necessary? How can they be integrated into the work of road traffic managers without overloading them? Which supporting resources are required to do this? These are all Human Factors questions that need to be answered in the time to come.

Workload, task integration, and adaptive automation

In view of developments related to proactive traffic management, the increase in network area covered and the expansion of information and networks, extra attention will have to be paid to the workload of the road traffic operators. Especially when the aim is to do the work as efficiently as possible. For the safe flow of traffic, it is important to have fit and well-trained operators. The question is: How can the work be structured in such a way that traffic managers have the optimal workload − not too much, but also definitely not too little?

A high level of efficiency can be achieved by integrating tasks on the work floor. To help achieve this, job responsibilities will be designed with a coherent grouping of activities that jointly contribute to the objective of the task. One example involves the integration of traffic management tasks for the motorways and the regional road network (often not yet put into practice). For task integration, a number of issues should be considered. In terms of the result, it is important to define what will be produced, such as better service, fewer people or more effective communication and coordination. For the personnel, it is important to determine what is feasible. Will task integration result in work that people are capable of doing, with sufficient room for manoeuvre, development opportunities and social interaction? By determining the best possible job responsibilities, people will continue to be motivated and contribute to the quality and productivity of the work on the basis of that intrinsic motivation.

Operational traffic management has to cope with peaks and troughs in the workload. Peaks in the workload can be overcome by creating a good task design (alternate critical tasks with tasks that can be postponed or planned) and tasks to be assigned to teams as their responsibility. During peak load, team members can (temporarily) take over each other's tasks. That can be done, for example, by working in duo teams or by rapidly upscaling with standby staff that can be paged. In the future in connected traffic management centres, the workload can be distributed proportionately by asking other control centres for assistance.

The adaptive automation of activities can help to reduce the workload. The automation of management and control tasks entails certain risks, however. People can be taken 'out-of-the-loop' due to the fact that activities are carried out automatically. Because of this, the employee is no longer familiar with the situation. If there is a high workload, people can then make incorrect estimates or lose sight of the big picture. Adaptive automation offers a middle way: help when the workload is high, but people doing enough themselves during quiet periods so that employees are fully aware of the situation. One additional advantage is that this helps to prevent underactivity – the workload is perfectly balanced.

Competencies and skills; proactive traffic management
The work involved in operational traffic management is changing fast. This means that road traffic managers, transport specialists and coordinators and managers must learn to master new competencies and skills. The most important aspect is to develop traffic management from "traffic monitoring" into "proactive traffic management". Management requires people who are working under pressure (or pressed for time) to come up with creative solutions, to act proactively and to be solution-oriented. People can no longer fall back on routines and they must be capable of thinking out-of-the-box to devise the right measures (especially in the case of calamities). This asks for new competencies of traffic management operators, when compared to more reactive monitoring and (procedural) action based on events .

Cooperation is also becoming more important, both inside and between teams and organisations. Not just for optimal workload distribution, but also to enable people to work in a more interdisciplinary way. That means that team members must be familiar with each other's work (or region), must be able to communicate well, and must perform various team activities to build up a shared awareness that enables them to coordinate and cooperate effectively and efficiently. Working in multi-teams, cross-organisationally, requires people to be aware of each other's corporate culture and of their divergent organisational interests. Acting diplomatically, negotiating and building up trust are important competencies in a networked organisation. It also requires the team managers and the leadership to develop new competencies: managing on the basis of cooperation, all-inclusive rather than authoritarian leadership – always being mindful of the diverse interests of the various partners.

