The Use of Persuasive In-Car Technology to Persuade Drivers at the Tactical Level

van Gent, Paul; Farah, Haneen; Nes, Nicole Van; van Arem, Bart

Publication date
2017

Document Version
Accepted author manuscript

Published in
Proceedings of the Road Safety and Simulation Conference

Citation (APA)
van Gent, P., Farah, H., Nes, N. V., & van Arem, B. (2017). The Use of Persuasive In-Car Technology to Persuade Drivers at the Tactical Level. In *Proceedings of the Road Safety and Simulation Conference: 17-19 October 2017, The Hague, Netherlands* Article 285

This paper will be published in: Proceedings of the Road Safety and Simulation Conference 2017
17-19 October 2017, The Hague, Netherlands

The Use of Persuasive In-Car Technology to Persuade Drivers at the Tactical Level

Paul van Gent[a], Haneen Farah[a], Nicole van Nes[b], Bart van Arem[a]

a. Department of Transport&Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology. Stevinweg 1, 2628CN Delft.

p.vangent@tudelft.nl; h.farah@tudelft.nl; B.vanArem@tudelft.nl

b. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV), Bezuidenhoutseweg 62, 2594AW Den Haag.

Nicole.van.nes@swov.nl

Abstract

The use of in-car technology has become more prevalent, both as driver assistance systems as well as connectivity or entertainment systems. Driver assistance systems can be built-in, after-market or run on a smartphone. The challenge however, is to increase drivers' compliance with these systems. Stimulating the driver to adopt certain behaviours over others is a growing area within driver assistance systems. These approaches have the potential to be very effective, but only when they attract or persuade road users to use it.

This study has two main aims. The first, is to provide a review of the different approaches in the literature to influence driver behaviour using in-car technology. The second aim is to develop a conceptual model to guide the research efforts on influencing driver behaviour at the tactical level.

A structured review was conducted exploring the literature available in the automotive, behavioural and traffic safety domains. First, we explored the available psychological models that describe behaviour and their applicability to the driving task. Following this, we investigated the methodological ways used to influence behaviour with a focus on the traffic domain. Finally, a conceptual model is presented which encompasses the behavioural basis, methods and techniques for influencing the behaviour using in-car technology and the strategic planning of behavioural change technology. The role of driver workload within the model is discussed. Possible applications using the composite model are discussed.

1. Introduction

1.1 The Problem and Scope

The way drivers interact with their cars is changing [1], [2]. Modern cars are more and more equipped with advanced driver assistance systems (ADAS) that can assist the driver, as well as in-vehicle information systems (IVIS) that provide the driver with information and advice. Increases in IVIS/ADAS systems mean the driving environment becomes more information rich, as more systems compete for a part of the driver's attention. While these systems increase safety, they also introduce new risks [3]. For example there is a risk that using such a system can lead to indirect behavioural adaptation (unwanted side-effects) [4]. Adding more systems to the car can negatively influence safety by overloading the driver or by causing distractions at inappropriate times [5].

In this study, we look at IVIS systems with the goal of persuading the driver to change his behaviour at the tactical level. These can for example include systems for lane-specific advice to improve traffic flow [6], [7] or systems that encourage eco-driving with the goal of reducing pollution [8]. For these systems, safety and persuasion are important. If the system negatively impacts driver safety, it should not be used in a traffic setting. Ensuring safety in this setting means considering driver variables such as driver workload and distraction, environmental variables such as proximity of other vehicles and weather conditions, as well as the possibility that behavioural adaptation may occur from using the system [4]. Similarly, if the persuasive system has little to no persuasive effect on the driver, it will not reach its design goals.

To be able to safely and effectively design a persuasive in-car system, we need a model to describe how techniques for behavioural influence affect driver behaviour at the tactical level, how to minimise the impact on safety and how to maximise behavioural outcomes. The main aim of this study is to develop a model to help design tactical-level persuasive in-car systems to ensure both safety and compliance.

First, we describe driver behaviour at the tactical level and present general requirements for an in-car persuasive system. Following this, we give an overview of the available behavioural models and select one for our model, then highlight the different persuasive approaches used in the literature and discuss how these approaches fit into the driving environment. Finally, we propose a conceptual model to structure the attempts to influence driver behaviour at the tactical level using persuasive in-car advice systems.

1.2 Driver Behaviour at the Tactical Level

Driver behaviour is often divided into three levels, the strategic, tactical and control levels [9]. The Strategic level pertains to high-level choices such as where to go and what route to take, and is generally constant over longer periods of time. At the tactical level, drivers decide upon and perform manoeuvres (i.e. change lane, take exit, overtake car) to reach their strategic goals. While, at the control level the driver performs actions to operate the vehicle (i.e. change gears, press accelerator pedal, turn on blinker).

Demands placed on the driver by tasks at the tactical level vary. If these demands exceed a driver's capability, then according to the Task-Capability Interface Model (TCI) by Fuller [10], this might lead to risky situations, such as loss of control or collision. A useful hierarchy of behaviour to understand driver demand at the tactical level comes from Rasmussen [11], who divides behaviour into knowledge-based, rule-based and skill-based levels. Skill-based behaviour is highly automatic and can be performed without much attentional demands, which is highly correlated to the control level. In rule-based behaviour, a response or set of responses is selected based on earlier learned rules, while the knowledge-based behaviour is applied in mostly unknown situations and requires most effort from the driver. Required attentional demands increase from skill-based to rule-based to knowledge-based behaviour. When influencing the behaviour at the tactical level of the driving task, the persuasive system should aim to act on the control and tactical level, and target either skill-based or rule-based behaviours, as changing behaviours at these levels imposes little extra workload on the driver [12]. For example, according to Fuller's Task-Capability Interface Model and Rasmussen's taxonomy, requesting a driver to reduce speed in response to traffic disturbances downstream (skill-based, control level) or requesting a lane change to make way for a busy on-ramp ahead (rule-based, tactical level) is not likely to increase demands placed on the driver by much. On the other hand, asking a driver to take a different route along a busy unknown road (strategic level, knowledge-based behaviour) is likely to place higher demands on the driver.

