A Conceptual Model for Persuasive In-Vehicle Technology to Influence Tactical Level Driver Behaviour

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

DOI
10.1016/j.trf.2018.10.004

Publication date
2019

Document Version
Final published version

Published in
Transportation Research. Part F: Traffic Psychology and Behaviour

Citation (APA)
van Gent, P., Farah, H., Nes, N. V., & van Arem, B. (2019). A Conceptual Model for Persuasive In-Vehicle Technology to Influence Tactical Level Driver Behaviour. Transportation Research. Part F: Traffic Psychology and Behaviour, 60, 202-216. https://doi.org/10.1016/j.trf.2018.10.004

Transportation Research Part F 60 (2019) 202–216

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

A conceptual model for persuasive in-vehicle technology to influence tactical level driver behaviour

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, 2628 CN Delft, the Netherlands
[b] Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV), Bezuidenhoutseweg 62, 2594 AW Den Haag, the Netherlands

ARTICLE INFO

Article history:
Received 26 September 2017
Received in revised form 20 September 2018
Accepted 11 October 2018
Available online 2 November 2018

Keywords:
driver persuasion
human factors
persuasive technology
in-vehicle information systems
IVIS

ABSTRACT

Persuasive in-vehicle systems aim to intuitively influence the attitudes and/or behaviour of a driver (i.e. without forcing them). However, the challenge in using these systems in a driving setting, is to maximise the persuasive effect without infringing upon the driver's safety.

This paper proposes a conceptual model for driver persuasion at the tactical level (i.e., driver manoeuvring level, such as lane-changing and car-following). The main focus of the conceptual model is to describe how to safely persuade a driver to change his or her behaviour, and how persuasive systems may affect driver behaviour.

First, existing conceptual and theoretical models that describe behaviour are discussed, along with their applicability to the driving task. Next, we investigate the persuasive methods used with a focus on the traffic domain. Based on this we develop a conceptual model that incorporates behavioural theories and persuasive methods, and which describes how effective and safe driver persuasion functions. Finally, we apply the model to a case study of a lane-specific advice system that aims to reduce travel time delay and traffic congestion by advising some drivers to change lanes in order to achieve a better distribution of traffic over the motorway lanes.

1. Introduction

1.1. The problem and scope

The way drivers interact with their vehicles is changing (Damiani, Deregibus, & Andreone, 2009; Ulrich et al., 2013). Modern vehicles 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 traffic information or driving advice. Increases in IVIS/ADAS in-vehicle systems mean that the driving environment becomes more information rich, and more systems compete for the driver's attention.

One field of development within IVIS is that of persuasive systems. Persuasive systems employ techniques or incentives to change drivers' voluntary attitudes or behaviours (Fogg, 2010). The implementation of such persuasive systems in the driving environment can for example help reduce speeding and improve driver engagement during monotonous driving

* Corresponding author.
E-mail addresses: p.vangent@tudelft.nl (P. van Gent), h.farah@tudelft.nl (H. Farah), Nicole.van.nes@swov.nl (N. van Nes), B.vanArem@tudelft.nl (B. van Arem).

https://doi.org/10.1016/j.trf.2018.10.004
1369-8478/

(Steinberger, Proppe, Schroeter, & Alt, 2016). Persuasive systems have also been used to encourage drivers to adopt a more eco-friendly driving style (Ecker, Holzer, Broy, & Butz, 2011), or a safer driving style (Shi, Lee, Kurczak, & Lee, 2012).

While persuasive systems can positively influence driver behaviour and increase safety, they might also introduce new risks (van Nes & Duivenvoorden, 2017). For example, the use of these systems can lead to indirect behavioural adaptations (unwanted and unplanned side-effects) (Martens & Jenssen, 2012), such as the anti-lock braking system (ABS) which when implemented led drivers to maintain shorter headways (Sagberg, Fosser, & Sætermo, 1997). Additionally, increasing the number of in-vehicle systems can negatively influence traffic safety by overloading or distracting the driver at inappropriate times (Reyes & Lee, 2004; Young, Brookhuis, Wickens, & Hancock, 2015).

To our knowledge, a conceptual model tying driver persuasion to safety and behavioural outcomes has not been developed yet. In this study, we aim to fill this research gap by developing a conceptual model that describes the effects of in-vehicle persuasive systems on driver behaviour, with the goal of effectively and safely persuading the driver. We will focus specifically on IVIS systems aiming at persuading drivers to change their behaviour at the tactical level. Examples of such systems include lane-specific advice to improve traffic flow (Risto & Martens, 2013; Schakel & Van Arem, 2014), and systems that encourage eco-driving with the goal of reducing pollution (Ecker et al., 2011).

1.2. Context of the developed framework

The framework was developed in the context of a lane-specific advice system. The goal of this system is to reduce travel time delay and congestion by encouraging a better distribution of the vehicles over the available motorway lanes. This means advising drivers on which lane to take, depending on external factors. For instance, an unbalanced distribution, an upcoming on-ramp or lane drop, or an incident upstream may require a redistribution of traffic to ensure continued flow and avoid congestion. Because the system focuses on optimising traffic flow of a road segment, the generated advices will be in the collective benefit of drivers on the specific stretch of the road in terms of minimising the total travel time. This means the advices might not be in the benefit of individual drivers receiving the advice (e.g. ‘stay behind this slow truck for now’), creating a potential problem of drivers not complying with these messages (Risto & Martens, 2012). We incorporated persuasive strategies into the framework to engage drivers with the system and to also stimulate adherence to lane-specific advices, especially when they are not in the driver’s own benefit. The goal of the applied persuasive techniques, is to make the advices attractive enough and convince drivers to follow them. Various ways of accomplishing this are discussed in Section 3.

We apply the model to the design of our lane-specific advice system, as described in Section 6 of this paper. The developed model can be applied in a broader sense, for example to cooperative driving systems that require drivers to behave in a certain way (Lütteken, Zimmermann, & Bengler, 2016; Risto, 2014), eco-driving systems (Ecker et al., 2011; Magana & Organero, 2011), or systems stimulating safer driving styles (Rodríguez et al., 2014; Steinberger et al., 2016).

The proposed model is essentially a system-centric model, where a traffic system decides upon for example an ideal traffic distribution, or on which set of driving styles are ‘safe’, and subsequently stimulates the driver to conform to these types of behaviours. This is in line with persuasive technology, which aims to stimulate certain attitudinal or behavioural patterns over others (Fogg, 1998).

1.3. Why target driver behaviour at the tactical level?

Driver behaviour is often divided into three levels: the strategic, tactical and control level (Michon, 1985). The strategic level considers high-level choices related to driver’s route choice behaviour, which is generally constant over longer periods of time. At the tactical level, drivers decide upon and perform manoeuvres (e.g. change lane, take exit, overtake car) considering the observable and anticipated part of the road network to reach their strategic goals. At the control level, the driver performs actions to operate the vehicle (e.g. change gears, press accelerator pedal, turn on blinker).

Our conceptual model will focus on safely persuading driver behaviour at the tactical level. From a persuasive perspective, targeting short-term behavioural responses (e.g. adjusting speed, changing lane) increases the effectiveness of the persuasion (see for example Fogg, 2009a; 2009b, Oinas-Kukkonen, 2013, Sections 3.2, 4.2). From a safety perspective, it is important to manage the demands placed on the driver. According to the Task-Capability Interface model (TCI) by Fuller (Fuller, 2005), driving demands that exceed driver capability might lead to risky situations such as loss of control or a collision. Persuasive effectiveness and safety need to be balanced: targeting tactical level behaviours such as changing lane, especially in demanding traffic conditions, does carry risk and requires careful implementation of in-car interfaces to not become distracting or affect driving adversely. Managing task demands is crucial and a key element in ensuring driver safety when applying persuasive approaches, or when communicating information to the driver.

In order to keep task demands low, a persuasive system should focus on short term behavioural responses that are low effort. These low-effort behaviours can be identified through the behaviour taxonomy of Rasmussen (Rasmussen, 1983). The taxonomy divides driver behaviour into three levels: skill-based, rule-based, and knowledge-based. Skill-based behaviour is highly automatic and can be performed without much attentional demands. Tasks at the control level fall into this category, and for experienced drivers likely some highly automated behaviours at the tactical level as well in non-complex traffic conditions (e.g. lane changing, overtaking, merging). In rule-based behaviour, a response or a set of responses is selected based on earlier learned rules. Knowledge-based behaviour is applied in mostly unknown situations when novel behavioural responses are needed. Required attentional demands and effort increase from skill-based to rule-based to knowledge-based behaviour. Since behaviour at the tactical level (mostly) consists of skill-based and rule-based behaviours, changing these types of behaviours carries the least risk of imposing high demands on the driver (Birrel, Young, Staton, & Jennings, 2017). Aside from the targeted behaviours, the context and complexity of the driving environment may influence the difficulty of the tactical level manoeuvres as well. An example of a low effort behavioural response is requesting a driver to reduce speed in response to downstream traffic disturbance (skill-based, control level). On the other hand, asking a driver to take a different route along a busy unknown road is likely to place higher demands on the driver, since the execution of a task at the strategic level (knowledge-based behaviour) also involves the tactical (rule-based), and operational level (skill-based) (Alexander & Lunenfeld, 1986).

We hypothesise that a trade-off exists between persuasive effectiveness and the described task complexity. As task complexity increases, persuasive effectiveness should decrease in theory, based on the work of Rasmussen (1983) and Fogg (2009b, Section 3.1), and on research showing how a lower perceived ability to perform a target behaviour can lower the intention to perform the behaviour, as well as the likelihood of that behaviour (Elliott, Thomson, Robertson, Stephenson, & Wicks, 2013). The decision which behaviours to select depends on the driver workload, as under- or overloading the driver can create dangerous situations (Young, Brookhuis, Wickens, & Hancock, 2014). In combination with for example a driver monitoring system (Aghaei et al., 2016; van Gent, Melman, Farah, van Nes, & van Arem, 2018b), it becomes possible to monitor a driver's state and make inferences about which advices a driver likely can or cannot safely handle. If at any point during the generation of the advice or the execution of the behaviour driver workload exceeds safe levels, the system might decide not to display the advice, retract it, or recommend termination of the execution of the advice.

