

Cooperative Mobility Systems: The Human Factor Challenges

Marieke H. Martens^{1,2*} & Elisabeth C.M. Kroon³

1. TNO, The Netherlands
Kampweg 5, 3769 DE Soesterberg
+31 (0)888665832, marieke.martens@tno.nl
2. University of Twente, The Netherlands
3. TNO, The Netherlands

Abstract

This paper presents a vision on cooperative mobility systems from a human factors perspective. To create a common ground for future developments, it's important to define the common research themes and knowledge gaps. This article presents what steps need to be taken in order to come to proper ex-ante evaluations of cooperative systems. Since the actual effect of these systems on traffic flow, safety and air quality will not only depend on the technological potential of these systems but largely on the actual behavioural effects of using these systems, the Human Factor is crucial in the design and evaluation. This article can make researchers and designers aware of the potential as well as the behavioural pitfalls when designing cooperative systems. By working together with industry, government and knowledge partners, the Dutch Integrated Testsite for Cooperative Mobility and exchanging data and evaluations, cooperative mobility can be taken to the next level.

Keywords:

Cooperative systems, behaviour, human factors.

Introduction

At this moment congestion on the motorways in the Netherlands cost about 0.5 to 1 billion euros every year. The exact numbers depend on whether one includes the increase in fuel consumption, vehicle loss hours, increased medical costs due to decreased air quality, etc. It is been estimated that about 80% of all congestion in the Netherlands is caused by a demand which is greater than the road capacity. Furthermore, about 14% is due to accidents and resulting congestion by drivers looking at these accidents. In addition, about 6% is caused by road constructions (Rijkswaterstaat, 2012).

This is the reason why so many activities have been undertaken to address this traffic problem in the last 10 years. However, due to all economic and social developments the demand for mobility is still expected to increase in the upcoming decennia according to mobility experts. This increasing demand coincides with new technological innovations in the field of traffic management. Developments such as nanotechnology and ICT are going strong and new opportunities rise due converging technologies.

One of the new opportunities are cooperate mobility systems. Cooperate mobility will change the way we currently drive our cars. It is the vision that in-car and on road sensors will support the road user in this driving task, as an addition to the limited cognitive capacity and sensors of the human being. For example, humans can only respond to what they observe in their direct surroundings and need time to make decisions. Due to direct vehicle to vehicle or

vehicle to infrastructure communication, more and quicker exchange of information can take place. Anticipating communication systems have the potential to influence individual vehicles, which will make the traffic system more safe, efficient and comfortable, with less emissions. Whereas the focus was first on traffic flow and efficiency, there is an increasing attention for the possibilities to improve traffic safety, driving comfort and eco-friendly driving. With cooperate mobility systems there is much to be gained.

In addition, there is a trend that provision of traffic information shifts from the government to private companies. More often drivers obtain their information directly from apps or their navigation systems, and only to a lesser extent by information provided by the road authorities on signs along the side of the road. This makes the driver an important stakeholder in the development of new mobility solutions in the nearby future.

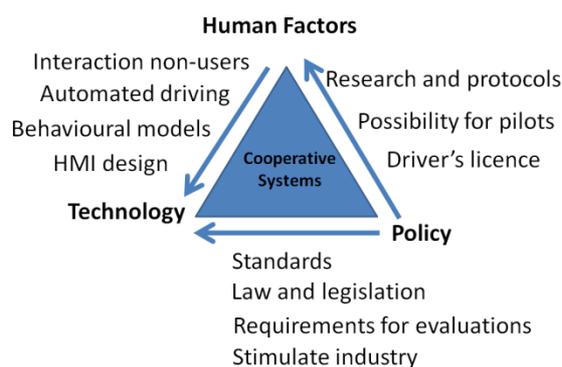


Figure 1 - Expression of the interrelation between technology, human factors and policy with regard to the development of cooperative systems.

Industry, knowledge institutes and governments invest a lot in research and development of cooperative mobility systems. However, how safe, efficient, comfortable and clean these innovations will be depends to a large extent on how drivers will incorporate and use the cooperative systems in their daily lives. If these systems are not used properly by drivers, it will be a show stopper for successful mobility solutions. Therefore Human Factors are the key to a successful innovation. Developments with regard to technique, human factors and policy are all interrelated. Figure 1 shows some future developments in relation to these three basic elements of the traffic system. Only when these three areas of experience go hand in hand and enhance each other, cooperative mobility will become a success.