2. General Persuasive In-Car System Requirements

We argue that the two main requirements for a persuasive in-car system are that it does not infringe upon safety, and that it is effective in persuading the drivers. In this section, we discuss these two requirements.

2.1 Safety

The driving task is complex, requires constant attention from the driver [13] and presents frequent distractions. Stutts, J. and Gish, K. [14] report that drivers typically engaged in distracting activities 16.10% of the time the car was moving (31.42% if in-car conversations were included) [14]. In-car technology has the potential to add to this by increasing driver workload [15], distracting the driver [16] and potentially create unsafe situations. In the context of the TCI by Fuller [10], in a safe system the demands placed on the driver should not exceed the driver's capability. This requires considering driver variables such as driver workload, environmental variables such as proximity of other vehicles and weather conditions, as well as the possibility that behavioural adaptation may occur from using the system.

Driver workload is an important factor that influences the performance of drivers, as under- or overload can create hazardous situations [17]. The Multiple Resource Theory (MRT) by Wickens [18] can help understand when using an in-car system may lead to a high driver workload. In this theory, interference from a secondary task is most likely when it accesses the same resources as the primary task. Driving is mainly a visual task, diverting the eyes from the road for extended time has serious consequences for lane keeping ability [19]. If the demands of one or both tasks are high, two tasks that use different resources may still cause interference. Minimising the effect on workload therefore means choosing the correct modality to convey information to the driver, but also keeping the cognitive demands of interacting with the in-car system low to prevent interference with the main driving task. In this context driver workload is important. If the cognitive demands of the main task (driving) are already high, per the Multiple Resources Theory even a simple secondary task may create dual-task interference, degrading the performance on the main task and thereby potentially compromising driver safety. This is the rationale behind adaptive interfaces [12], [20]: by changing either the complexity of messages presented, the modality used to convey the message to the driver, or by suppressing messages in certain conditions, safety can be improved.

Unsafe situations can arise from using in-car systems. For example, a lane change advice system needs to take the environment into consideration when advising a lane change to ensure safety [21]. The driver may place too much trust in the system and change lane when the request is made, without checking whether a lane change is safe.

2.2 Persuasion

A persuasive in-car system needs to be able to consistently persuade the driver. This means using effective persuasive techniques. Apart from the persuasive techniques, the context in which the driver is persuaded is of importance as well. Persuasive interventions timed to periods when both the motivation and the ability of the driver to perform the target behaviour are high, have a higher chance of resulting in the driver complying [22]. An advice that is given to a driver when he/she is highly motivated will have a higher probability to be complied to. Similarly, an advice given at a time when the driver ability is high, i.e. he/she can follow the advice, will be more likely to result in the target behaviour when it is easy rather than when the target behaviour is difficult. This difficulty can be based on multiple factors and conditions, such as the weather conditions, traffic conditions, secondary tasks or driver state [23]. Driver workload needs to be considered for the effectiveness of persuasion as well as for safety. When driver workload is high, presenting an advice and requesting an action from the driver may increase the difficulty of the driving task further, in turn reducing the likelihood of the driver to comply to the system request. In this sense, we argue that a high workload may be counterproductive when trying to persuade the driver.

In addition to persuading a driver effectively, a persuasive system needs to be, and keep on being, used. To a large degree, this usage will depend on the acceptance of a system [24]. Without taking steps to ensure acceptance, there is the risk that a persuasive in-car system falls into disuse or works counterproductively [4]. This is especially damaging if the system relies on a user base to function, as for example with cooperative lane change systems [25]. To describe this acceptance of new technology several models have been developed, such as the Unified Theory of Acceptance and Use of Technology (UTAUT) [26] and the Technology Acceptance Model (TAM) [27], a detailed discussion of which is beyond the scope of this work.

3. Behavioural Models

In order to develop our persuasive model, we needed a behavioural model capable of describing the effects of persuasion on driver behaviour at the tactical level. We have searched the literature for behavioural models that have been used in connection with behavioural change. The search engines used were Google Scholar, Scopus and Web of Science, with the keywords: "behaviour* model AND behaviour* change OR persuasi*". We limited the results to papers of 2005 and newer. Backward snowballing was performed to find the original papers proposing the models. This led to the Social Learning Theory (SLT) [28], Self-Determination Theory (SDT) [29], the Trans-Theoretical Model [30] and the Theory of Planned Behaviour (TPB) [31]. For each model, we reviewed their applicability to the driving task, ability to explain the relatively short-term changes in behavioural patterns resulting from persuasion at the tactical level, longer term attitudes towards the use of the system, as well as the ability to accommodate the effects of persuasive efforts.