We first conduct a critical overview of available behavioural models and select the model most applicable to driver behaviour. We then describe driver behaviour at the tactical level and present the general requirements for an in-vehicle persuasive system. Following this, in Section 4, we investigate the different persuasive approaches used in the literature and discuss how these approaches fit into the driving environment. Finally, in Section 5 we describe the proposed conceptual model and its relation to the current literature. As an example, we apply the conceptual model to the design of a persuasive lane-specific advice system currently in development.

2. Describing behaviour at the tactical level

In order to develop our persuasive conceptual model, a behavioural model capable of describing the effects of persuasion on driver behaviour at the tactical level is needed. 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) (Bandura, 1971), Self-Determination Theory (SDT) (Deci & Ryan, 1985), the Trans-Theoretical Model (Norcross, Krebs, & Prochaska, 2011), and the Theory of Planned Behaviour (TPB) (Ajzen, 1991). 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.

2.1. Overview of behavioural models

The *Social Learning Theory (SLT)*, also known as Social Cognitive Theory, suggests that human behaviour emerges from a constant interaction between environmental, behavioural and cognitive influences (Bandura, 1971; Fluegge, 2016). It incorporates elements of operant conditioning to explain how behaviours are learned through social interactions with others (Watkins, 2016). SLT has been applied to a wide range of fields, including how unwanted behaviours may arise (criminal, drug misuse, smoking, traffic violations) and ways to induce a positive change (Hoeben & Weerman, 2016; Lochbuehler, Schuck, Otten, Ringlever, & Hiemstra, 2016; Watkins, 2016; Zaso et al., 2016), how public perception is formed and influenced (Fluegge, 2016) and students' tendencies to procrastinate (Gadong & Chavez, 2016). The model is directed at describing how learning experiences are shaped by cognitive and social factors.

The *Self-Determination Theory (SDT)* is often cited for its use of intrinsic and extrinsic motivation to explain behaviour (Deci & Ryan, 1985), but actually postulates three basic psychological needs that drive behaviour: autonomy (being in control of one's decisions and behaviour), competence (feeling able to attain behavioural outcomes) and relatedness (feeling understood and respected by others) (Ridgway, Hickson, & Lind, 2016). This model has mostly been applied to behavioural change towards healthier behaviours in the health domain (Friederichs, Bolman, Oenema, Verboon, & Lechner, 2016; Lekes, Houlfort, Milyavskaya, Hope, & Koestner, 2016; Niven & Markland, 2015; Sebire et al., 2016; Staunton, Gellert, Knittle, & Sniehotta, 2015), to medical training (Hoffman, 2014), and to volunteering behaviours (Wu, Li, & Khoo, 2015). The SDT describes behavioural motivation at the macro level (Niven & Markland, 2015).

The *Trans Theoretical Model (TTM)* describes behaviour as consisting of five stages: pre-contemplation (not thinking about changing behaviour), contemplation (thinking about changing behaviour), preparation (making preparations for changing behaviour), action (changing behaviour) and maintenance (keeping changed behavioural patterns intact) (Norcross et al., 2011). The model originated as a fusion of models from several fields of therapy. Like the SDT, the TTM is a macro model

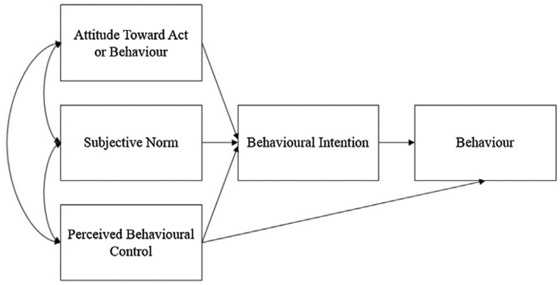

Fig. 1. The theory of planned behaviour.

of behaviour, describing high level behavioural processes (see for example Brick, Velicer, Redding, Rossi, & Prochaska, 2016; Kushnir, Godinho, Hodgins, Hendershot, & Cunningham, 2015; Prochaska et al., 1994; Yusufov et al., 2016).

The *Theory of Planned Behaviour (TPB)*, based on the Theory of Reasoned Action (Fishbein & Ajzen, 1975), posits that behaviour is directly predicted by 'behavioural intention' and 'perceived behavioural control' (the perceived volitional control over the behaviour). 'Behavioural intention' is predicted by 'attitude towards behaviour', 'social norms regarding the behaviour' as well as 'perceived behavioural control'. The model is displayed in Fig. 1. In the traffic domain, the TPB has been used to predict traffic violations (Castanier, Deroche, & Woodman, 2013), speeding behaviour (Elliott, Armitage, & Baughan, 2005), evaluating engagement in distracting secondary tasks (Chen, Donmez, Hoekstra-atwood, & Marulanda, 2016), and aggressive driving (Efrat & Shoham, 2013). It has also been used successfully in experiments with the goal of behavioural change (Chorlton & Conner, 2012). It describes how situational constraints and long-term attitudes can influence behaviour.

2.2. Representing persuasive effects on tactical driver behaviour

We have selected the TPB as a behavioural basis for the conceptual model. This is because this theory can explain both short-term behaviour at the tactical level in the driving setting, as well as the long-term social and attitudinal factors acting on behavioural patterns, which might be relevant when explaining variables like continued system usage. The other reviewed models were either geared more towards changing long-term behavioural patterns (SLT, SDT), describing behaviour at a macro level (SDT, TTM), or describing (changing) behaviour in clinical settings (SDT, TTM). The TPB also plays a central role in models of technology acceptance and trust, such as the Technology Acceptance Model (TAM) (Davis et al., 1989; Davis, 1986) and the UTAUT (Venkatesh, Morris, Davis, & Davis, 2003; Vlassenroot, Brookhuis, Marchau, & Witlox, 2010), which adds usefulness in the context of persuasive systems that need to be trusted and accepted before they can have an effect. In this study, we will utilise the TPB (Fig. 1) as a behavioural basis for the conceptual model.

In more 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 their own 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 (perceptions about whether the person has control over the behaviour or outcomes), with only the self-efficacy component being related to changes in the intent to perform a behaviour and the actual behaviour (Elliott et al., 2013). This indicates that PBC is more closely related to 'ability' from the Fogg Behaviour Model (FBM, see 3.1), 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 potential rewards, or the averting of negative consequences. 'Subjective norms' refers to how displaying the behaviour is evaluated by the social network around the individual, and how displaying the behaviour might affect social relationships.

3. Influencing behaviour at the tactical level

We searched the literature for persuasive methods that were used or have the potential to be used in the traffic domain. The search engines used were Google Scholar, Scopus and Web of Science, with the keywords: "driver persuasion AND system OR ivis OR adas", "persuasi* AND traffic OR in-car", "persuasive systems OR persuasive technology", "persuasive methods". We limited the results to experimental papers of 2010 and newer. For methodological papers proposing persuasive methods, no time frame was used. Forward and backward snowballing was performed. This resulted in the persuasive categories of Gamification, Behavioural Economics and Captology. These different methods often overlap to some degree in the persuasive elements used. In this section, we discuss these persuasive methods and motivate our choice for the models we adopt for developing the conceptual model.

3.1. Persuasive methods

The persuasive methods we reviewed can broadly be divided into Gamification, Behavioural Economics and Captology, although these fields show some overlap in the persuasive elements used or approaches taken.

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 takes the elements that elicit this motivational behaviour and applies them to other situations (Deterding, Dixon, Khaled, & Nacke, 2011). The most often and successfully applied game design elements are leader boards, achievements and challenges (Hamari, Koivisto, & Sarsa, 2014). Gamification may work through raising the driver's implicit motivation, by inducing group-effects such as in-group/out-group bias – simply assigning people to a group, induces positive feelings to other group members (Baron & Dunham, 2015) and a motivation to help achieve group goals (Musicant, Lotan, & Grimberg, 2015) –, as well as through a 'fear of missing out' effect (Przybylski, Murayama, DeHaan, & Gladwell, 2013). For example, Musicant et al. (2015) found that, when offering financial incentives and inducing a common group goal of collecting as many safe driving miles as possible, motivation to use a driving safety app on a smartphone was high over a period of more than a hundred days, as indicated by app usage and the active recruitment of friends as users. App usage dropped significantly once the group goal was achieved, indicating that any persuasive system should be cautious with formulating group goals and financial incentives. 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 (Hamari, Koivisto, & Sarsa, 2014). Gamification effectiveness might also be reduced over time due to a novelty-like-effect (Farzan et al., 2008a), although motivation can remain high when using group-based goals as long as these goals remain active (Musicant et al., 2015). Examples of gamification applied to the transportation domain include EcoChallenge (Ecker et al., 2011): a reward and competition-based system to persuade drivers to engage in a more eco-friendly behaviour, I-GEAR (McCall & Koenig, 2012): a system to change driver behaviour by providing small financial and non-financial rewards, and 'Driving Miss Daisy' (Shi et al., 2012): a gamified solution to help drivers improve their driving skills by providing a virtual passenger that occasionally comments on driving styles.

Behavioural economics has been defined as the 'body of work seeking to understand behaviour by incorporating insights from behavioural sciences into economics' (Avineri et al., 2010). Rather than being rational thinkers, people use a range of heuristics and display biases that often work well, but can lead to reasoning errors in certain situations (Kahneman, 2003). An overview can be found for instance in the work of Kahneman (Kahneman, 2013) or Cialdini (Cialdini, 2006). Persuasive elements from Behavioural Economics applied to the transportation domain can be found in for example the design of travel information systems (Avineri, 2011), approaches to promoting safe driving behaviours (Millar & Millar, 2000), and methods analysing travel behaviour (Metcalfe & Dolan, 2012).