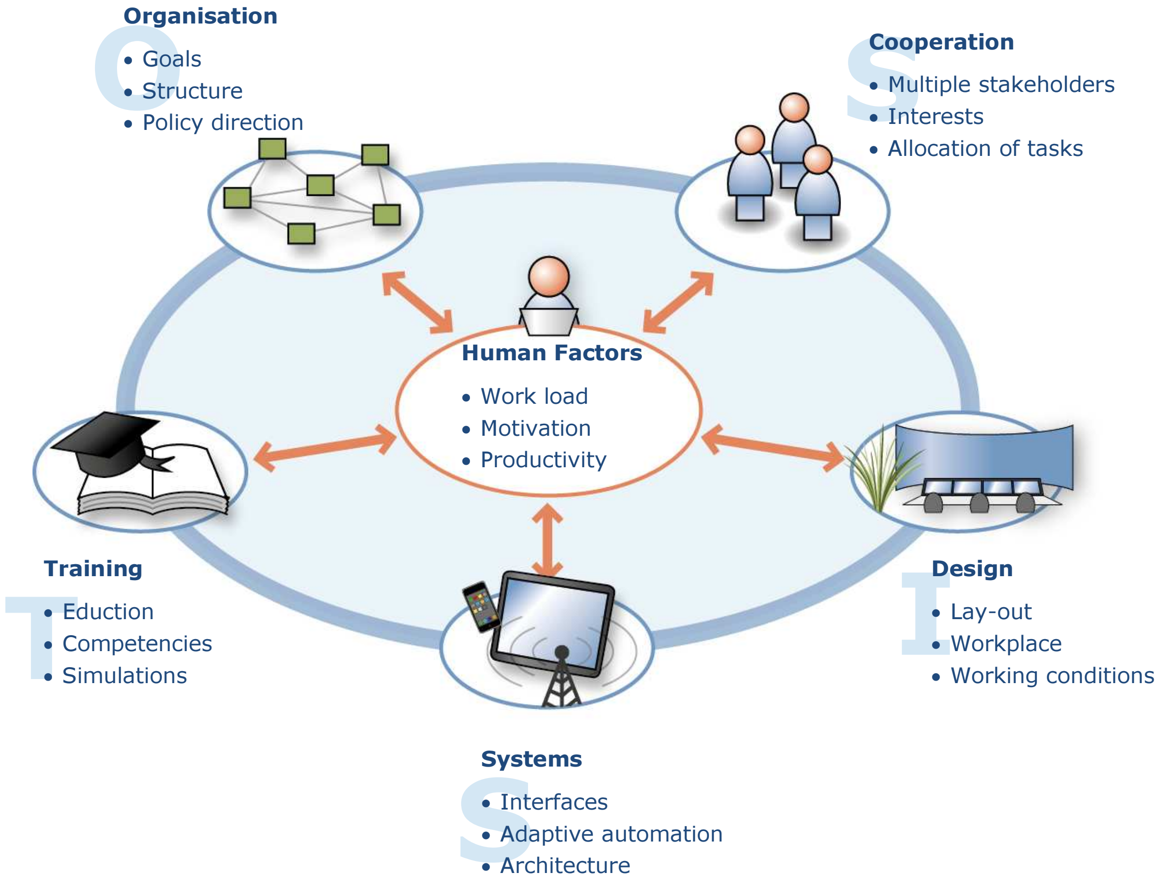


Figure 2: OSIST framework for integral design approach to operational traffic management in traffic management centres

Organisation, cooperation, structure, systems and training

The integration of Human Factors is essential for the future development of operational traffic management. The OSIST framework (see Figure 2) stands for organisation, cooperation, structure, systems and training and focuses on all the facets that are important for the development of networked organisations and operational spaces. The integrated approach helps all the way from the development of a blueprint of organisational objectives to the tasks performed on the work floor. This results in a programme of requirements for the structure, the systems and the technology. By making Human Factors the centre of focus, technology can be used to bring about genuine innovation. Technology presents operational traffic management with countless opportunities, but only if the organisation, the cooperative relationship and the execution of tasks are structured properly.

4. What is the perspective for the future?

The traffic management of the future will be based on intelligent information systems. To get the most out of those systems, optimal organisation, cooperation and task execution will be required of the traffic manager. This system approach demands in-depth knowledge of the behaviour of road users. By recording this behaviour in a design road user and in behavioural models, Human Factors tools will be generated that can be used to design new traffic management systems. The most important development lines are discussed in the following section.

4.1. In general

Over the next ten years, new sensors, media and information systems will be merged into a new information system, both for individual travellers and motorists and for traffic managers. The user-friendliness of this system will be crucial to its success. An information-ergonomic approach is necessary to ensure that this system works properly. The Human Factors expert has access to a set of tools that can be used to evaluate new designs on the both component and the system level, resulting in valid relationships. It is therefore increasingly important that the Human Factors expert becomes involved in the design and evaluation activities right from the start.