We have found that only the TPB can explain both short-term behaviour in a way that is meaningful in the tactical level in the driving setting, as well as the long-term social and attitudinal factors acting on behavioural patterns that are relevant when explaining continued in-vehicle system use. The TPB describes how persuasive efforts might affect behaviour (see 5.3). The other models were either geared more towards changing long-term

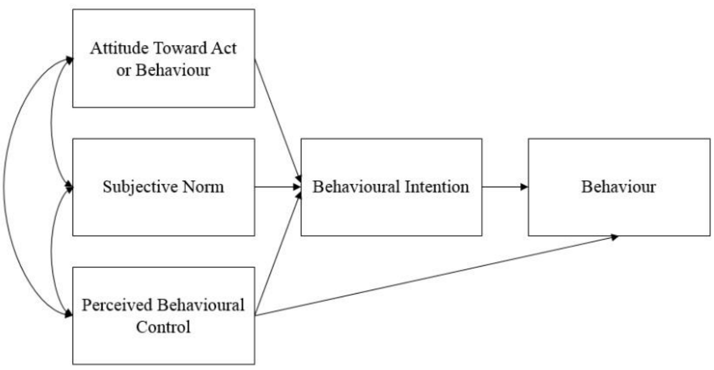

Figure 1: The Theory of Planned Behaviour

behavioural patterns (SLT, SDT), describing behaviour at a macro level (SDT, TTM), or describing (changing) behaviour in clinical settings (SDT, TTM).

More in detail, the TPB posits that behaviour is directly predicted by two factors: 'Behavioural Intention' (BI) and 'Perceived Behavioural Control' (PBC). PBC reflects the degree to which the individual perceives to have volitional control over the behaviour. In other words, whether the individual believes they are able to successfully perform the target behaviour. PBC directly influences behaviour as well as the intention to perform a behaviour. In some studies, PBC has been split into self-efficacy (perceived ability to perform target behaviour) and perceived controllability [32] (perceptions about whether the person has control over the behaviour or outcomes), with only the self-efficacy component being related to changes in BI and behaviour. This indicates that PBC is more closely related to 'ability' from the Fogg Behavioral Model (see 4.1), rather than to a locus-of-control type of evaluation. BI is predicted by 'Attitude Towards Behaviour', 'Subjective Norms' regarding the behaviour and PBC. The attitude towards the behaviour represents how the behaviour is appraised not only in terms of the act, but also in relation to the possible outcomes of displaying the behaviour, such as rewards or the averting of negative consequences. The subjective norms refer to how displaying the behaviour is evaluated by the social network around the individual, and how displaying the behaviour might affect social relationships.

4. Methods of Influencing Behaviour

In this section, we describe the methods for eliciting behavioural change with persuasive technology. We searched the literature for persuasive methods that were used or have the potential to be used in the traffic domain. The different methods we found often overlap in the persuasive elements used. In this section, we discuss these persuasive methods, and motivate our choice for the method to be adopted in this study for developing the conceptual model.

4.1 Persuasive methods

After surveying the literature, we found several methods. These can broadly be divided into Gamification, Behavioural Economics and the Fogg Behavioural Model.

Gamification is a term that has emerged relatively recently. Video games create an environment in which the player is highly motivated to perform certain behaviours to achieve game-related goals (finishing a level, getting a high score). Gamification is about taking the elements that elicit this motivational behaviour and applying them to other situations [33]. The most often and successfully applied game design elements are leader boards, achievements and challenges [34]. A quite extensive review of previous studies found that generally the effects of gamification are positive, although this is moderated by the context in which gamification is used as well as the users that are targeted [34]. Examples from the traffic literature include EcoChallenge [8]: a reward and competition-based system to persuade drivers to engage in a more eco-friendly behaviour, I-GEAR [35]: a system to change driver behaviour by providing small financial and non-financial rewards, and 'Driving Miss Daisy' [36]: a gamified solution to help drivers improve their driving skills by providing a virtual passenger.

Behavioural economics has been defined as the 'body of work seeking to understand behaviour by incorporating insights from behavioural sciences into economics' [37]. Rather than being rational thinkers [38], people use a range of heuristics and display biases that often work well, but also can lead to reasoning errors. An overview can be found in the work of Kahneman [39]. Examples of persuasive elements from Behavioural Economics applied to persuasive context can be found in for example the design of travel information systems [40], promoting safe driving behaviours [41] and analysing travel behaviour [42].

The Fogg Behaviour Model (FBM) [22], which is also geared towards behavioural influence, postulates that in order for a behavioural intervention to be successful, three factors need to converge. The person needs to be able to perform the behaviour, be motivated to perform the behaviour, and finally a trigger should be present to trigger the actual behaviour. The model is mostly applied in persuasive technology in fields such as health [43] and energy consumption behaviour [44], but is suitable to explain the environmental factors important for driver persuasion applications.

4.2 Connecting Persuasive Methods

Oinas-Kukkonen & Harjumaa present a systematic framework for designing and evaluating persuasive systems in the Persuasive Systems Design model (PSD) [45]. It brings concepts from gamification, behavioural economics and the Fogg Behavioural Model together. It states that a system can be made persuasive by providing the user with support of distinct categories: primary task support, dialogue support, system credibility support and social support. Here we will give brief overview of the support levels and how these broadly tie into concepts of discussed persuasive methods.

Primary task support shows many of the principles put forth by the Fogg Behavioural Model and Behavioural Economics. The focus here is to support the user by making the behavioural tasks more manageable, personal and transparent. Making the tasks more manageable by reducing complex behaviour to a series of steps and then leading the user through them is especially important for in-car systems. Apart from increasing the system's persuasive power, this approach also has the potential to reduce task demand on the driver, which increases system safety [10], [18]. An example of primary task support can be a lane change system that guides the driver through the steps of making room and merging.