Captology (acronym: computers as persuasive technology) was introduced by Fogg (1998). It is a field of study which uses computers to influence behaviour in various ways (Fogg, 2010). The Fogg Behavioural Model (FBM) (Fogg, 2009a) is prominent in the field of persuasion. It postulates that in order for a persuasive intervention to be successful, three factors need to converge: the person needs to be able to perform the behaviour ('ability'), be motivated to perform the behaviour ('motivation'), and finally a trigger should be present to elicit the behaviour. Targeting simple behaviours has a higher likelihood of success (Fogg, 2009b). In the context of driver persuasion: making sure 'ability' is high means requesting short, simple to perform behaviours such as a speed change, an overtaking manoeuvre, a lane change, or a merging manoeuvre, as well as timing persuasive attempts to moments when driver workload is not high and when traffic conditions allow for the requested behaviour (e.g. don't request a lane change when the neighbouring lane is crowded). 'Motivation' can be raised by using persuasive techniques (see also 3.2). The FBM has been applied to the traffic setting, for instance it has been applied in a persuasive intervention that successfully reduced texting behaviour while driving (Miranda et al., 2013).

3.2. Integrating persuasive methods

The Persuasive Systems Design model (PSD) (Oinas-Kukkonen & Harjumaa, 2008) presents a systematic framework for designing and evaluating persuasive systems. It brings concepts from Gamification, Behavioural Economics and Captology together. The PSD states that a system can be made persuasive by providing the user with support in distinct categories: primary task support, dialogue support, system credibility support and social support.

Primary task support shows many of the principles put forth by the FBM and Behavioural Economics. The focus is on supporting 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 when considering in-vehicle systems. Apart from increasing the system's persuasive power, this approach reduces task demands placed on the driver, which in turn increases system safety (Fuller, 2005; Wickens, 2002). An example of primary task support can be a lane change system that guides the driver through the steps of finding a gap, matching speed and merging. There is a growing similarity between primary task support and ADAS, such as lane-change assist systems (Habenicht, Winner, Bone, Sasse, & Korzenietz, 2011), as ADAS become more capable. In primary task support, one way of increasing persuasiveness is reducing complex behaviour to a series of steps and guiding the user through them, which is similar to what for example lane-change assistance systems do (Habenicht et al., 2011).

Dialogue support is aimed at keeping users moving towards their goals. This support level contains elements from Gamification, Behavioural Economics and the FBM. Offering praise and rewards can increase motivation, which is an important factor for persuasion in the FBM (Fogg, 2009a). If applicable, providing reminders for target behaviour or suggesting certain behavioural responses may be a way to increase behavioural effects by facilitating the creation of habits. Habits are a main factor in making persuasive effects last over time (Lally & Gardner, 2013). Further important factors in dialogue support are similarity and liking (Fogg, 2010), which can increase trust and intentions to comply to system requests.

System credibility support is mainly important from the perspective of trust and acceptance. It is about showing the driver that the system makes correct decisions and recommendations. Trust and acceptance are major factors in whether a persuasive system's suggestions or advices will be considered by the driver (Risto & Martens, 2013; Vlassenroot et al., 2010). Factors at this support level relate to the accuracy of the information presented, its transparency, and how users will evaluate it. This in turn is important for forming and maintaining trust in the system (Lee & Moray, 1992; Martens & Jenssen, 2012). The need for trust in a persuasive system is underscored by the work of Risto (Risto & Martens, 2013), who reported that, in their study, drivers constantly tried to verify the accuracy of system requests before following them, and refused to follow messages they interpreted as incorrect. Apart from validity of the advices, acceptance can also be influenced by what modality is used (Donmez, Boyle, Lee, & Mcgehee, 2006).

Social support aims at 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 (see for example Lütteken et al., 2016). Social factors vary in importance and effects on different age groups (McEachan, Conner, Taylor, & Lawton, 2011), which is important for instance when targeting specific demographic groups.

To summarise, Gamification has been shown to be effective in motivating people to change their behaviour. However, some studies report that its effectiveness might reduce over time (Farzan et al., 2008a, 2008b). Behavioural Economics as a field has many applicable concepts that can persuade drivers effectively, and the FBM 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 persuasive elements that can be used depending on the type of system and the context in which it is intended to be applied. For example, in a cooperative system, which is social by nature, the 'social support level' provides ways to add persuasive elements to the social aspects present in the system (see Lütteken et al., 2016). More generally: system credibility can assist persuasion in most systems by increasing trust in the validity of the messages over time, which has been shown to be a large factor in whether a driver responds to the advice or not (Abe & Richardson, 2006; Risto & Martens, 2013), or even a factor in determining system usage over time (Martens & Jenssen, 2012).

4. Considerations for safe driver persuasion

The driving task is complex, requires constant attention from the driver (de Waard, 1996) and presents frequent distractions. Stutts and Gish (2003) report that drivers engaged in distracting activities for 16.10% of the time the car was moving (31.42% if in-car conversations were included). Poorly designed or implemented persuasive in-vehicle systems may increase this percentage by providing more distractions to a driver (Hibberd, Jamson, & Carsten, 2010), potentially increasing driver workload (Horberry, Anderson, Regan, Triggs, & Brown, 2006), inducing behavioural adaptation (Martens & Jenssen, 2012), or otherwise creating unsafe situations. Safety, therefore, is an important characteristic of a persuasive in-vehicle system. An effective but unsafe system is not likely to be used long term, either through consumer choice or through changing legislation. In this section, we discuss how improving safety can also increase persuasive effectiveness in the short and long run.

4.1. Safety, driver demand and unsafe situations

A persuasive system needs to communicate with the driver. At the very least this means transmitting information to the driver, and in more complex cases it may require interaction. One way of limiting negative effects of this communication on driving performance, based on the TCI (Fuller, 2005), is by ensuring that the demands placed on the driver do not create dangerous high workload situations. Although this is a broad statement, it can be assessed using for example environmental variables that may affect the driver, such as the proximity of other vehicles, traffic conditions and weather conditions, and driver variables such as driving demand and driver workload as well.

Driver workload results from the interplay between the demands placed on the driver by the driving task, the complexity of the environment, and the driver's capacity to meet those demands (de Waard, 1996). It is an important factor in terms of safety, since under- or overload can influence a driver's performance and create hazardous situations (Young et al., 2015). In Section 1.2 we have discussed how targeting the tactical level for persuasive attempts will likely limit the impact on driver demand (compared to targeting the strategic level), and by extension, on driver workload. Despite this, a poorly designed persuasive system targeting tactical-level behaviours can still result in high driving demand and/or workload. The Multiple Resource Theory (MRT) by Wickens (Wickens, 2002) can help understand why, even when a persuasive in-vehicle system targets simple-to-change behavioural tasks, high driver demand or workload may still result.

In the MRT, interference from a secondary task is most likely when it accesses the same resources as the primary task. Since driving is mainly a visual task, transmitting information to the driver through a visual channel may cause interference. For instance, diverting the eyes from the road for extended time has serious consequences for driving performance and lane-keeping ability (Peng, Boyle, & Hallmark, 2013). Heads-Up-Displays do not require the driver to take his eyes off the road and can be a better alternative (Liu & Wen, 2004), but do not mitigate all negative effects, and can introduce some new potential problems related to sharing visual resources (Wickens, 2002) and to characteristics of the human visual system, such as involuntary accommodation responses from the eye that cause the driver to temporarily lose optical focus of the road scene, even though both the HUD and the road scene are in the same field of view (Edgar, 2007). Competing resource types are not the only factor in the MRT that can lead to reduced task performance: if the demands of one or both tasks are higher than what the driver can handle, two tasks that use very different resources are still likely to cause dual-task interference and degrade driving performance. In terms of a persuasive in-car system, minimising the effect on workload therefore means choosing the correct modality to transmit information to the driver, keeping the cognitive demands of the interaction low to prevent interference with the main driving task, and timing the messages to periods when the driver can accommodate them. If the cognitive demands of the main task (driving) are already high, per the MRT a simple secondary task may create dual-task interference even when using a different modality from the main task, degrading the performance on the main task and thereby potentially compromising driver safety. Adaptive interfaces (Birrel et al., 2017; Park & Kim, 2015) try to counter this by changing either the complexity of messages presented, the modality used to convey the message to the driver, or by suppressing messages in conditions where safety or workload may be dangerously affected, safety can be improved.

Unsafe situations can still arise from persuasive in-vehicle systems even when changes induced in driver demand and workload are minimal. A system that distracts the driver at the wrong moment may create a potentially dangerous situation (Young & Regan, 2007), highlighting the importance of timing the communication with the driver. Unsafe situations may also arise from the way drivers accommodate the functions of in-vehicle devices into their driving habits, giving rise to behavioural adaptation effects (Martens & Jenssen, 2012; Smiley, 2000). As an example of an unintended behavioural effect, in response to having Anti-Lock Braking (ABS) and Airbag systems installed, headways decreased and seatbelt usage reduced (Sagberg et al., 1997). Overreliance on a system is another potential problem, and research has shown that the degree of reliance by human operators doesn't always match the system capabilities (Parasuraman & Riley, 1997). For example, with a lane-change advice system: if a driver places too much trust in the lane change advice system, a lane change may be initiated when the system gives an advice, without the driver checking whether it is actually safe to change lane.

4.2. Persuasive attempts and acceptance

A persuasive in-vehicle system needs to be able to consistently persuade the driver. According to the Fogg Behaviour Model (FBM) (Fogg, 2009a), persuasive interventions timed to periods when both motivation and ability are high, have a higher chance of resulting in changed behavioural outcomes. In terms of an in-vehicle system, an advice that is given to a driver when there is a high motivation to follow it, will have a higher probability to be complied to. Similarly, an advice given at a time when the driver ability is high, i.e. when the driver perceives they can follow the advice, will be more likely to result in the target behaviour. This again underscores the importance of targeting behaviours that require less effort to change, such as tactical level driver behaviour: not only it is safer, persuasive effectiveness is also likely to increase when doing so (Fogg, 2009a). In the traffic context, the FBM's 'ability' to follow a persuasive advice can be impacted by multiple factors and conditions, such as weather conditions, traffic conditions, secondary tasks or driver states (de Waard, Kruizinga, & Brookhuis, 2008). One such driver state is driver workload, which needs to be considered for the effectiveness of persuasion as well as for safety. When driver workload is high, presenting an advice and/or requesting an action from the driver may increase the difficulty of the driving task further, in turn reducing the likelihood that the driver complies to the persuasive request because the requested behaviour is seen as difficult or impossible given the circumstances. In other words, high workload is likely 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 (Vlassenroot et al., 2010). Without taking steps to ensure acceptance, there is the risk that a persuasive in-vehicle system falls into disuse or works counterproductively (Martens & Jenssen, 2012). This is especially damaging if the system relies on a user base to function, as for example with cooperative (lane change) systems (Lütteken et al., 2016). To describe the acceptance of new technology several models have been developed, such as the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) and the Technology Acceptance Model (TAM) (Davis, 1986).