To achieve a successful utilization of cooperative mobility, a vision on future developments is formulated. This results in the support of alienated and coherent innovations and ensures that all involved parties work towards an overall solution based on a common ground.

Since the driver is the key to a successful development of cooperate mobility, research towards human factors in relation to cooperate systems is essential. Therefore this article focusses on how to reach the ideal future situation for cooperate mobility, with the focus on human factors. What are exactly the issues that need to be solved to reach this desired future situation?

DITCM: Ideal future with cooperative systems.

Within the next decade, full support and automated driving will take its first step on our roads. However, to determine which developments and what research is currently needed, we will need to start today with the most imminent issues. Before fully automated driving, there will be a phase of active control, in which cooperative systems advice or (partly) take over some driving tasks. Based on this vision the intermediate steps to reach this ideal goal on the horizon can be defined. Which includes well-functioning and accepted cooperative systems

that have the desired effect on safety, efficiency, comfort and the environment. In order to enhance the developments of cooperative mobility systems in an integrated approach, the Netherlands initiated DITCM (Dutch Integrated Testsite for Cooperative Mobility, see www.ditcm.eu). DITCM is a non-profit collaboration between Dutch industry, local and national governments and research institutes, for solving traffic congestion and traffic safety problems in The Netherlands using cooperative technologies and applications based on a shared roadmap. Within this program DITCM *Innovations* will develop an open innovation environment (fieldtest-facilities, software stack, data protocols, simulation, communication and evaluation tools and corresponding standards) from which partners and customers will profit towards their national and international ambitions to supply technologies, facilities and services with respect to Cooperative Mobility by large-scale demonstrators and pilots and participating in pre-competitive demonstrative projects and conferences.

Achieving the above mentioned objectives requires the involvement and contribution in the pre-competitive stages of several and diversified industrial sectors, which need a common platform for developing, addressing, testing and applying devices and technologies.

DITCM Innovations goal is to establish the pre-competitive environment in which Dutch industry, governments and research institutes collaborate according to a common roadmap with respect to cooperative technology and applications. As a joint partners organization, DITCM Innovations services will be based on the joint objectives, projects and roadmaps of the partners.

This article refers to the Human Factors roadmap within DITCM. In order to focus on the Human Factor within DITCM, three important themes were identified. To attain the described future situation, investments in research and development on cooperative systems, in relation to human factors, are needed. To determine on which research areas these investments should be made three themes are specified, which should become the focus of studies in the upcoming years. The following three chapters will address the identified themes for research and development.

Theme 1 Development and evaluation of behaviour models for traffic flow, safety and environment

Currently behaviour of road users is mainly described in traffic models, which analyse and assess effects of different traffic scenarios on traffic flow and determine the cost-efficiency of measures. Micro simulations of traffic flows do take into account individual driving behaviour, but are based on assumptions on human behaviour that do not take response to new technology into account. For instance, these models do not include behaviour adaptations due to self-learning systems which change over time. Most models do not focus on behavioural effects of supporting systems at all. The ones that do model such effects are not complete. For example, the behavioural effect of driving with ACC is simulated by adjusting the following distance and the response times of road users. These models however do not take into account disrupting effects of switching an ACC system on or off. Therefore models currently in use are not mature enough to incorporate all behavioural aspects of cooperative mobility, sometimes simply because we do not know yet how drivers will respond. The first priority is to increase the flexibility of behavioural models to incorporate more parameters which can be tuned, as for example the degree of penetration, or the number of activated systems. Subsequently, the first behavioural models will be developed that take into account the different stages of automation of control: inform, advice, warn and intervene. In the end, validated behavioural models will be used as plugins for macroscopic models, such that all effects on traffic safety, efficiency and environment can be predicted and assessed. For this reason knowledge will need to be developed on the following research questions:

How will road users adapt their driving behaviour as a result of the implementation of cooperate systems?

Since this question addresses new systems it is unknown how road users will adapt their behaviour on a short and long term. With the introduction of new systems, drivers tend to interpret these systems in the light of their known context, leading to suboptimal use of the provided information (e.g. Risto & Martens, 2013). To what extent will road users comply and accept new cooperative systems in their car? And how can this change in behaviour be modelled?

To what extent will the effects on driving behaviour be different when the system informs, guides or even (partly) takes over some driving tasks?