Dialogue support is aimed at keeping users moving towards goals. This support level contains elements from Gamification, Behavioural Economics and the Fogg Behavioural Model. Offering praise and rewards can increase motivation, which is an important factor for persuasion in the Fogg Behavioural Model [22]. Providing reminders for target behaviour or suggesting behaviours may be a way to increase compliance rate. Further important factors are similarity and liking [46], which works to increase trust and intentions to comply to system requests.

System credibility support is mainly important from the perspective of trust. It is about showing the driver that the system makes correct decisions or recommendations. Trust is a major factor in whether a persuasive system's suggestions or advices will be considered by the driver [7]. Factors here relate to the accuracy of the information presented, its transparency and how users evaluate it. The need for trust in a persuasive system is underscored by the work of Risto [7], who reported that drivers constantly tried to verify the accuracy of system requests before following them.

Social support is about persuading users by increasing motivation using social factors. This level has parallels with Gamification. It includes factors to incentivise behavioural change by allowing performance comparison with other users, facilitating cooperation and/or competition, creating transparency in behaviour-result relationships of other users and even applying forms of normative social pressure.

To summarise, Gamification has been shown to be quite effective in motivating people to change their behaviour, however, some studies report that its effectiveness could reduce over time. Behavioural Economics as a field has many applicable concepts, and the Fogg Behavioural Model presents a view of how driver motivation and ability need to converge in the presence of a trigger for persuasive influence to be effective. The PSD model unifies these persuasive methods using the described four support groupings. These provide different avenues of persuasion that can be used depending on the type of system and the context in which the system works. For example, for a cooperative system 'Social support' provides ways to use social aspects of the system in a persuasive way, whereas in a lane-change system primary task support can help the improve persuasion and safety by breaking a requested lane change down into steps. In both contexts, system credibility can persuade the driver by increasing their trust in the validity of the messages, which has been shown to be a large factor in whether a driver follows the advice or not [7].

5. A Model for Influencing Tactical Driver Behaviour

In this section, we present the proposed model for driver persuasion at the tactical level using in-car systems. The model has three levels: The System Level, the Information Transfer Level and the Driver Level. The System Level is where the persuasive strategy is formed and safety checks are performed. It incorporates the defined safety criteria and the four support levels from the Persuasive Systems Design model discussed earlier. The Information Transfer Level is where communication with the driver takes place, and incorporates elements from Wickens' MRT and Fuller's TCI Model. The Driver Level describes the behavioural effects of the persuasive attempt. It incorporates the TPB (2.2), along with considerations regarding effects on driver workload, indirect behavioural effects and driver safety (4.1, 4.2). The following sub-sections explain these levels and how they are built up from the existing models and theories in the literature.