4.3. Technical feasibility of in-car persuasion

As discussed, persuading the driver safely assumes that an in-car system has awareness of the driver ability and the driving context, so that messages can be transmitted at the right time (i.e. the driver has available capacity). Various technological building blocks exist that facilitate this, as briefly outlined in the following paragraphs.

Driver workload is mentioned as an important factor both for safety and persuasive effectiveness. Using various approaches, on-line driver workload predictors have been proposed and tested based on physiological characteristics and driver performance measures (Kim, Chun, & Dey, 2015; Solovey, Zec, Garcia Perez, Reimer, & Mehler, 2014; van Gent, Melman, et al., 2018b). These predictors often take at least heart rate into account. We recently developed a toolkit that allows for online analysis of (noisy) heart rate data collected in in-car settings (van Gent, Farah, van Nes, & van Arem, 2018). This allows the reliable collection of this type of input for the workload predictors.

Capturing driver ability can be done through surrogate measures, for example by combining the workload prediction with traffic conditions. Camera-based systems exist that can detect and label other road users accurately (Ashraf, Wu, Iandola, Moskewicz, & Keutzer, 2016). This opens up the possibility to automatically take aspects like traffic density and position of nearby vehicles into account. In this case, advising a lane change when driver workload is predicted to not be high and when a sufficiently large gap is detected on an adjacent lane, provides a way to select safe situations where 'driver ability' is estimated to be high as well.

The motivation to follow an advice is difficult to capture. The role of the persuasive system is to raise the motivation of the driver to follow an advice, by using one or several of the discussed persuasive techniques. It is conceivable that the system monitors the results of different persuasive attempts made and optimises the methods used to each driver individually based on performance statistics, but more research would be required to determine the optimal performance statistics.

4.4. Persuasion in time

Any persuasive attempt will need time to be successful: the persuasive message needs to be generated, transmitted to the driver, interpreted by the driver, and finally followed if the driver decides to. Whether messages are time critical or not depends on the implementation. For example, a persuasive eco-driving application as described in (Ecker et al., 2011; McCall & Koenig, 2012) is not time critical. However, in the context of the lane-specific advice system described in this paper, a correct advice depends on current traffic conditions, and therefore is time critical. Traffic conditions are dynamic, meaning that if persuasion takes too long in this case, the advice might be obsolete. Advices incongruent with the surroundings are not only a problem for the functioning of the system, but also harm drivers' trust in the system (Risto & Martens, 2013). In our research we aim to generate advices with a time validity of approximately two minutes. Within these two minutes, the lane change system will determine, based on the current and predicted traffic distribution, the optimal traffic distribution to work towards. The main challenge being worked on from a traffic modelling point of view is to predict the risk of congestion far enough ahead (i.e. 2 minutes) to allow the driver enough time to follow any advices.

5. The conceptual model for driver persuasion at the tactical level

In this section, we present the proposed conceptual model for driver persuasion at the tactical level using in-vehicle systems. The conceptual model is displayed in Fig. 2. The model is meant to help guide the development of persuasive in-car systems by integrating persuasive methods as well as behavioural models. It 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 (4.1, 4.2) and the four support levels from the Persuasive Systems Design model discussed earlier (3.2). The Information Transfer Level is where communication with the driver takes place. It 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). Design of factors at the system and information transfer level should take human factors described in the driver level into account, and reflect the desired outcomes of the system-driver interaction (safety, persuasive effectiveness). The following sub-sections detail these levels and how they are built up from the existing models and theories in the literature.

In the conceptual model three types of relationships are indicated. Solid lines indicated relationships that have been empirically validated and are known from meta-analyses. We have added the reported correlation coefficients and R^2 statistics of these relationships to the model. The two types of dashed lines indicate relationships that are established in the literature, and hypothesised relationships. The basis for the hypotheses relationships is discussed in the corresponding sections (5.1–5.3).

5.1. Planning driver persuasion: The system level

The System Level represents the back-end of the persuasive in-vehicle system. It is built up from the PSD model (3.2) and the considerations of driver safety and the persuasiveness (4).

Safety is central to the persuasive system design and operation. 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. An existing type of driver monitoring system could perform this role effectively (Aghaei et al., 2016; van Gent et al., 2018b). Ideally, the persuasive system should (either directly or indirectly) take driver workload into account, should not create unsafe traffic situations, and should aim not to distract the driver at the wrong time. For example, a lane-change system designed to assist the driver in dense traffic, needs to take into account not only the surrounding traffic but also the driver state, when deciding on whether to continue or abort a lane-change manoeuvre (Habenicht et al., 2011). In situations where safety criteria are not met, they must be re-evaluated until they are met, represented in the model by the conditional loop. Ways to automatically evaluate these safety

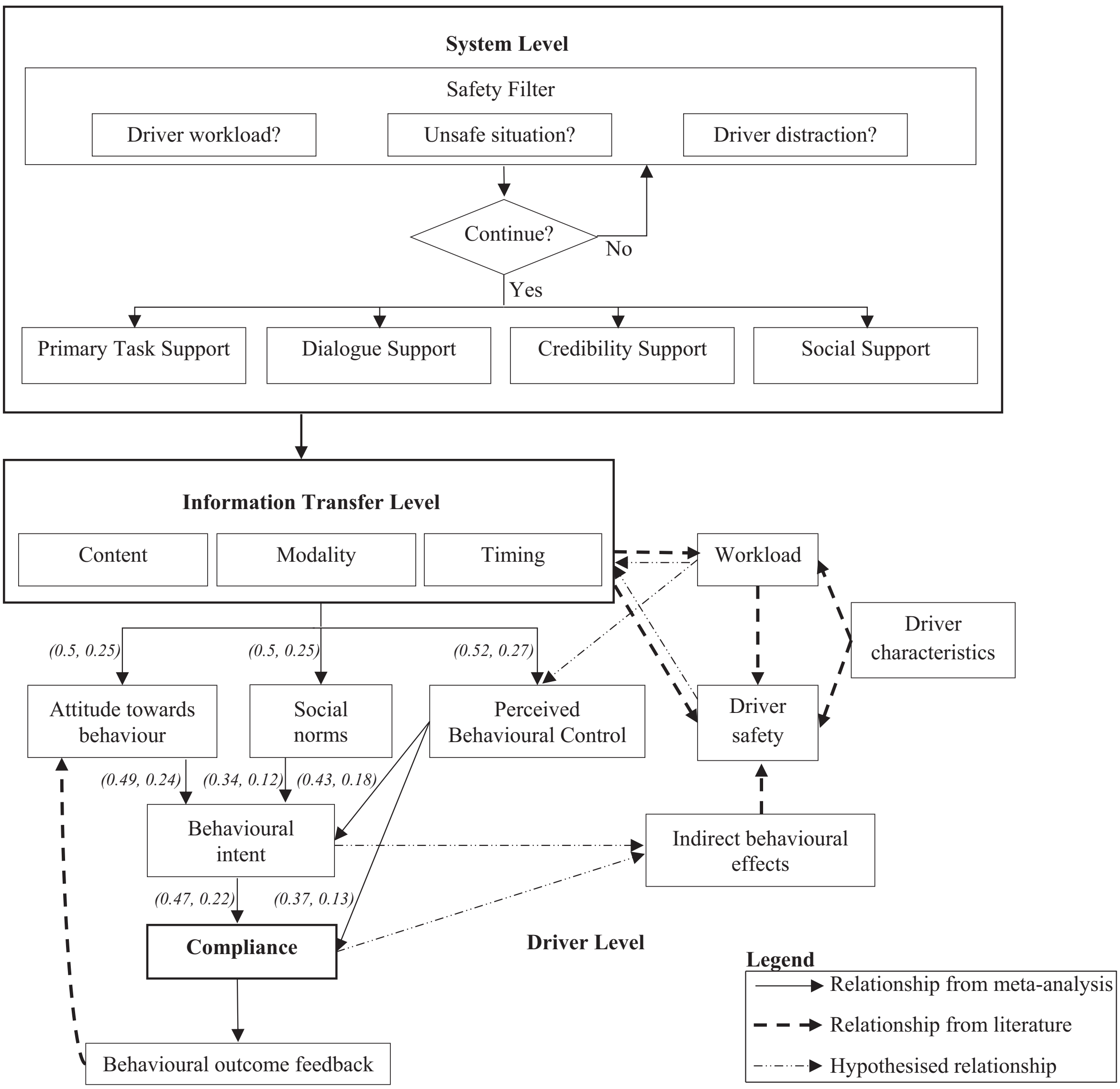

Fig. 2. Proposed conceptual model for influencing tactical driver behaviour. Solid arrows indicate relationships known from the literature, dashed arrows indicate hypothesised relationships. Statistical properties are given where available from meta analyses in the format (correlation coefficient, R^2).

criteria exist, such as in systems that monitor on-coming traffic (Curry, Blommer, Tijerina, Greenberg, Kochhar, Simonds, & Watson, 2010), label nearby road users (Ashraf et al., 2016), detect weather conditions (Green, 2004), and systems that attempt to estimate driver state (Ferreira et al., 2014; Liang, Reyes, & Lee, 2007; van Gent, Melman, et al., 2018b).

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 in this paper combines persuasive techniques into four support levels. These four levels of support are included as possible routes to persuasion (see also Oinas-Kukkonen & Harjumaa, 2009; Oinas-Kukkonen & Harjumaa, 2008, 3.2). A recent meta-analysis study by Hamari, Koivisto, and Pakkanen (2014) report that from 95 empirical studies looking at persuasive techniques applied to diverse fields, the majority report positive (52 studies) or partially positive (36 studies) results. Many of the included papers utilise the PSD framework. This indicates the viability of using persuasive methods to achieve behavioural change effectively.