Since the early 1990s, the envisaged integration of information systems in-car and en-route has not progressed as smoothly as expected. However, cooperation between vehicles and between vehicles and roadside systems will ultimately be implemented. Particularly from a behavioural science perspective, scenarios can map out the potential added value of this integration and indicate the direction to be taken by the required developments. In the broader social context, the New World of Work will develop: with a good mix of new organisations, communication and working relationships tailored to that. Innovations in traffic management can capitalise on and facilitate this development.

When new traffic management systems are being developed, Human Factors knowledge can be used for design, evaluation and traffic prediction purposes. Quite a lot is known about traffic behaviour on a tactical level, but more knowledge is required to translate this knowledge into valid predictions. That will require new knowledge as well as model-based interpretations of the relationships between speed, following and overtaking under the influence of psychological, infrastructural and vehicle-linked characteristics in various light and weather conditions. Modern behavioural influence does not focus on one specific behavioural level. The challenge is to make use of the interactions between the levels: departure time, speed behaviour, route choice and modality behaviour. These interactions will then also have to be linked to the macro, meso and microscopic traffic simulation models.

4.2. Models

Among other things, the link between Human Factors knowledge and traffic management tools should be realised by filling traffic models with models of strategic, tactical and operational traffic *behaviour* on the macro, meso and micro level. The various layers of these models can then also be linked to each other. This approach reflects the development of ideas in terms of a behavioural chain. By linking this new generation of traffic models to effect models in the field of throughput, traffic safety and the environment, it will be possible to predict the efficiency of measures in a valid way.

Behavioural models are becoming more dominant in generic traffic models. However, the implementation of behavioural models in generic traffic models must improve. To do this, the models should contain valid behavioural simulations of economic, psychological and social decision-making motives. The effects of habitual behaviour, the power of price incentives and the impact of personalised information should be incorporated into these models. We still only have a limited understanding of the mutual relationships between these motives. Many of the current models are one-dimensional and based only on cost criteria. However, there are also other aspects – such as habitual behaviour – that play an important role in many choice processes. This occurs not just on the macro level but also on the meso and micro level. The reaction of motorists, for example, to the different types of traffic management, in-car and en-route, should therefore be described in terms that actually produce the requisite model data. The structure of observation and evaluation studies should focus on this.

4.3. The new traffic management

The work involved in operational traffic management is changing fast. This means that road traffic managers, transport specialists and coordinators and managers need to master new competencies and skills. The most important of these changes is the way traffic management is evolving from "traffic monitoring" in the direction of "proactive traffic management". The formulation of creative solutions is supported by traffic models that provide previews of the expected traffic situation. These previews will be indispensable to the traffic manager of the future.

In the traffic management centres of the future, traffic models will predict the future traffic situation. Behavioural models will be integrated into these traffic models and therefore also in the predictions. These tools will help the traffic manager to choose measures with which traffic flows can be controlled and stabilised. For operational traffic management, the cooperative relationship must be made operational on the work floor of the traffic management centre. The question is how this should be tackled; should we aim for far-reaching integration of the traffic management tasks for the motorways and the regional road network? Or should those tasks be handled separately as specialist subjects by different desks or perhaps even in different traffic management centres? What can the various working methods give us, both on the service side and on the organisational side? Which coordination principles are necessary? How can they be integrated into the work of road traffic managers without overburdening them? Which support resources are needed to do this? These are all Human Factors questions that need to be answered in the time to come. In this new context, the workload of traffic managers also needs to be looked at. It is important to determine how the work can be structured to ensure the optimal workload for traffic managers.

References

Aarts, H. & Dijksterhuis A., (2000), "The automatic activation of goal directed behaviour: The case of travel habit", in: Journal of Environmental Psychology, 20, 75-82.

Absil, N.E., Hogema, J.H., Feenstra, P.J. & Pauwelussen, J.J.A. (2009). "Driver Behavior Models; Applications & Developments", Soesterberg, TNO Defence, Security and Safety, TNO report TNO – DV 2009 IN 468.

AGV (2004), "Evaluatie stedelijke DRIPs; Eindrapport", Bureau AGV Adviseurs in mobiliteit & Arane, adviseurs in verkeer en vervoer, Gemeente Rotterdam, 2004.