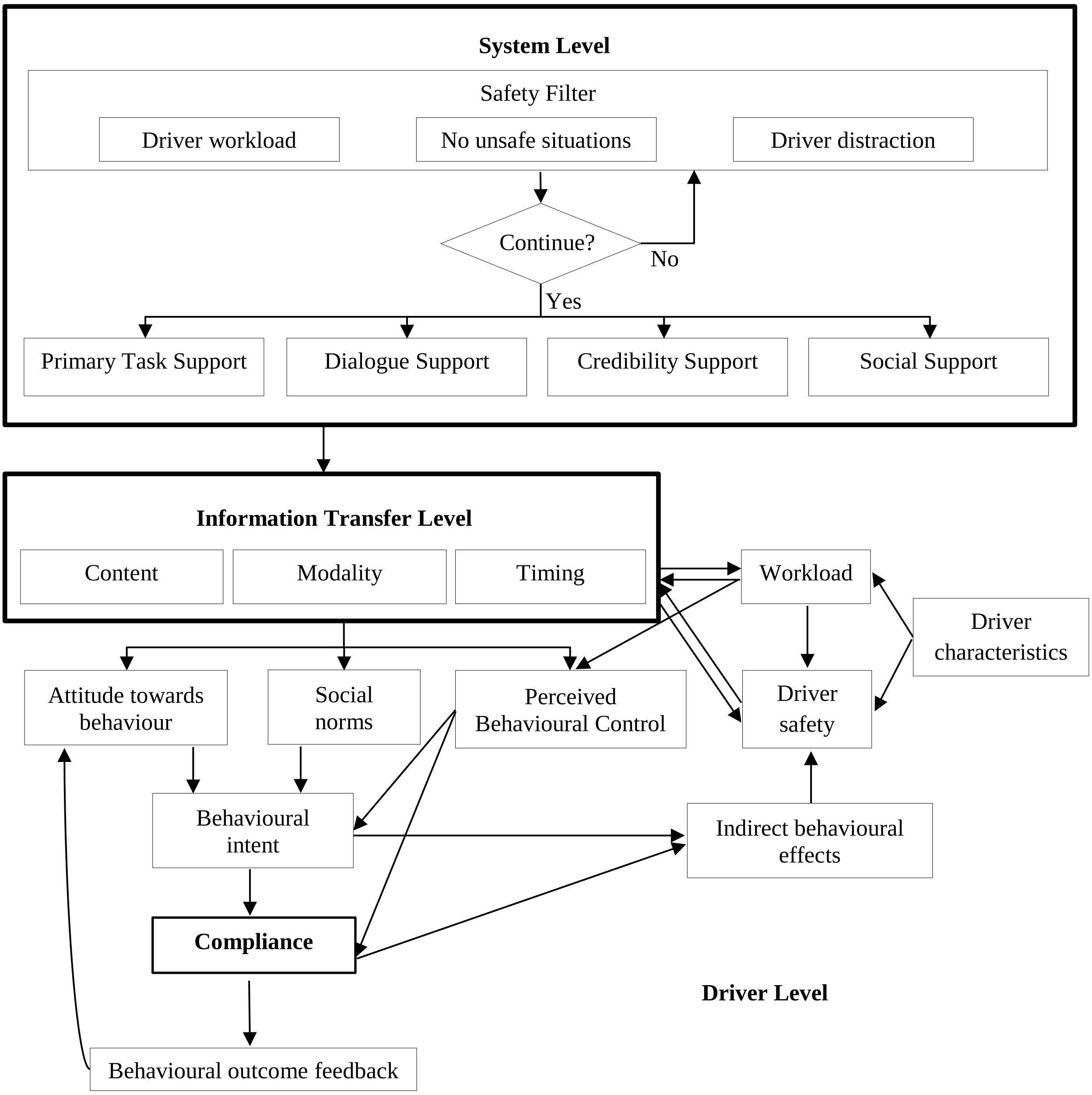

Figure 2: Proposed model for influencing tactical driver behaviour

5.1 Planning Driver Persuasion: The System Level

The System Level represents the back-end of the persuasive in-car system. It is built up from the PSD model (section 4.2) and the considerations of driver safety and the persuasiveness (section 2).

Safety should be central to the persuasive system design and operation, as outlined in 2.1. This is explicitly reflected in the model, where the first evaluation made is whether it is safe to initiate an information transfer to the driver. Ideally, the persuasive system should (either directly or indirectly) take driver workload into account, should not create unsafe traffic situations and should not distract the driver at the wrong time. Only then can an attempt to persuade the driver be made with a high likelihood of being safe (see 2.1). In situations where safety criteria are not met, they can be re-evaluated until they are met, represented in the model by the conditional loop. These safety criteria can be evaluated directly, such as in systems that monitor on-coming traffic [47] or weather conditions [48], or indirectly, such as in systems that try to estimate driver state [49], [50].

Once it is determined that interacting with the driver does not pose a safety risk, tactical driver advice may be given to persuade the driver. The PSD described earlier combines persuasive techniques into four support levels. These four levels of support are included as possible routes to persuasion (see also [45], [51], 4.2). We do not provide guidelines to which persuasive elements should be picked, as this is dependent on the system type and the situations where the driver will be persuaded.

5.2 Interacting with the Driver: The Interface Level

The information transfer level is where the communication between the persuasive system and the driver takes place. Usually this is through a type of interface (visual, auditory, tactile or multimodal). The information transfer level and its effects on behaviour (driver level, 5.3) are built up from the TPB, MRT, TCI and FBM discussed in the previous sections. The information transfer itself is operationalised as having 'content' (what's in the message?), 'modality' (how is it transmitted to the driver?) and 'timing' (when is it transmitted?) as key factors. In the model, the information transfer influences workload, driver safety and the behavioural determinants of the TPB (attitude, social norms and perceived behavioural control). Here we discuss these effects in terms of the impact on safety and the impact on persuasive potential.

From a safety perspective, the model shows an effect of the information transfer on 'workload' and 'perceived behavioural control' based on the TPB, MRT and TCI. Remember that according to the MRT, dual-task interference is likely when two concurrent tasks use the same modality, or when the cognitive load from one or both tasks is high. Dual-task interference reduces performance on the main (driving) task and increases demands placed on the driver, which in turn can raise workload. As demands and workload rise, the perceived behavioural control of the driver reduces: the higher the driver workload, the more difficult it will be to pay attention to or comply with persuasive messages. These effects are crucial, since they can lead to persuasion being ineffective, a degradation of driver performance, or even undesirable situations such as a loss of control or a collision (TCI, see also 2.1, 5.3). A direct link to driver safety is also included, which includes for example situations where the information transfer leads to eyes-off-road situations [19], [52] or to distraction at a critical moment.

From the persuasion perspective, the FBM [22] specifies that motivation and ability need to be high at the moment of a behavioural trigger, in order for persuasion to have a high chance of being successful. The goal of the persuasive techniques used ('content') is to raise motivation to perform a behaviour, for instance by using social support to increase motivation to comply to a message. Making sure 'ability' is high, essentially means timing the information transfer to situations where the driver's PBC is high [32] (see also 5.3). In a driving setting, the PBC term implicitly includes an environmental component (e.g. give a lane change request only when there is sufficient room on the adjacent lane), and a driver component (a high workload will result in lower PBC). Both are important for persuasion and safety: when a driver does not feel capable of performing the requested behaviour, it is unlikely the persuasion will have an effect. Alternatively, should an already overloaded driver attempt the requested behaviour, this may have a detrimental effect on safety.

5.3 Human Factors: The Driver Level

The driver level provides a basis to describe expected behavioural effects of the persuasion. In this section, we describe how the TPB fits into the model, how workload relates to both safety and persuasion, its dependence on driver characteristics and factors on the information transfer level, possible behavioural effects and the importance of outcome feedback.

We argued both motivation and ability need to be high in order for persuasive technology to actually persuade [22]. In the conceptual model, motivation is captured by the TPB terms 'attitude towards behaviour' and 'social norms', and ability is captured by 'perceived behavioural control' (PBC). The attitude and social norms influence driver behaviour through the 'behavioural intent' (BI) [31], [53], [54]. PBC affects both BI and the actual behaviour [53], [54]. Additionally, PBC acts as a modulator of workload on behaviour. As discussed in 2.2, PBC relates to the perceived ability a person has to perform a given behaviour, rather than a locus of control-like evaluation of whether the behaviour lies within the control of the individual (see also Elliott et al., 2013). The relationship between workload and behavioural outcomes is inversed: a high PBC means a driver feels competent and able to perform a requested behaviour, whereas a low PBC will negatively influence the likelihood of a behavioural result occurring.