5.2. Interacting with the driver: The information transfer level

The information transfer level comprises the communication between the persuasive system and the driver. Usually this communication takes place 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' is in the message?), 'modality' ('how' is the message transmitted to the driver?) and 'timing' ('when' is the message transmitted?) as factors. The modality used to convey the message could be dependent on the type of information being transmitted (Donmez, Boyle, Lee, & City, 2006), and can influence the acceptance of the advices as well (Donmez et al., 2006). In the conceptual model, the information transfer influences driver workload, driver safety and the behavioural determinants of the TPB (attitude, social norms and perceived behavioural control). This impact on the behavioural determinants is the goal of the conceptual model: in order to affect behavioural change, the system needs to influence these motivations (Elliott et al., 2013). 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 and MRT. 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, we hypothesised that the perceived behavioural control of the driver lowers. As we discussed in Section 2.2 PBC reflects self-efficacy (judgement of being able to perform the target behaviour), not perceived level of control over the behaviour (Elliott et al., 2013). This means that the higher the (perceived) driver workload, the lower the driver's appraisal of being able to comply with persuasive messages will be. This appraisal of ability is important in the persuasive context: if a driver lacks the confidence to follow up on a persuasive advice, the persuasive attempt will likely not succeed. In addition, this could lead to a degradation of driver performance, or even undesirable situations such as a loss of control or a collision (TCI, 4.1, 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 (Dozza, 2013; Peng et al., 2013) or to distraction at a critical moment.

From the persuasion perspective, the FBM (Fogg, 2009a) 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 (Elliott et al., 2013, see also Section 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 components are important for persuasion and safety. For example, if a lane-specific advice system requests a lane-change when a driver does not feel capable of performing the requested manoeuvre, it is unlikely the persuasion will have an effect. Alternatively, if an already overloaded driver complies with the requested behaviour, unsafe or outright dangerous situations can result.

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.

As argued in the previous section, both motivation and ability need to be high in order for persuasive systems to actually persuade (Fogg, 2009a). In the conceptual model, motivation is captured by the TPB terms 'attitude towards behaviour' and 'social norms'. The attitude and social norms influence driver behaviour through the 'behavioural intent' (BI) (Ajzen, 1991; Armitage & Conner, 2001; McEachan et al., 2011). The ability to follow persuasive advices is captured through 'perceived behavioural control' (PBC) and its interaction with workload. PBC affects the intent to perform a behaviour as well as the behaviour directly (Armitage & Conner, 2001; McEachan et al., 2011), and additionally we hypothesize that it acts as a modulator of workload on behaviour. As discussed previously, this hypothesis is based on earlier work showing that 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 (Elliott et al., 2013). This means that with a high PBC the driver feels competent and able to perform a requested behaviour, whereas a low PBC will negatively influence the likelihood of a persuasion from resulting in the desired behaviour (Armitage & Conner, 2001; McEachan et al., 2011).

Apart from the information transfer (5.2), driver workload is also affected by 'driver characteristics'. This component is a broad term meant to capture the heterogeneity of the drivers and how this relates especially to driver workload and driver safety. For example, driver ability is not static and varies between and within individuals over time (Young et al., 2015), which may cause workload experienced by two different drivers in a comparable situation to be very different. 'Driver characteristics' also includes differences in inherent driver safety. For example, some age groups display more risky behaviour (Carter, Bingham, Zakrajsek, Shope, & Sayer, 2014), there may be sex differences or geographical differences in driver behaviour and capability (Twisk & Stacey, 2007; Vlakveld, 2011), or individual differences in driver aggression (Hennessy & Wiesenthal, 2001). These characteristics may result in some classes of drivers being exposed to higher risk while driving, especially in combination with in-car systems.

'Indirect behavioural effects' (Martens & Jenssen, 2012) were discussed in 4.2. These refer to 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 (Smiley, 2000) or with shorter headway and varying seatbelt usage (Sagberg et al., 1997).

When developing and implementing a persuasive in-car system it is imperative to include these possible indirect behavioural effects in experiments to evaluate it.

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 Lütteken et al., 2016). For instance, if a driver observes that complying to an in-vehicle 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 (Oinas-Kukkonen & Harjumaa, 2008). It is also in line with an earlier study into compliance to tactical driving advice (Risto & Martens, 2013), 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. Application to a lane-specific advice system

In this last section, we present a case study based on a lane-specific advice system, in which we apply the developed model to the system and discuss how this helps structure system design for safety and persuasion.

The goal of the system is to reduce travel time delay and congestion by encouraging a better distribution of the vehicles over the available motorway lanes. This means advising drivers on what lane to take, depending on external factors. For instance, an unbalanced distribution, an upcoming on-ramp or lane drop, or an incident upstream may require a redistribution of traffic to ensure continued flow and avoid congestion. The system's advices will be in the collective benefit of drivers on a specific stretch of road (minimised total travel time), but will sometimes not be in the benefit of individual drivers receiving the advice (e.g. stay behind this slow truck for now), creating a potential problem (Risto & Martens, 2012). The challenge is to persuade drivers to follow the advices that are in the benefit of the collective rather than the individual. We aim to apply the persuasive techniques to engage drivers with the system and to also stimulate adherence to lane-specific advices, especially when they are not in the individual's benefit. By applying the various persuasive techniques described in the paper, driver motivation and the attractiveness of the advices are hypothesised to increase. We will verify this experimentally. The designed system will consist of an in-vehicle part and a back-end that predicts traffic states and approximates the optimal lane use situation.

The developed conceptual model described in this paper helped to direct our research in several ways. At the 'System Level', a safety filter is required. Early in the design phase, this redirected the process from focusing mostly on the effectiveness of the persuasive design, to an approach that considered potential effects on safety and on the driver as well. As a result, we are developing an affordable driver monitoring system to estimate driver state (Gent, Farah, Nes, & Arem, 2017; van Gent, Melman, Farah, van Nes, & van Arem, 2018a). In combination with environmental sensing systems built into the vehicle, this provides a safety filter that will suppress messages to drivers that are estimated not to respond (safely) to the persuasion. The result of this message filtering, we argue, is two-fold (see 4.2, 5.2, 5.3): apart from increasing the safety of the system, it works to increase persuasive effectiveness and facilitate long-term usage of the system as well.

Persuasive strategies are outlined in the four support levels from the PSD model (Oinas-Kukkonen & Harjumaa, 2008, see also 4.2). These support levels offer persuasive strategy elements from which a selection can be made. We selected strategies mainly from primary task support and dialogue support, with some elements from the other two support levels. The system will support the driver by breaking down a requested lane-change into smaller steps, and guiding the driver through them (primary task support: 'reduction' and 'tunnelling'). This will increase persuasive power and make the task less demanding, benefitting both safety and persuasion (Fuller, 2005; Wickens, 2002, see also 4.1). Second, the system will provide the user with transparent information regarding obtained benefits in terms of travel time saved in relation to the performed behaviour through either an app or a web-portal (primary task support: 'self-monitoring'). Providing a means of 'self-monitoring' of on-going benefits increases immediate persuasive effects, but also works to increase 'trustworthiness' and 'verifiability' of the system (credibility support). As discussed in 3.1 the effectiveness of persuasive methods might decrease over time. In one study, especially the presence of clear (group) goals was found to keep system usage high (Musicant et al., 2015). In the case of our lane-specific advice system, the group goal is to reduce congestion on the road that the user is driving on, which is a relevant goal along the whole drive. Whether the use of group-based incentives can be implemented will be evaluated at a later stage of the system design.

At the information transfer level, an advice is communicated to the driver, the effects of which are described at the driver level (5.3). As described in 5.2, in the model the information transfer between system and driver is operationalised as having content, modality and timing. The model shows how these factors mediate safety and persuasive effectiveness through workload and perceived behavioural control (see also 4.2, 5.2). This means that, in further development of our lane-specific advice system, our research will focus on how driver workload and perceived behavioural control are influenced by content, modality and timing decisions with our lane-specific advice system. Additionally, it simplifies the scope of our research: in order to estimate the effects on the behavioural outcome, we only need to investigate how the three information transfer factors influence the 'attitude towards behaviour', the perceived 'social norms' and the PBC. How these three factors in turn influence BI and Behaviour is known from several exhaustive meta analyses (Armitage & Conner, 2001; McEachan et al., 2011; Notani, 1998). To assist in estimating how our persuasive system influences these factors, it is useful to point out that guidelines have been formulated on how to operationalise these constructs (Ajzen, 2010; French & Hankins, 2003).

In this section, we have applied the model to the design of our persuasive lane-specific advice system, and have discussed how this helped shift the focus of our research away from one emphasizing persuasion, to one that includes the driver's behaviour and traffic safety as well. We have shown how this shift will benefit not just traffic safety but the persuasive effectiveness of the system as well.

7. Conclusion

In this paper, we have proposed a conceptual model to help guide the design of persuasive in-vehicle systems with the aim of influencing driver behaviour at the tactical level. The model was designed with safety and persuasion as core elements, and explains how a persuasive in-vehicle system is expected to affect driver behaviour, workload, and safety. The model contains four 'support levels' from the PSD from Oinas-Kukkonen and Harjumaa (2009), that can be used as guidelines for implementing specific persuasive elements in persuasive in-vehicle systems. Similarities exist between ADAS and for example the primary task support level from the PSD, and similarities will likely increase as ADAS become more complex. This provides an interesting possibility for the integration of persuasive driver methods using existing systems.

The proposed model is split into three levels explaining the different elements of the information chain: the system level where the persuasive strategy is formed after a safety check, the information transfer level where communication with the driver takes place, and the driver level where the act of presenting advice impacts driver behaviour, workload and safety in several ways. The focus while designing the model was on safely attaining effective driver persuasion. As a behavioural basis, the Theory of Planned Behaviour was selected. The persuasive elements come from the PSD model. We have discussed how the PSD is built from elements in Gamification, Behavioural Economics and Captology. We have also included elements from Wickens' MRT Model and Fuller's TCI that help explain why the timing and modality of the information transfer are key factors in both safety and persuasive effectiveness. Finally, we have applied the model to a persuasive system which aims to reduce travel time delay and congestion by encouraging a better distribution of the cars over the available motorway lanes, to illustrate how the application of the model guided our research efforts and helped shape a safe and effective design.