Arem, B. van, B. Jansen, & M. van Noort (2008), "Slimmer en beter: de voordelen van intelligent verkeer, Delft, TNO report 2008-D-R0996/A.

Bakker, P. en P. Zwaneveld (2009), "Het belang van openbaar vervoer; de maatschappelijke effecten op een rij", The Hague, CPB/KiM, Bijzondere Publicatie 87, 2009.

Van den Berg, De Goede, Koning & Stroek (under preparation), "Connected Traveller – Using personalized information to break the habit when choosing modality", Soesterberg, TNO Report.

Ben-Elia, E. and D. Ettema (2010), "Commuters choice behaviour with rewards for avoiding peak-hour driving", paper presented at the 89th Annual meeting of the Transportation Research Board, January 2010.

Brookhuis,K.A, M. Dicke, R.L. Rademaker, S.R.F. Grunnekemeijer, J.N.J. van Duijn, M. Klein Nijenhuis, N.A. Benedictus & E. Eser (2008), "The effects of travel information presentation on driver behaviour", in: D. de Waard, F.O. Flemisch, B. Lorenz, H. Oberheid, and K.A. Brookhuis (Eds.). Human Factors for assistance and automation (pp. 431 - 444). Maastricht, The Netherlands, Shaker Publishing, 2008.

Burgmeijer, J. A. Eisses, J. Hogema, E. Jonkers, S. van Ratingen, I. Wilmink & T. Bakri (2010), "Evaluatie dynamisering maximumsnelheden – Resultaten proef A12 Voorburg", Delft, TNO, 25 August 2010, report number TNO-034-DTM-2010-02285.

Chorus, C., T.A. Arentze, H.J.P. Timmermans (2007), "Information impact on quality of multimodal travel choices: conceptualizations and empirical analyses", in Transportation, 34: pp 625-645.

Chorus, C. (2010), "Multimodale reisinformatie – voetangels en kansen", in: NM Magazine, March 2010.

Crompton, A. (2006), "Perceived distance in the city as a function of time", in: Environment and behavior, 38: pp 173-182.

CROW (2005), "Handboek wegafzettingenautosnelwegen 96a", ISBN 90-6628-447-1.

De Goede, M., F. Faber, G.J. Boertjens, T. Vonk & T. Hof (2010), "The Connected Traveller: Factors affecting travel behaviour on an individual and network level", Soesterberg, TNO Defense, Security & Safety, Report nr: TNO-DV 2010 IN148.

European Commission (2008), "C(2008)1742 final. Commission Recommendation 0f 26/V/2008 on safe and efficient in-vehicle information and communication systems: Update of the European Statement of Principles on Human-Machine Interface", Brussels, Commission of the European Communities, 2008.

FESTA Consortium (2008), "FESTA Handbook, Version 2", Field opErational teSt supporT Action Deliverable D6.4, Leeds, ITS University of Leeds, 2008.

Fujii S. & R. Kitamura (2003), "What does a one-month free bus ticket do to habitual drivers? An experimental analysis of habit and attitude change", in: Transportation, 30, pp 81–95.

Godthelp, J en E. Tenkink (1990), "Zichtcriteria voor wegen en informatiedragers langs de weg", Soesterberg, TNO report IZF 1990 C-10.

Gonzalez, M.C., C. Hidalgo & A.L. Barabasi (2008), "Understanding human mobility patterns", in: Nature, 453: pp 779-782.

Grotenhuis, J.W., B.W. Wiegmans & P. Rietveld (2007), "The desired quality of integrated multimodal travel information in public transport: Customer needs for time and effort savings", in: Transport Policy 14 (2007), pp 27–38.

Heijs (2009), "Huishoudelijk energieverbruik: Gewoontegedrag en interventiemogelijkheden", Study commissioned by Novem b.v., Eindhoven, Eindhoven University of Technology, 2009.

ISO TC 22/SC 13/WG 8 TICS on-board – MMI (2010), *http://www.iso.org/iso/iso_technical_committee?commid=46880*.

Knippenberg, C.W.F. van, J.A. Rothengatter & J.A. Michon (1989), "Handboek Sociale Verkeers-kunde", Groningen, Verkeerskundig Studiecentrum, University of Groningen, 1989.