Apart from the information transfer (5.2), driver workload is also affected by 'driver characteristics'. Driver ability is not static and varies between and within individuals over time [55], which may cause workload experienced by two different drivers or a single driver in two comparable situations to be very different. 'Driver characteristics' also includes differences in inherent driver safety, for example some age groups display more risky behaviour [56], there may be sex differences or geographical differences in driver behaviour and capability [57], [58], or individual differences in driver aggression [59]. These characteristics may result in some classes of drivers being exposed to higher risk while driving.

'Indirect behavioural effects' (Martens & Jenssen, 2012) we discussed in 2.2, meaning changes in driver behaviour or intentions to perform behaviours that are not intended by the designers of the (persuasive) system. An often-cited example of indirect behavioural effects is that of the anti-lock braking system (ABS), which helps reduce stopping distances of the cars in which it is installed. Positive effects were offset by behavioural effects: adaptation was reported from drivers choosing to driver faster on wet surfaces [60] or with shorter headway and varying seatbelt usage [61].

The last undiscussed term in the model is feedback about behavioural outcomes. This feedback, including information on the behaviour-result relationships in other drivers, is expected to influence the driver's attitude towards future behaviours in a feedback loop (see also [25]). For instance, if a driver observes that complying to an in-car system has resulted in shorter travel times on previous occasions or with other drivers, this might bias the driver to comply more with the system's advices in the future. This ties into the "system credibility support" level of the PSD [45]. It is also in line with an earlier study into compliance to tactical driving advice [7], where drivers were observed attempting to evaluate the validity of tactical advice in the context of what they observed on the road and the history of the system's accuracy.

6. Conclusion and Discussion

In this paper, we have proposed a model to help guide the design of persuasive in-car systems with the aim of influencing driver behaviour at the tactical level. We have surveyed the literature on behavioural models and on methods of influencing behaviour, mainly used or that have the potential to be used in the traffic domain.

The proposed model is split into three levels explaining the different elements of the information chain: the system level where the persuasive advice is generated, the interface level where it is communicated to the driver and the driver level where the act of presenting advice changes driver behaviour in several ways. The focus while designing the model was on safety and persuasive effects. The behavioural basis is the Theory of Planned Behaviour. The persuasive elements come from the Persuasive Systems Design model, which itself contains many elements from Gamification, Behavioural Economics and the Fogg Behavioural Model. We have also included elements from Wickens' Task-Capability Inferace Model and Fuller's Mutltiple-Resource Theory that help explain why the timing and modality of the interface are key factors in both persuasive effectiveness and safety management.

Persuading drivers is complex, especially since the driving environment requires extra considerations in terms of safety and because the demands the environment places on the driver are highly dynamic.

Acknowledgements

This research was performed in the Taking the Fast Lane project, which was funded by "Applied and Technical Sciences" (TTW), which is a subdomain of the Dutch Institute for Scientific Research ('NWO').