Future work will focus on evaluating the best set of persuasive techniques for driver persuasion, as well as the most promising delivery method ('content', 'modality' and 'timing') to ensure persuasive effectiveness as well as safety and low distraction caused by the advice.

Other opportunities for research still exist within the model apart from our planned future work. For example, the building blocks of the described 'safety filter' exist as discussed in the paper, but a unified application that takes the driver into account as well is still lacking.

Several relationships are unique to each specific implementation of an in-car persuasive system and can only be evaluated in that specific context. For example, the indirect effects on behaviour will be different for different systems, and as such will need to be determined every time a new persuasive system is developed and tested.

Persuading drivers is a complex task, especially since the driving environment requires extra considerations in terms of safety, and because the demands the environment places on drivers are highly dynamic. In the near future persuasion might become easier to accomplish once vehicle automation becomes more prevalent: as drivers get used to sharing the driving task with their vehicle, it is likely they develop a stronger sense of trust, which may favour complying with generated advices. The presented work and model in this paper aim to assist those working on driver persuasion by providing a theoretical framework within which persuasive systems can be developed.

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'). Furthermore, we would like to thank Prof. Dr. Bert van Wee for his insightful feedback during the development of the conceptual model.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2018.10.004.

References

Abe, G., & Richardson, J. (2006). Alarm timing, trust and driver expectation for forward collision warning systems. *Applied Ergonomics, 37*(5), 577–586. https://doi.org/10.1016/j.apergo.2005.11.001.

Aghaei, A. S., Donmez, B., Liu, C. C., He, D., Liu, G., Plataniotis, K. N., ... Sojoudi, Z. (2016). Smart driver monitoring: When signal processing meets human factors: In the driver's seat. *IEEE Signal Processing Magazine, 33*(6), 35–48. https://doi.org/10.1109/MSP.2016.2602379.

Ajzen, I. (1991). The theory of planned behavior. *Orgnizational Behavior and Human Decision Processes, 50*, 179–211. https://doi.org/10.1016/0749-5978(91)90020-T.

Ajzen, I. (2010). Constructing a theory of planned behavior questionnaire. *Biofeedback and Selfregulation, 17*, 1–7. https://doi.org/10.1016/0749-5978(91)90020-T.

Alexander, G., & Lunenfeld, H. (1986). Driver Expectancy in Highway Design and Traffic Operations. NHTSA Technical Report. https://doi.org/FHWA-TO-86-1.

Armitage, C. J., & Conner, M. (2001). Efficacy of the theory of planned behaviour: A meta-analytic review. *British Journal of Social Psychology, 40*, 471–499.

Ashraf, K., Wu, B., Iandola, F. N., Moskewicz, M. W., & Keutzer, K. (2016). Shallow networks for high-accuracy road object-detection. https://doi.org/10.5220/0006214900330040.

Avineri, E. (2011). Applying behavioural economics in the design of travel information systems. In *43rd Universities transport study group conference* (pp. 1–12). https://doi.org/10.1017/CBO9781107415324.004.

Avineri, E., Chatterjee, K., Darnton, A., Goodwin, P., Lyons, G., Musselwhite, C., ... Wiltshire, P. (2010). Individual Behaviour Change : Evidence in transport and public health.

Bandura, A. (1971). Social learning theory. *Social Learning Theory*. https://doi.org/10.1111/j.1460-2466.1978.tb01621.x.

Baron, A. S., & Dunham, Y. (2015). Representing 'Us' and 'Them': Building blocks of intergroup cognition. *Journal of Cognition and Development*, 1–22. https://doi.org/10.1080/15248372.2014.1000459.

Birrel, S., Young, M., Staton, N., & Jennings, P. (2017). Using adaptive interfaces to encourage smart driving and their effect on driver workload, *Proceedings of the AHFE 2016 International Conference on Human Factors in Transportation* 484, 31-43. https://doi.org/10.1007/978-3-319-41682-3.

Brick, L. A. D., Velicer, W. F., Redding, C. A., Rossi, J. S., & Prochaska, J. O. (2016). Extending theory-based quantitative predictions to new health behaviors. *International Journal of Behavioral Medicine, 23*(2), 123–134. https://doi.org/10.1007/s12529-015-9506-y.

Carter, P. M., Bingham, C. R., Zakrajsek, J. S., Shope, J. T., & Sayer, T. B. (2014). Social norms and risk perception: Predictors of distracted driving behavior among novice adolescent drivers. *Journal of Adolescent Health, 54*(5), S32–S41. https://doi.org/10.1016/j.jadohealth.2014.01.008.

Castanier, C., Deroche, T., & Woodman, T. (2013). Theory of planned behaviour and road violations: The moderating influence of perceived behavioural control. *Transportation Research Part F: Traffic Psychology and Behaviour, 18*, 148–158. https://doi.org/10.1016/j.trf.2012.12.014.

Chen, H. W., Donmez, B., Hoekstra-atwood, L., & Marulanda, S. (2016). Self-reported engagement in driver distraction : An application of the Theory of Planned Behaviour. *Transportation Research Part F: Psychology and Behaviour, 38*, 151–163. https://doi.org/10.1016/j.trf.2016.02.003.

Chorlton, K., & Conner, M. (2012). Can enforced behaviour change attitudes: Exploring the influence of Intelligent Speed Adaptation. *Accident Analysis & Prevention, 48*, 49–56. https://doi.org/10.1016/j.aap.2010.06.007.

Cialdini, R. B. (2006). *Influence: The psychology of persuasion*. London: Harper Collins Publishers Ltd. https://doi.org/10.1017/CBO9781107415324.004.

Curry, R., Blommer, M., Tijerina, L., Greenberg, J., Kochhar, D., Simonds, C., & Watson, D. (2010). A mental model perspective of a driver workload system. In Proceedings of the human factors and ergonomics society, (Vol. 3, pp. 2096–2100). https://doi.org/10.1518/107118110X12829370264682.

Damiani, S., Deregibus, E., & Andreone, L. (2009). Driver-vehicle interfaces and interaction: Where are they going? *European Transport Research Review, 1*(2), 87–96. https://doi.org/10.1007/s12544-009-0009-2.

Davis, F. D., Bagozzi, R. P., Warshaw, P. R., Davis, F. D., Bagozzi, R. P., Bagozzi, R. P., ... Warshaw, P. R. (1989). User acceptance of computer technology: a comparison of two theoretical models. *Management Science, 35*(8), 982. https://doi.org/10.2307/2632151.

Davis, F. D. (1986). A technology acceptance model for empirically testing new end-user information systems: Theory and results. https://doi.org/oclc/56932490.

de Waard, D. (1996). *The measurement of drivers' mental workload.*. Alphen aan den Rijn: Drukkerij Haasbeek https://doi.org/10.1016/j.apergo.2003.11.009.

de Waard, D., Kruizinga, A., & Brookhuis, K. A. (2008). The consequences of an increase in heavy goods vehicles for passenger car drivers' mental workload and behaviour: A simulator study. *Accident Analysis and Prevention, 40*(2), 818–828. https://doi.org/10.1016/j.aap.2007.09.029.

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. New York: Plenum.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: Defining "Gamification.". In *Proceedings of the 15th international academic mindtrek conference on envisioning future media environments - MindTrek '11* (pp. 9–11). https://doi.org/10.1145/2181037.2181040.

Donmez, B., Boyle, L. N. ,, & Lee, J. D. (2006). The impact of distraction mitigation strategies on driving performance. *Human Factors: the Journal of the Human Factors and Ergonomics Society, 48*(4), 785–804. https://doi.org/10.1518/001872006779166415.

Donmez, B., Boyle, L. N., Lee, J. D., & Mcgehee, D. V. (2006). Drivers ' attitudes toward imperfect distraction mitigation strategies. *Transportation Research Part F: Traffic Psychology and Behaviour, 9*, 387–398. https://doi.org/10.1016/j.trf.2006.02.001.

Dozza, M. (2013). What factors influence drivers' response time for evasive maneuvers in real traffic? *Accident Analysis and Prevention, 58*, 299–308. https://doi.org/10.1016/j.aap.2012.06.003.

Ecker, R., Holzer, P., Broy, V., & Butz, A. (2011). Ecochallenge: A race for efficiency. In *Proceedings of the 13th international conference on multimodal interfaces - ICMI '11, 13* (pp. 91–94). https://doi.org/10.1145/2037373.2037389.

Edgar, G. K. (2007). Accommodation, cognition, and virtual image displays: A review of the literature. *Displays, 28*(2), 45–59. https://doi.org/10.1016/j.displa.2007.04.009.

Efrat, K., & Shoham, A. (2013). The theory of planned behavior, materialism, and aggressive driving. *Accident Analysis and Prevention, 59*, 459–465. https://doi.org/10.1016/j.aap.2013.06.023.

Elliott, M. A., Armitage, C. J., & Baughan, C. J. (2005). Exploring the beliefs underpinning drivers' intentions to comply with speed limits. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(6), 459–479. https://doi.org/10.1016/j.trf.2005.08.002.

Elliott, M., Thomson, J., Robertson, K., Stephenson, C., & Wicks, J. (2013). Evidence that changes in social cognitions predict changes in self-reported driver behavior: Causal analyses of two-wave panel data. *Accident Analysis and Prevention, 50*, 905–916. https://doi.org/10.1016/j.aap.2012.07.017.

Michon, J. A. (1985). A critical view of driver behavior models: What do we know, what should we do? In L. Evans & R. C. Schwing (Eds.), *Human behavior and traffic safety* (pp. 485–520). New York: Plenum Press. https://doi.org/10.1007/978-1-4613-2173-6.

Farzan, R., Dimicco, J. M., Millen, D. R., Brownholtz, B., Geyer, W., & Dugan, C. (2008b). When the experiment is over : Deploying an incentive system to all the users. In *Proceedings of the AISB 2008 symposium on persuasive technology* (pp. 33–38). https://doi.org/10.1145/2145204.2145362.

Farzan, R., Dimicco, J. M., Millen, D. R., Brownholtz, B., Geyer, W., & Dugan, C. (2008a). Results from deploying a participation incentive mechanism within the enterpris. In *Proceedings of the SIGCHI conference on human factors in computing systems (CHI'08)* (pp. 563–572). https://doi.org/10.1145/1357054.1357145.