How road users will react and adapt their behaviour to a system is highly dependent on the degree in which the driver stays in control, for instance drivers can autonomously decide whether they obey or ignore a speed advice (e.g. Biding & Lind, 2002, whereas compulsory ISA (Intelligent Speed Adaptation) cannot be overruled (for an overview see Jamson, Carsten, Chorlton, Fowkes, 2006). If drivers are still able to decide whether they obey an advice or not, the effectiveness of a cooperative system will never be 100%. This should be taken into account when estimating the effect of different cooperative systems over time.

To what extent does behavioural adaption take place?

The definition of behavioural adaption includes behaviour adaption due to the implementation of a measure or system, which is not intended by the designers of the system (OECD, 1990). Often negative effects on behaviour are addressed which occur when drivers are willing to take more safety risks with such a system installed. Though the definition of behavioural adaption is more comprehensive and, for instance, also includes negative effects on the environment due to undesired changes in driving behaviour (for an extensive overview of behavioural adaptation see Rudin-Brown & Jamson, 2013).

The first type of behavioural adaptation takes place when road users will get used to the new way of cooperate driving. As a result road users may drive in an environment (like an intersection) that is not equipped with cooperate systems, while they expected to be. In that case, drivers will expect early warnings. If those will not occur, drivers will continue driving without paying much attention to the road, with all its consequences. Discrepancy between expectations and reality may also occur when drivers drive a car that is not equipped with cooperate systems, while they think it is. This error should be taken seriously, since it is expected that the demand for Car Sharing becomes greater in the future.

A second type of behavioural adaption occurs when drivers implicitly trust the system (see also Martens, 2013). As a result drivers pay less attention to the road and remaining traffic. Duivenvoorden (2007) identified the problem of a trend towards more red traffic light violations in case of an in-car green traffic light advice. Diminished situational awareness may cause great problems, particularly with semi-automated systems.

The third type of behavioural adaptation is a potential negative effect on safety, efficiency and the environment. Since drivers are aware that they drive more safe, efficient and eco-friendly, they might be inclined to drive more kilometres or take more risks.

The possible fourth effect of behaviour adaptation might occur if specific user groups will participate more in traffic with the support of cooperate systems, than when these systems were not available. This may be the case for elderly people. However, there might be a discrepancy between what road users believe they are capable of and what they actually can handle. In addition, with those user groups more risks are involved. It might have negative effects on safety, efficiency or the environment, if the share of such user groups increases.

How will drivers with cooperative systems interact with drivers who don't have such systems installed and vice versa?

The behaviour of individual vehicles will change due to cooperate systems, either by acts of the driver directly, or automatically by the system. This change will also affect drivers without a system installed (e.g. Biding & Lind, 2002). Non-cooperate drivers might experience the driving behaviour of others as odd and unnatural. For instance at an intersection where a cooperate driver will not slow down, keeping a short headway since they already know the traffic light will turn green in advance. Another negative interaction effect might occur on motorways where a cooperate driver slows down and leaves space, to anticipate on an approaching shockwave. Non-cooperate drivers without this knowledge will take up this space, as a result cooperate drivers will have to slow down even more. On the other hand, non-cooperate drivers might also follow cooperate drivers, which will contribute to positive effects of cooperate systems.

In addition to these research questions behavioural models will have to be extended, such that they can cope with different driver types, vehicle types and cooperative systems. This in relation to detailed estimations of effects on traffic flow, safety and environmental impact, which are currently not available yet.

Theme 2: Adaptive human machine interaction

To what extent cooperative systems actually have the desired effect is largely dependent on the design of the HMI. Many factors influence how drivers will use the system, as the experienced usefulness, availability, learnability, usability, trust and reliability, comfort of the system, provided user information and satisfaction. If drivers do not understand a system or if a system is laborious in use, drivers will not utilize the full potential of the system. Even if the system itself is technically well-functioning and efficient, the desired effects will remain absent or limited. How drivers experience a system also depends on how cues and information are presented to the driver. For instance, by means of a display or via haptic signals as vibrations in the steering wheel or driver seat. HMI design is therefore very extensive and complex. It is expected that the first developments will focus on reliable and self-explaining HMIs providing information in-car. After the introduction of an HMI prototyping platform, which describes the functionality of flexible interfaces, it will become possible to develop standardized, individualized, intelligent and adaptive interfaces. Although many international standards exist, describing design guidelines for in-vehicle HMI (e.g. European Union, 2007; International Standards Organization, 2009, 2011; Ahlstrom & Kundrick, 2007), these guidelines are general and do not specify exact guidelines on how to present the information.