References

[1] S. Damiani, E. Deregibus, and L. Andreone, "Driver-vehicle interfaces and interaction: Where are they going?," *Eur. Transp. Res. Rev.*, vol. 1, no. 2, pp. 87–96, 2009.
[2] T. A. Ulrich, Z. Spielman, J. Holmberg, C. Hoover, N. Sanders, K. Gohil, and S. Werner, "Playing Charades With Your Car - The Potential of Free-form and Contact-based Gestural Interfaces for Human Vehicle Interaction," *Proc. Hum. Factors Ergon. Soc. Annu. Meet.*, vol. 57, no. 1, pp. 1643–1647, 2013.
[3] N. van Nes and K. Duivenvoorden, "Safely towards self-driving vehicles," 2017.
[4] M. H. Martens and G. D. Jenssen, "Behavioral Adaptation and Acceptance," in *Handbook of Intelligent Vehicles*, A. Eskandarian, Ed. London: Springer-Verlag London Ltd., 2012, pp. 117–138.
[5] M. L. Reyes and J. D. Lee, "The Influence of IVIS Distractions on Tactical and Control Levels of Driving Performance," *Proc. Hum. Factors Ergon. Soc. Annu. Meet.*, vol. 48, no. September 2004, pp. 2369–2373, 2004.
[6] W. J. Schakel and B. Van Arem, "Improving traffic flow efficiency by in-car advice on lane, speed, and Headway," *IEEE Trans. Intell. Transp. Syst.*, vol. 15, no. 4, pp. 1597–1606, 2014.
[7] M. Risto and M. H. Martens, "Factors Influencing Compliance to Tactical Driver Advice: An Assessment Using a Think-Aloud Protocol," *Proc. 16th Int. IEEE Annu. Conf. Intell. Transp. Syst. (ITSC 2013)*, pp. 1923–1928, 2013.
[8] R. Ecker, P. Holzer, V. Broy, and A. Butz, "Ecochallenge: a race for efficiency," *Proc. 13th Int. Conf. multimodal interfaces - ICMI '11*, vol. 13, pp. 91–94, 2011.
[9] L. Evans and J. A. Michon, "A critical view of driver behavior models: what do we know, what should we do?," in *Human behavior and traffic safety*, L. Evans and J. A. Michon, Eds. New York: Plenum Press, 1985, pp. 485–520.
[10] R. Fuller, "Towards a general theory of driver behaviour.," *Accid. Anal. Prev.*, vol. 37, no. 3, pp. 461–72, May 2005.
[11] J. Rasmussen, "Skills, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models," *IEEE Trans. Syst. Man. Cybern.*, vol. 13, no. 3, pp. 257–266, 1983.
[12] S. Birrel, M. Young, N. Staton, and P. Jennings, "Using Adaptive Interfaces to Encourage Smart Driving and Their Effect on Driver Workload," vol. 484, p. 764, 2017.
[13] D. de Waard, *The Measurement of Drivers ' Mental Workload*. Alphen aan den Rijn: Drukkerij Haasbeek, 1996.
[14] J. Stutts and K. Gish, "Distraction in Everyday Driving," 2003.
[15] T. Horberry, J. Anderson, M. a. Regan, T. J. Triggs, and J. Brown, "Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance," *Accid. Anal. Prev.*, vol. 38, no. 1, pp. 185–191, 2006.
[16] D. L. Hibberd, S. L. Jamson, and O. M. J. Carsten, "Managing in-vehicle distractions," *Proc. 2nd Int. Conf. Automot. User Interfaces Interact. Veh. Appl. - AutomotiveUI '10*, vol. 2, pp. 4–11, 2010.
[17] M. S. Young, K. a Brookhuis, C. D. Wickens, and P. a Hancock, "State of science: mental workload in ergonomics.," *Ergonomics*, vol. 139, no. January 2015, pp. 1–17, 2014.
[18] C. D. Wickens, "Multiple resources and performance prediction," *Theor. Issues Ergon. Sci.*, vol. 3, no. 2, pp. 159–177, 2002.
[19] Y. Peng, L. N. Boyle, and S. L. Hallmark, "Driver's lane keeping ability with eyes off road: Insights from a naturalistic study," *Accid. Anal. Prev.*, vol. 50, pp. 628–634, 2013.
[20] H. S. Park and K. H. Kim, "Adaptive multimodal in-vehicle information system for safe driving," *ETRI J.*, vol. 37, no. 3, pp. 626–636, 2015.
[21] M. Roelofsen, J. Bie, L. Jin, and B. Van Arem, "Assessment of safety levels and an innovative design for the lane change assistant," *IEEE Intell. Veh. Symp. Proc.*, pp. 83–88, 2010.
[22] B. J. Fogg, "A behavior model for persuasive design," *Proc. 4th Int. Conf. Persuas. Technol. - Persuas. '09*, p. 1, 2009.
[23] D. de Waard, A. Kruizinga, and K. A. Brookhuis, "The consequences of an increase in heavy goods vehicles for passenger car drivers' mental workload and behaviour: A simulator study," *Accid. Anal. Prev.*, vol. 40, no. 2, pp. 818–828, 2008.
[24] S. Vlassenroot, K. Brookhuis, V. Marchau, and F. Witlox, "Towards defining a unified concept for the acceptability of Intelligent Transport Systems (ITS): A conceptual analysis based on the case of Intelligent Speed Adaptation (ISA)," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 13, no. 3, pp. 164–178, 2010.
[25] N. Lütteken, M. Zimmermann, and K. J. Bengler, "Using gamification to motivate human cooperation in a lane-change scenario," *IEEE Conf. Intell. Transp. Syst. Proceedings, ITSC*, pp. 899–906, 2016.
[26] V. Venkatesh, M. G. Morris, G. B. Davis, and F. D. Davis, "User Acceptance of Information Technology: Toward a Unified View," *MIS Q.*, vol. 27, no. 3, pp. 425–478, 2003.
[27] F. D. Davis, "A technology acceptance model for empirically testing new end-user information systems: Theory and results," 1986.
[28] A. Bandura, "Social learning theory," *Social Learning Theory*. pp. 1–46, 1971.
[29] E. L. Deci and R. M. Ryan, *Intrinsic Motivation and Self-determination in Human Behavior*. New York: Plenum, 1985.
[30] J. C. Norcross, P. M. Krebs, and J. O. Prochaska, "Stages of change," *J. Clin. Psychol.*, vol. 67, no. 2, pp. 143–154, 2011.
[31] I. Ajzen, "The theory of planned behavior," *Orgnizational Behav. Hum. Decis. Process.*, vol. 50, pp. 179–211, 1991.
[32] M. Elliott, J. Thomson, K. Robertson, C. Stephenson, and J. Wicks, "Evidence that changes in social cognitions predict changes in self-reported driver behavior: Causal analyses of two-wave panel data," *Accid. Anal. Prev.*, vol. 50, pp. 905–916, 2013.
[33] S. Deterding, D. Dixon, R. Khaled, and L. Nacke, "From Game Design Elements to Gamefulness: Defining 'Gamification,'" *Proc. 15th Int. Acad. MindTrek Conf. Envisioning Futur. Media Environ. - MindTrek '11*, pp. 9–11, 2011.

[34] J. Hamari, J. Koivisto, and H. Sarsa, “Does gamification work? - A literature review of empirical studies on gamification,” in *Proceedings of the Annual Hawaii International Conference on System Sciences*, 2014, pp. 3025–3034.

[35] R. McCall and V. Koenig, “Gaming concepts and incentives to change driver behaviour,” *2012 11th Annu. Mediterr. Ad Hoc Netw. Work. Med-Hoc-Net 2012*, pp. 146–151, 2012.

[36] C. Shi, H. J. Lee, J. Kurczak, and A. Lee, “Routine Driving Infotainment App: Gamification of Performance Driving,” *Proc. 4th Int. Conf. Automot. User Interfaces Interact. Veh. Appl.*, pp. 181–183, 2012.

[37] E. Avineri, K. Chatterjee, A. Darnton, P. Goodwin, G. Lyons, C. Musselwhite, P. Pilkington, G. Rayner, A. Tapp, E. Owen, D. Waygood, and P. Wiltshire, “Individual Behaviour Change : Evidence in transport and public health,” 2010.