Martens, M.H., R.F.T. Brouwer, I.R. Wilmink & A.R.A. van der Horst (2010), "Korte en langere termijn oplossingen rood kruis negatie in het verkeer", Soesterberg, TNO, TNO Report DV 2010 C310.

Martens, M.H. & G.T. Tertoolen (2010), "Human factors advies landelijke uitrol Dynamax", Soesterberg, TNO, report TNO-DV 2010 C132.

Dutch Ministry of Transport and Public Works (2005), "Advies voor de spoedwetprojecten – Herziene versie. Ontwerp en Inrichting Spitsstroken, Plusstroken en Bufferstroken", Rijkswaterstaat, 2005.

Dutch Ministry of Transport and Public Works (2007), "Maatregelen Catalogus Benutten (2007)", available @ *http://www. MaatregelcatalogusBenutten.nl*.

Dutch Ministry of Transport and Public Works (2008), "10 gouden regels", Rijkswaterstaat.

Norren, D. van (1981), "Informatiedragers langs de weg: en overzicht van zichtbaarheidsproblemen", Soesterberg, TNO, Report TNO IZF 1981 C-25.

REVI (2010), "Richtlijn First Veiligheidsmaatregelen bij Incidenten op (auto) snelwegen", New edition January 2010, Verkeerscentrum Nederland, ISBN 90-369-1733-6.

RVV(1990), "Reglement Verkeersregels en Verkeerstekens', Wegenverkeerswet, 1990.

Rothengatter, J.A. (1991), "Automatic policing and information systems for increasing traffic law compliance", in: Journal of Applied Behavior Analysis, 24, pp 85-87.

Schuurman, H. (2011), "Verkeerscentrales en netwerkmanagement", State-of-the-Art Achtergronddocument, Delft, TrafficQuest, 8 November 2011, available @ *http://www.trafficquest.nl/images/stories/documents/verkeerscentrales_sota_achtergrond_rapport_v1.1.pdf*

Schuurman, H. (2011b), "advies 'Keep Your Lane' (addition to version 12 June)", TrafficQuest memo, Delft, 28 June 2011.

Steg. L. (2009), "Informeren versus sturen. Inzichten vanuit de sociale psychologie", presentation at Seminar on travel and route information and the human factor, Rijkswaterstaat - Dienst Verkeer en Scheepvaart, 2009.

Taale, H. en S. Hoogendoorn (2009), "De essentie van verkeersmanagement - Basisprincipes en gedragseffecten", presentation at Symposium Human Factors in Traffic Management, Rijkswaterstaat - Dienst Verkeer en Scheepvaart, 2009.

Taale, H. en H. Schuurman (2012). Effecten verkeersmanagement, cijfers van meer dan 160 (praktijk) evaluaties uit Nederland, Delft, Rijkswaterstaat - Dienst Verkeer en Scheepvaart, 2012.

Theeuwes. J (2009), “Informeren versus sturen”, presentation at Seminar on travel and route information and the human factor, Rijkswaterstaat - Dienst Verkeer en Scheepvaart, 2009.

Thøgersen, (2005), “Understanding repetitive travel mode choices in a stable context: A panel study approach”, in: Transportation Research Part A, 40, pp 621-638.

TrafficQuest (2011), “De toekomst van verkeersmanagement - Stand van Zaken, ontwikkeling en perspectief”, Delft, TrafficQuest, March 2011, available @ *http://www.traffic-quest.nl/images/stories/documents/toekomst%20van%20verkeersmanagement%20-%20rapport.pdf*

Vaessens, B., M. Hagen & M. Exel (2008), “Auto vs. Trein – De context bepaalt de keuze”, Utrecht, NS, 23 December 2008.

Verkeerscentrum Nederland (2010), New edition January 2010. ISBN 90-369-1733-6.

Wilmink, I & R. van der Horst (eds.) (2004), “An ITS evaluation environment for safety, quality of the environment and throughput: Research questions & model requirements”, Delft, TNO Inro, report number 04-7N-131, August 25, 2004.

Verplanken, B., H. Aarts & A. van Knippenberg (1997), “Habit, information acquisition and the process of making travel mode choices”, in: European Journal of Social Psychology, 27, pp 539-560.