Ferreira, E., Ferreira, D., Kim, S., Siirtola, P., Röning, J., Forlizzi, J. F., & Dey, A. K. (2014). Assessing real-time cognitive load based on psycho- physiological measures for younger and older adults. *Computational intelligence, cognitive algorithms, mind, and Brain (CCMB)*.

Fishbein, M., & Ajzen, I. (1975). *Belief; attitude, intention and behavior: An introduction to theory and research*. MA: Addison-Wesley.

Fluegge, K. (2016). Social learning theory and public perception of GMOs: What Blancke *et al* . (2015) and other plant biotechnologists are missing. *Journal of the Science of Food and Agriculture, 96*(9), 2939–2940. https://doi.org/10.1002/jsfa.7634.

Fogg, B. J. (1998). Persuasive computers: Perspectives and research directions. In *Proceedings of the SIGCHI conference on human factors in computing systems, (April)* (pp. 225–232). https://doi.org/10.1145/274644.274677.

Fogg, B. J. (2009b). Creating persuasive technologies: An eight-step design process. *Technology, 91*, 1–6. https://doi.org/10.1145/1541948.1542005.

Fogg, B. J. (2009a). A behavior model for persuasive design. In *Proceedings of the 4th international conference on persuasive technology - persuasive '09* (pp. 1). https://doi.org/10.1145/1541948.1541999.

Fogg, B. J. (2010). *Persuasive technology: Using computers to change what we think and do*. Elsevier Science & Technology.

French, D. P., & Hankins, M. (2003). The expectancy-value muddle in the theory of planned behaviour - and some proposed solutions. *British Journal of Health Psychology, 8*(Pt 1), 37–55. https://doi.org/10.1348/135910703762879192.

Friederichs, S. A. H., Bolman, C., Oenema, A., Verboon, P., & Lechner, L. (2016). Exploring the working mechanisms of a web-based physical activity intervention, based on self-determination theory and motivational interviewing. *Internet Interventions, 3*, 8–17. https://doi.org/10.1016/j.invent.2015.11.003.

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident; Analysis and Prevention, 37*(3), 461–472. https://doi.org/10.1016/j.aap.2004.11.003.
Gadong, E. S. A., & Chavez, M. R. (2016). Procrastination and sense of community: Patterns and relationships in a blended learning setting Retrieved from. *Journal of Institutional Research South East Asia, 14*(1), 5–16 http://www.scopus.com/inward/record.url?eid=2-s2.0-84964916782&partnerID=tZOtx3y1.
Green, P. (2004). Driver distraction, telematics design, and workload managers : safety issues and solutions. In *Proc. Int. Congr. Transp. Electron* (pp. 165–180). https://doi.org/10.1167/3.9.157.
Habenicht, S., Winner, H., Bone, S., Sasse, F., & Korzenietz, P. (2011). A maneuver-based lane change assistance system. In *IEEE intelligent vehicles symposium, proceedings* (pp. 375–380). https://doi.org/10.1109/IVS.2011.5940417.
Hamari, J., Koivisto, J., & Pakkanen, T. (2014). Do persuasive technologies persuade?-A review of empirical studies. *Persuasive Technology, 8462*, 118–136. https://doi.org/10.1007/978-3-319-07127-5_11.
Hamari, J., Koivisto, J., & Sarsa, H. (2014). Does gamification work? - A literature review of empirical studies on gamification. In *Proceedings of the annual Hawaii international conference on system sciences* (pp. 3025–3034). https://doi.org/10.1109/HICSS.2014.377.
Hennessy, D. A., & Wiesenthal, D. L. (2001). Gender, driver aggression, and driver violence: An applied evaluation. *Sex Roles, 44*(11–12), 661–676. https://doi.org/10.1023/A:1012246213617.
Hibberd, D. L., Jamson, S. L., & Carsten, O. M. J. (2010). Managing in-vehicle distractions. In *Proceedings of the 2nd international conference on automotive user interfaces and interactive vehicular applications - AutomotiveUI '10, 2* (pp. 4–11). https://doi.org/10.1145/1969773.1969775.
Hoeben, E. M., & Weerman, F. M. (2016). Why is involvement in unstructured socializing related to adolescent delinquency?*. *Criminology, 54*(2), 242–281. https://doi.org/10.1111/1745-9125.12105.
Hoffman, B. D. (2014). Using self-determination theory to improve residency training: learning to make omelets without breaking eggs. *Academic Medicine: Journal of the Association of American Medical Colleges, XXX*(X), 1–3. https://doi.org/10.1097/ACM.0000000000000523.
Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis and Prevention, 38*(1), 185–191. https://doi.org/10.1016/j.aap.2005.09.007.
Kahneman, D. (2003). Maps of bounded rationality: Economicst psychology for behavioral. *The American Economic Review, 93*(5), 1449–1475. https://doi.org/10.1257/000282803322655392.
Kahneman, D. (2013). Thinking fast and slow. *Journal of Chemical Information and Modeling. Penguin Books Ltd.*. https://doi.org/10.1017/CBO9781107415324.004.
Kim, S., Chun, J., & Dey, A. K. (2015). Sensors know when to interrupt you in the car. In *Proceedings of the 33rd Annual ACM conference on human factors in computing systems - CHI '15* (pp. 487–496). https://doi.org/10.1145/2702123.2702409.
Kushnir, V., Godinho, A., Hodgins, D. C., Hendershot, C. S., & Cunningham, J. A. (2015). Motivation to quit or reduce gambling: associations between self-determination theory and the transtheoretical model of change. *Journal of Addictive Diseases, 35*(1), 58–65. https://doi.org/10.1080/10550887.2016.1107315.
Lally, P., & Gardner, B. (2013). Promoting habit formation. *Health Psychology Review, 7*, S137–S158. https://doi.org/10.1080/17437199.2011.603640.
Lee, J., & Moray, N. (1992). Trust, control strategies and allocation of function in human-machine systems. *Ergonomics, 35*(10), 1243–1270. https://doi.org/10.1080/00140139208967392.
Lekes, N., Houlfort, N., Milyavskaya, M., Hope, N. H., & Koestner, R. (2016). The role of intrinsic values for self-growth and community contribution at different life stages: Differentially predicting the vitality of university students and teachers over one year. *Personality and Individual Differences, 98*, 48–52. https://doi.org/10.1016/j.paid.2016.03.093.
Liang, Y., Reyes, M. L., & Lee, J. D. (2007). Real-time detection of driver cognitive distraction using support vector machines. *IEEE Transactions on Intelligent Transportation Systems, 8*(2), 340–350. https://doi.org/10.1109/TITS.2007.895298.
Liu, Y. C., & Wen, M. H. (2004). Comparison of head-up display (HUD) vs. head-down display (HDD): Driving performance of commercial vehicle operators in Taiwan. *International Journal of Human Computer Studies, 61*(5), 679–697. https://doi.org/10.1016/j.ijhcs.2004.06.002.
Lochbuehler, K., Schuck, K., Otten, R., Ringlever, L., & Hiemstra, M. (2016). Parental smoking and smoking cognitions among youth: A systematic review of the literature. *European Addiction Research, 22*(4), 215–232. https://doi.org/10.1159/000446022.
Lütteken, N., Zimmermann, M., & Bengler, K. J. (2016). Using gamification to motivate human cooperation in a lane-change scenario. In *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC* (pp. 899–906). https://doi.org/10.1109/ITSC.2016.7795662.
Magana, V. C., & Organero, M. M. (2011). The impact of using gamification on the eco-driving learning. *Advances in Intelligent and Soft Computing, 92*, 141–148. https://doi.org/10.1007/978-3-642-19937-0.
Martens, M. H., & Jenssen, G. D. (2012). Behavioral adaptation and acceptance. In A. Eskandarian (Ed.), *Handbook of intelligent vehicles* (pp. 117–138). London: Springer-Verlag, London Ltd.. https://doi.org/10.1007/978-0-85729-085-4.
McCall, R., & Koenig, V. (2012). Gaming concepts and incentives to change driver behaviour. In *2012 the 11th Annual mediterranean Ad hoc networking workshop, Med-Hoc-Net 2012* (pp. 146–151). https://doi.org/10.1109/MedHocNet.2012.6257115.
McEachan, R. R. C., Conner, M., Taylor, N. J., & Lawton, R. J. (2011). Prospective prediction of health-related behaviours with the Theory of Planned Behaviour: A meta-analysis. *Health Psychology Review, 5*(2), 97–144. https://doi.org/10.1080/17437199.2010.521684.
Metcalfe, R., & Dolan, P. (2012). Behavioural economics and its implications for transport. *Journal of Transport Geography, 24*, 503–511. https://doi.org/10.1016/j.jtrangeo.2012.01.019.
Millar, M. G., & Millar, K. U. (2000). Promoting safe driving behaviors: The influence of message framing and issue involvement. *Journal of Applied Social Psychology, 30*(4), 853–866. https://doi.org/10.1111/j.1559-1816.2000.tb02827.x.
Miranda, B., Jere, C., Alharbi, O., Lakshmi, S., Khouja, Y., & Chatterjee, S. (2013). Examining the efficacy of a persuasive technology package in reducing texting and driving behavior. In *Lecture notes in computer science (including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics), 7822 LNCS* (pp. 137–148). https://doi.org/10.1007/978-3-642-37157-8_17.
Musicant, O., Lotan, T., & Grimberg, E. (2015). Potential of Group incentive schemes to encourage use of driving safety apps. *Transportation Research Record: Journal of the Transportation Research Board, 2516*(2516), 1–7. https://doi.org/10.3141/2516-01.
Niven, A. G., & Markland, D. (2015). Using self-determination theory to understand motivation for walking: Instrument development and model testing using Bayesian structural equation modeling. *Psychology of Sport and Exercise, 23*, 90–100. https://doi.org/10.1016/j.psychsport.2015.11.004.
Norcross, J. C., Krebs, P. M., & Prochaska, J. O. (2011). Stages of change. *Journal of Clinical Psychology, 67*(2), 143–154. https://doi.org/10.1002/jclp.20758.
Notani, A. (1998). Moderators of perceived behavioral control's predictiveness in the theory of planned behavior: A meta-analysis. *Journal of Consumer Psychology, 7*(3), 247–271. https://doi.org/10.1207/s15327663jcp0703_02.
Oinas-Kukkonen, H. (2013). A foundation for the study of behavior change support systems. *Personal and Ubiquitous Computing, 17*(6), 1223–1235. https://doi.org/10.1007/s00779-012-0591-5.
Oinas-Kukkonen, H., & Harjumaa, M. (2008). A Systematic framework for designing and evaluating persuasive systems. In *Persuasive technology, third international conference, PERSUASIVE 2008, Oulu, Finland, June 4-6, 2008. Proceedings, 5033* (pp. 164–176). https://doi.org/10.1007/978-3-540-68504-3.
Oinas-kukkonen, H., & Harjumaa, M. (2009). Persuasive systems design : Key issues, process model, and system features. *Communications of the Association for Information Systems, 24*(1).
Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 39*(2), 230–253. https://doi.org/10.1518/001872097778543886.
Park, H. S., & Kim, K. H. (2015). Adaptive multimodal in-vehicle information system for safe driving. *ETRI Journal, 37*(3), 626–636. https://doi.org/10.4218/etrij.15.0114.1104.
Peng, Y., Boyle, L. N., & Hallmark, S. L. (2013). Driver's lane keeping ability with eyes off road: Insights from a naturalistic study. *Accident Analysis and Prevention, 50*, 628–634. https://doi.org/10.1016/j.aap.2012.06.013.