[38] D. Kahneman, “Maps of Bounded Rationality : Economicst Psychology for Behavioral,” *Am. Econ. Rev.*, vol. 93, no. 5, pp. 1449–1475, 2003.

[39] D. Kahneman, *Thinking Fast and Slow*. Penguin Books Ltd., 2013.

[40] E. Avineri, “Applying behavioural economics in the design of travel information systems,” *43rd Univ. Transp. Study Gr. Conf.*, pp. 1–12, 2011.

[41] M. G. Millar and K. U. Millar, “Promoting Safe Driving Behaviors: The Influence of Message Framing and Issue Involvement,” *J. Appl. Soc. Psychol.*, vol. 30, no. 4, pp. 853–866, 2000.

[42] R. Metcalfe and P. Dolan, “Behavioural economics and its implications for transport,” *J. Transp. Geogr.*, vol. 24, pp. 503–511, 2012.

[43] L. Kroes and S. Shahid, “Empowering young adolescents to choose the healthy lifestyle: A persuasive intervention using mobile phones,” in *Human-Computer Interaction*, Berlin Heidelberg: Springer-Verlag Berling Heidelberg, 2013, pp. 117–126.

[44] V. Sugarman and E. Lank, “Designing Persuasive Technology to Manage Peak Electricity Demand in Ontario Homes,” *Proc. 33rd Annu. ACM Conf. Hum. Factors Comput. Syst. - CHI ’15*, pp. 1975–1984, 2015.

[45] H. Oinas-Kukkonen and M. Harjumaa, “A Systematic Framework for Designing and Evaluating Persuasive Systems,” *Persuas. Technol. Third Int. Conf. Persuas. 2008, Oulu, Finland, June 4-6, 2008. Proc.*, vol. 5033, pp. 164–176, 2008.

[46] B. J. Fogg, *Persuasive Technology: Using computers to change what we think and do*. Elsevier Science & Technology, 2010.

[47] R. Curry, M. Blommer, L. Tijerina, J. Greenberg, D. Kochhar, C. Simonds, and D. Watson, “A mental model perspective of a driver workload system,” *Proc. Hum. Factors Ergon. Soc.*, vol. 3, pp. 2096–2100, 2010.

[48] P. Green, “Driver distraction , telematics design , and workload managers : safety issues and solutions,” *Proc. Int. Congr. Transp. Electron*, pp. 165–180, 2004.

[49] E. Ferreira, D. Ferreira, S. Kim, P. Siirtola, J. Röning, J. F. Forlizzi, and A. K. Dey, “Assessing real-time cognitive load based on psycho- physiological measures for younger and older adults,” in *Computational Intelligence, Cognitive Algorithms, mind, and Brain (CCMB)*, 2014.

[50] Y. Liang, M. L. Reyes, and J. D. Lee, “Real-time detection of driver cognitive distraction using support vector machines,” *IEEE Trans. Intell. Transp. Syst.*, vol. 8, no. 2, pp. 340–350, 2007.

[51] H. Oinas-kukkonen and M. Harjumaa, “Persuasive Systems Design : Key Issues , Process Model , and System Features Persuasive Systems Design : Key Issues , Process Model , and System Features,” *Commun. Assoc. Inf. Syst.*, vol. 24, no. 1, 2009.

[52] M. Dozza, “What factors influence drivers’ response time for evasive maneuvers in real traffic?,” *Accid. Anal. Prev.*, vol. 58, pp. 299–308, 2013.

[53] R. R. C. McEachan, M. Conner, N. J. Taylor, and R. J. Lawton, “Prospective prediction of health-related behaviours with the Theory of Planned Behaviour: a meta-analysis,” *Health Psychol. Rev.*, vol. 5, no. 2, pp. 97–144, 2011.

[54] C. J. Armitage and M. Conner, “Efficacy of the Theory of Planned Behaviour : A meta-analytic review,” *Br. J. Soc. Psychol.*, no. 40, pp. 471–499, 2001.

[55] M. S. Young, K. A. Brookhuis, C. D. Wickens, and P. A. Hancock, “State of science: mental workload in ergonomics,” in *Ergonomics*, vol. 58, no. 1, 2015, pp. 1–17.

[56] P. M. Carter, C. R. Bingham, J. S. Zakrajsek, J. T. Shope, and T. B. Sayer, “Social norms and risk perception: Predictors of distracted driving behavior among novice adolescent drivers,” *J. Adolesc. Heal.*, vol. 54, no. 5, pp. S32–S41, 2014.

[57] D. Twisk and C. Stacey, “Trends in young driver risk and countermeasures in European countries,” *J. Safety Res.*, vol. 38, pp. 245–257, 2007.

[58] W. Vlakveld, *Hazard anticipation of young novice drivers*. SWOV Institute for Road Safety Research, 2011.

[59] D. A. Hennessy and D. L. Wiesenthal, “Gender, driver aggression, and driver violence: An applied evaluation,” *Sex Roles*, vol. 44, no. 11–12, pp. 661–676, 2001.

[60] A. Smiley, “Behavioral adaptation, safety, and intelligent transportation systems,” *Transp. Res. Rec.*, no. 1724, pp. 47–51, 2000.

[61] F. Sagberg, S. Fosser, and I. A. F. Sætermo, “An investigation of behavioural adaptation to airbags and antilock brakes among taxi drivers,” *Accid. Anal. Prev.*, vol. 29, no. 3, pp. 293–302, 1997.