To make sure HMI design is incorporated well in future cooperative systems the following research questions need to be answered:

How can cooperate systems account for inter and intra individual differences?

The concept of One Fits All has been abandoned more than 10 years ago. What works for one road user, might not work for someone else. Therefore new systems are customized, personalized and adaptive. Besides inter individual differences, there are intra individual differences as well. Since the most optimal setting might differ under different conditions. This also relates to the condition of the driver (fatigue), type of trip (being in a hurry), as well as the environment (weather conditions or rush hour). Taking these inter and intra individual differences into account will contribute to the perceived usefulness, comfort of the system satisfaction, and acceptance by the driver.

What is the influence of Ambient Devices and other applications which will become available in the future?

There is an increased mutual exchange of data between drivers and service providers. Therefore the role of the government will change. This shift will influence driving behaviour and the way drivers perceive information. Only with a proper informational structure will utilize the full potential of cooperate systems optimally. Therefore it is necessary to study the influence of ambient devices and other applications on driving behaviour and its effects on traffic flow, safety and air-quality.

How to deal with the discrepancy between roadside information and in-car information?

Cooperative systems get information directly from other vehicles and/or infrastructure. However, while non-cooperative vehicles drive around, information should still be provided by the direct environment by means of road signs. As a result discrepancies between roadside information and in-car information are unavoidable. Also differences in information services between countries might result in errors. Due to these discrepancies acceptance and trustworthiness of cooperative systems can be undermined. Secondly, the variation in driving behaviour is expected to become greater with a mix of cooperate and non-cooperate drivers, since the later will not experience discrepancies. Finally, intended effects of cooperate systems are undermined to some extent, since drivers will choose the option which is most beneficial for themselves, for instance if the automatically regulated operational speed is lower than the speed limit along the roadside.

How to design fail safe and forgiving systems?

The greater the trust in a system is, the more drivers will comply with advices and accept the system to take over control. However, if a system fails this will have negative consequences since drivers will still follow the system or will not have the situational awareness to respond properly. For example when drivers end up ghost driving due to a wrong turn taken by their automated vehicle. The greater the success and therefore trust in cooperative systems, the more serious negative effects might be. Errors occur when drivers do not notice that information is incorrect, or do not know how to take control when a system fails. It could also be that the response time of drivers is too high when drivers have to take over control, since drivers are less aware of the situation or less capable of responding because they might have forgotten how to. It is therefore important to study in which way and how a driver should be informed of a system failure, in relation to driver state and the road situation.

How to persuade drivers to act according to what is most beneficial for the whole society instead of what is most beneficial for them individually?

With the use of cooperative systems a conflict might arise between individual short term interest (personal optimum) and the benefits for the community on the long term (system optimum). A situation which is optimal for the individual will undermine the full benefits of cooperate systems on a macro level. This may cause some problems with compliance and acceptance due to the social dilemma (Risto & Martens, 2013). To obtain the best system optimal situation, drivers will need to become aware of their adverse behaviour and the effects of it on society. Possible persuasive technologies can be applied, to influence driving behaviour.

How to support the driver: inform, advise, guide or control?

To what extent cooperative systems will effect traffic flow, safety, comfort and environment as intended depends highly on the degree in which the system takes over control. If the driver remains in control of the driving tasks variations in the degree in which driver follow the advice will be greater. In that case, the degree in which the advice is followed depends on if

drivers could understand the message, were willing to follow the message and were capable to act up on the advice. Therefore, if the degree of automation will be greater, variety will become smaller and more predictable. However, automation of the driving task also brings along risks with regard to transition of control (Flemisch, Kelsch, Löper & Schieben, 2007). In case driving is (partly) automated the transition to a fully manual system is great. The more the system is in control, the more it is important that the driver is still able to understand the system and be aware to what extent he has to act on situations except for when the system is a 100% failsafe. Adaptive support can provide the most optimal support and play a role in managing transition of control. Based on a drivers own decision or by means of a workload manager, it can be determined to which extent the system takes over control for specific situations and informs the driver. In this way the system is always in line with the needs of the road user, based on both driver type, as well as driver state.