Prochaska, J. O., Velicer, W. F., Rossi, J. S., Goldstein, M. G., Marcus, B. H., Rakowski, W., ... Rossi, S. R. (1994). Stages of change and decisional balance for 12 problem behaviors. *Health Psychology, 13*(1), 39–46. https://doi.org/10.1037/0278-6133.13.1.39.

Przybylski, A. K., Murayama, K., DeHaan, C. R., & Gladwell, V. (2013). Motivational, emotional, and behavioral correlates of fear of missing out. *Computers in Human Behavior, 29*(4), 1841–1848. https://doi.org/10.1016/j.chb.2013.02.014.

Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics, 13*(3), 257–266.

Reyes, M. L., & Lee, J. D. (2004). The influence of IVIS distractions on tactical and control levels of driving performance. In *Proceedings of the human factors and ergonomics society annual meeting, 48(September 2004)* (pp. 2369–2373). https://doi.org/10.1177/154193120404801935.

Ridgway, J., Hickson, L., & Lind, C. (2016). Decision-making and outcomes of hearing help-seekers: A self-determination theory perspective. *International Journal of Audiology, 2027*(February), 1–10. https://doi.org/10.3109/14992027.2015.1120893.

Risto, M. (2014). *Cooperative in-vehicle advice*. University of Twente.

Risto, M., & Martens, M. H. (2012). Improving traffic flow on motorways through individual driver advice: A social dilemma? *TRAIL-Beta congress 2012, (October)*.

Risto, M., & Martens, M. H. (2013). Factors influencing compliance to tactical driver advice: An assessment using a think-aloud protocol. In *Proceedings of the 16th international IEEE annual conference on intelligent transportation systems (ITSC 2013)* (pp. 1923–1928). https://doi.org/10.1109/ITSC.2013.6728510.

Rodríguez, M. D., Ibarra, J. E., Roa, J. R., Curlango, C. M., Bedoya, L. F., & Montes, H. D. (2014). Ambient gamification of automobile driving to encourage safety behaviors. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 8867*(2002), 37–43. https://doi.org/10.1007/978-3-319-13102-3_8.

Sagberg, F., Fosser, S., & Sætermo, I. A. F. (1997). An investigation of behavioural adaptation to airbags and antilock brakes among taxi drivers. *Accident Analysis and Prevention, 29*(3), 293–302. https://doi.org/10.1016/S0001-4575(96)00083-8.

Schakel, W. J., & Van Arem, B. (2014). Improving traffic flow efficiency by in-car advice on lane, speed, and Headway. *IEEE Transactions on Intelligent Transportation Systems, 15*(4), 1597–1606. https://doi.org/10.1109/TITS.2014.2303577.

Sebire, S. J., Kesten, J. M., Edwards, M. J., May, T., Banfield, K., Tomkinson, K., ... Jago, R. (2016). Using self-determination theory to promote adolescent girls' physical activity: Exploring the theoretical fidelity of the Bristol Girls Dance Project. *Psychology of Sport and Exercise, 24*, 100–110. https://doi.org/10.1016/j.psychsport.2016.01.009.

Shi, C., Lee, H. J., Kurczak, J., & Lee, A. (2012). Routine driving infotainment app: Gamification of performance driving. In *Proceedings of the 4th international conference on automotive user interfaces and interactive vehicular applications (AutomotiveUI'12)* (pp. 181–183).

Smiley, A. (2000). Behavioral adaptation, safety, and intelligent transportation systems. *Transportation Research Record, 1724*, 47–51. https://doi.org/10.3141/1724-07.

Solovey, E. T., Zec, M., Garcia Perez, E. A., Reimer, B., & Mehler, B. (2014). Classifying driver workload using physiological and driving performance data. In *Proceedings of the 32nd annual ACM conference on human factors in computing systems - CHI '14* (pp. 4057–4066). https://doi.org/10.1145/2556288.2557068.

Staunton, L., Gellert, P., Knittle, K., & Sniehotta, F. F. (2015). Perceived control and intrinsic vs. extrinsic motivation for oral self-care: A full factorial experimental test of theory-based persuasive messages. *Annals of Behavioral Medicine, 49*(2), 258–268. https://doi.org/10.1007/s12160-014-9655-2.

Steinberger, F., Proppe, P., Schroeter, R., & Alt, F. (2016). CoastMaster: An ambient speedometer to gamify safe driving. In *Proceedings of the 8th international conference on automotive user interfaces and interactive vehicular applications* (pp. 83–90). https://doi.org/10.1145/3003715.3005412.

Stutts, J., & Gish, K. (2003). Distraction in everyday driving. *AAA Foundation for Trafic Safety*. https://doi.org/10.1037/e364102004-001.

Twisk, D., & Stacey, C. (2007). Trends in young driver risk and countermeasures in European countries. *Journal of Safety Research, 38*, 245–257. https://doi.org/10.1016/j.jsr.2007.03.006.

Ulrich, T. A., Spielman, Z., Holmberg, J., Hoover, C., Sanders, N., Gohil, K., & Werner, S. (2013). Playing charades with your car - the potential of free-form and contact-based gestural interfaces for human vehicle interaction. In Proceedings of the human factors and ergonomics society annual meeting (Vol. 57, No. 1 pp. 1643–1647). https://doi.org/10.1177/1541931213571365.

Van Gent, P., Farah, H., Van Nes, N., & Van Arem, B. (2017). Towards Real-time, nonintrusive estimation of driver workload: A simulator study. *Road safety and simulation 2017 conference proceedings*.

van Gent, P., Farah, H., van Nes, N., & van Arem, B. (2018). Analysing noisy driver physiology real-time using off-the-shelf sensors: heart rate analysis software from the taking the fast lane project. *Submitted to Journal of Open Research Software*.

van Gent, P., Melman, T., Farah, H., van Nes, N., & van Arem, B. (2018a). Multi-class driver workload prediction using machine learning and off-the-shelf sensors. *Submitted to Transportation Research Board Conference 2018*.

van Gent, P., Melman, T., Farah, H., van Nes, N., & van Arem, B. (2018b). Multi-level driver workload prediction using machine learning and off-the-shelf sensors. *Transportation Research Record: Journal of the Transportation Research Board.*. https://doi.org/10.1177/0361198118790372.

van Nes, N., & Duivenvoorden, K. (2017). Safely towards self-driving vehicles. https://doi.org/R-2017-2E.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User Acceptance of information technology: Toward a unified view. *MIS Quarterly, 27*(3), 425–478.

Vlakveld, W. (2011). *Hazard anticipation of young novice drivers*. SWOV Institute for Road Safety Research.

Vlassenroot, S., Brookhuis, K., Marchau, V., & Witlox, F. (2010). 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). *Transportation Research Part F: Traffic Psychology and Behaviour, 13*(3), 164–178. https://doi.org/10.1016/j.trf.2010.02.001.

Watkins, W. C. (2016). A social learning approach to prescription drug misuse among college students. *Deviant Behavior, 37*(6), 601–614. https://doi.org/10.1080/01639625.2015.1060799.

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3*(2), 159–177. https://doi.org/10.1080/14639220210123806.

Wu, Y., Li, C., & Khoo, S. (2015). Predicting future volunteering intentions through a self-determination theory perspective. *Voluntas*, 1266–1279. https://doi.org/10.1007/s11266-015-9570-6.

Young, M. S., Brookhuis, K. A., Wickens, C. D., & Hancock, P. A. (2014). State of science: mental workload in ergonomics. *Ergonomics, 0139*(January 2015), 1–17. https://doi.org/10.1080/00140139.2014.956151.

Young, M. S., Brookhuis, K. A., Wickens, C. D., & Hancock, P. A. (2015). State of science: mental workload in ergonomics. In Ergonomics (Vol. 58, pp. 1–17). https://doi.org/10.1080/00140139.2014.956151.

Young, K., & Regan, M. (2007). Driver distraction : A review of the literature. *Distracted Driving*, 379–405. https://doi.org/10.1201/9781420007497.

Yusufov, M., Rossi, J. S., Redding, C. A., Yin, H. Q., Paiva, A. L., Velicer, W. F., ... Prochaska, J. O. (2016). Transtheoretical model constructs' longitudinal prediction of sun protection over 24 months. *International Journal of Behavioral Medicine, 23*(1), 71–83. https://doi.org/10.1007/s12529-015-9498-7.

Zaso, M. J., Park, A., Jueun, K., Gellis, L. A., Kwon, H., & Maisto, S. A. (2016). The associations among prior drinking consequences, subjective evaluations, and subsequent alcohol outcomes, *Psychology of Addictive Behaviors*, 30(3), 367-376. https://dx.doi.org/10.1037/adb0000166.