Theme 3: Evaluation and methodology

In order to come to predictions about the effects of cooperative systems in real traffic, these systems will need to be evaluated and assessed. It is therefore important to reach a common understanding on minimal requirements for these evaluations and to find a common methodological framework. It is a first priority to set standards for behavioural parameters that need to be evaluated in order to come to predictions with respect to traffic safety, traffic flow and air quality. Also, an assessment tool will need to be developed which will guarantee a proper experimental design and evaluation method, helping developers and designers of cooperative systems in choosing the right tools and methods for their ex-ante evaluations. Eventually, a common quality standard needs to be agreed upon, which addresses human factor issues with regard to cooperative systems. Therefore the following research questions need to be explored, to ensure high quality design in the future:

In what way do behavioural parameters need to be defined and logged?

To be able to evaluate and assess cooperative systems developed by different institutes it is necessary to create a common understanding on how to define and log parameters. A good international overview of all possible behavioural measures and their definition is provided by Society of Automotive Engineers (draft, 2013) and within various European projects (Kircher et al, 2008; Kircher, Heinig & Brouwer, 2009). Otherwise validation of and comparisons between different types of cooperative systems are difficult to establish. This is extremely important in case of pre-competitive research that will take place within DITCM. This step is also necessary to define proper boundaries as indicated in the sub question below.

What are proper boundaries for different behavioural and car parameters, with regard to acceptance and comfort?

It is important that drivers are comfortable with the cooperative system if it takes over control and have trust in its functioning. For example, strong deceleration rates should not be experienced as uncomfortable. Therefore boundaries set for such parameters should not deviate too much from the current values experienced with manual driving. Of course there will be differences, otherwise intended positive effects on safety, efficiency or environment will not occur. It should therefore be determined what is acceptable and comfortable to the driver. Not only physically, also with regard to perception of other traffic. If a car equipped with a cooperate system drives behind a non-cooperative car with only a meter in between, this will not be perceived as safe or comfortable by the driver in the non-cooperative car. This will also mean that boundaries set may change over time, when more cars will become equipped with cooperative systems and drivers are more experienced with cooperate

mobility. Determining these parameters and updating them, will make sure that cooperative systems can be utilized optimally.

Which experimental designs and evaluation methods are proper for assessing the behavioural effects of different types of cooperative systems?

To obtain valid data on the defined parameters and be able to interpret them correctly, it is of great importance that behavioural research is performed properly. Results need to be scalable and directly be the result of the intervention of the cooperate system. Therefore it should be standardized which methodologies are appropriate for testing and developing cooperative systems, such that results are reliable (e.g. Kircher et al, 2008; Jamson et al, 2009). However, there is not one tool which is suited to evaluate all types of cooperative systems under different conditions, with different objectives. Only by defining a toolbox which is capable of advising how to assess different behavioural aspects of cooperate mobility, we can guarantee that future developments meet the required quality standards set by governments and the industry.

How should interaction effects of multiple cooperative systems be evaluated?

Currently, separate cooperative systems are developed that focus on supporting different driving tasks and situations, such as C-ACC or cooperative traffic lights. However, to estimate the full potential of cooperative systems and overall effects on safety, efficiency and environment, it is important to realise that combined effectiveness of different cooperate systems can have an aberrant effect (see also Malta et al, 2012). This effect can be both positive as well as negative, as systems enhance each other or cause conflicts. Just adding the effects of separate cooperate systems is often not valid and would give bias results. It is therefore of interest to determine in which way interaction effects of multiple cooperative systems should be studied and evaluated.

Final statement

Within the next years, a state of active cooperative system control will be reached, in which cooperative systems advice or (partly) take over more and more driving tasks. To achieve this goal in an efficient and safe manner with predictable results, three Human Factors themes are addressed which are essential for the development of cooperative systems in the near future. These themes relate to behavioural models, adaptive HMI and evaluation and methodologies for assessments.

This article shows the need and necessity to study the effect of human factors in relation to cooperative systems. Only when human factors will be embedded in future cooperative systems, the most optimal utilization will be achieved with the maximum effect possible, with regard to traffic flow, traffic safety and air quality. Also, driver comfort and individual preferences need to be taken into account, such that successful cooperative systems are accepted by the road user. In addition, agreeing upon a common ground is vital to guarantee quality of cooperate systems and preclude errors of occurring. Only if the public sector, knowledge institutes and private companies work together towards one overall solution and create a common understanding, cooperate mobility will become successful. This is the idea of the Dutch Integrated Testsite for Cooperative Mobility

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