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Framework for behaviour change implemented in real-time and post-trip interventions of the H2020 i-DREAMS naturalistic driving project

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Abstract

The aim of the European funded Horizon 2020 project i-DREAMS[†] is to develop, implement and evaluate a cluster of innovative real-time and post-trip interventions to improve road safety among both private and professional drivers operating different modes in road (i.e., car, bus, truck) and rail by means of a field trial with 600 participants in five different countries (i.e., Belgium, UK, Germany, Greece, and Portugal). This paper presents the theoretical paradigms of behavioural change adopted in the i-DREAMS interventions, and elaborates on the methodological framework used to determine intervention objectives, select suitable techniques for behavioural change, and further translate these into a series of gamification features to be integrated into an in-vehicle feedback display, and a smartphone app supported by an online web-platform.

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Keywords: i-DREAMS; nudging; boosting; gamification; persuasive technology; Intervention Mapping

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†Information about the i-DREAMS project can be found on the website: https://idreamsproject.eu

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1. Introduction

The i-DREAMS project hinges upon the Task-Capability Interface Model (Fuller, 2000). Central is the idea that road users self-regulate their behaviour in function of personal estimations of the (im)balance between imposed task demand and available coping capacity. According to Horrey et al. (2015), driver calibration (i.e., the closed-loop process of sampling, judging, and acting upon the world) is constantly ongoing while driving, but at the same time, is under the influence of factors more stable over time. Influencing calibration *while driving*, implies an intervention that operates within a (milli)second time window, and that triggers the appropriate response in an almost automatic way every time the situation would require so. This actually aligns with 'nudging', i.e., deliberately changing behaviour by modifying cues in the physical/social context in which people act and through activation of nonconscious thought processes involved in human decision-making (Marchiori et al., 2017: p.3). Different from that, the influence on more stable factors is not limited to a specific situation or context, and typically requires reflective learning. This aligns with 'boosting', i.e., fostering people's competence to make their own choices – that is, to exercise their own agency (Hertwig and Grüne-Yanoff, 2017: p.1). The i-DREAMS interventions integrate nudging strategies (i.e., the real-time interventions) and boosting strategies (i.e., the post-trip interventions) to keep vehicle operators as much as possible within the acceptable boundaries of safe vehicle operation. Nudging strategies are operational *during* a trip and primarily meant to steer vehicle operators' decision-making while driving. Boosting strategies are operational *prior to or after* a trip and are primarily meant to empower vehicle operators in taking appropriate decisions while driving. More in detail, the i-DREAMS interventions are running on a platform that consists of two pillars, i.e., a monitoring module that makes a continuous and in-real-time assessment of task complexity and coping capacity and from that assessment, determines where inside the Safety Tolerance Zone (i.e., normal driving phase, danger phase, avoidable crash phase) a vehicle operator is situated (pillar I). The output of the monitoring module serves as input for the intervention module (i.e., pillar II) which combines real-time interventions (i.e., an in-vehicle display with visual and auditory feedback) with post-trip interventions (i.e., a smartphone app and a web-based coaching platform).

The current paper elaborates on the process of intervention development, and provides further details about design features and functionalities of the in-vehicle warning device, the smartphone app and the web dashboard. Illustrative screenshots of the in-vehicle display and the smartphone app are included to demonstrate how these different intervention devices were designed, and to illustrate what they are intended to do.

2. Methods

2.1. Intervention Mapping

To put theory into practice and initiate the process of intervention development, Intervention Mapping (IM) (Bartholomew Eldredge et al., 2016) was used as the organizing framework. IM is a 6-step methodology that provides a vocabulary for program planning, and maps the path from recognition of a need or problem to the identification of a solution. The first two steps of IM (i.e., needs assessment and formulation of intervention objectives) serve to gain a better understanding of the targeted problem (i.e., unsafe vehicle operation) and result in a so-called logic model of behaviour change. Following the COM-B Model (Michie et al., 2011), relevant Capacity-, Motivation-, and Opportunity-related factors that determine safe vehicle operation were inventoried. In step 3 of IM, suitable techniques for behavioural change are selected, using the Behaviour Change Taxonomy v1 (Michie et al., 2013). In step 4 of IM, these techniques are further translated into a set of gamification features (e.g., feedback, scores, credits, leaderboard, goals, challenges, quiz, etc.), which are then incorporated into an in-vehicle warning display and a smartphone app combined with an online web-dashboard for coaching, respectively. Step 5 (i.e., intervention implementation) and Step 6 (i.e., intervention evaluation) of IM fall outside the scope of this paper. This exercise resulted in a so-called 'operational toolbox' that contained what was needed to build the real-time and post-trip interventions. The main compartments of this toolbox are discussed in the next section.

2.2. The operational toolbox for the i-DREAMS interventions

The operational toolbox actually indicates what needs to be changed and how that change will be realized. The first compartment is where the *safety outcomes* can be found. Safety outcomes represent the highest level of impact targeted by the i-DREAMS interventions (i.e., crash reduction). The second compartment contains the *safety promoting goals* (SPG). These represent the domains of driver behaviour that need to change. The third compartment is dedicated to the *performance objectives* (PO), i.e., the more specific actions or behavioural parameters that need to change. The fourth compartment includes the *change objectives* (CO). These apply to the underlying determinants of driver behaviour that need to change. The fifth compartment contains the *change methods* (i.e., theoretical principles or processes for behavioural change such as goal setting). Compartment six includes the *practical applications*, i.e. the translation of the selected change methods into practically applicable formats.

3. Results

3.1. The logic model of change

As can be derived from how the operational toolbox is organized, there is a certain logic behind how the i-DREAMS interventions are believed to generate the desired impact. This logic is based on the (hierarchically structured) assumption that if vehicle operators are capable of and motivated to adopt safe behaviour, and if they have the opportunity to do so (i.e., change objectives), the probability that they demonstrate safe behaviour will be higher (i.e., performance objectives and safety promoting goals), and as a consequence, a reduction in crashes will be more likely (i.e., safety outcome). At the level of behaviour, six SPGs were included in the i-DREAMS project, i.e., vehicle control (three underlying POs), sharing the road with others (five underlying POs), speeding (one underlying PO), driver fitness (two underlying POs), and use of the i-DREAMS in-vehicle device (one underlying PO).

Figure 1 below gives a more detailed overview of (a selection of) performance objectives associated with the SPG *sharing the road with others*. Moreover, it indicates (a selection of) metrics used to capture the different performance objectives as well as (a selection of) sensors employed to collect the required data. Figure 1 also shows which performance objectives are collected for the different modes in the i-DREAMS project (i.e., bus, truck, car, train, tram) and whether they are targeted by the real-time interventions and/or the post-trip interventions alone. The selection of safety promoting goals and performance objectives was based on literature review and stakeholder consultancy (see Talbot et al., 2020). For more information about sensor selection, we refer to Katrakazas et al. (2020).

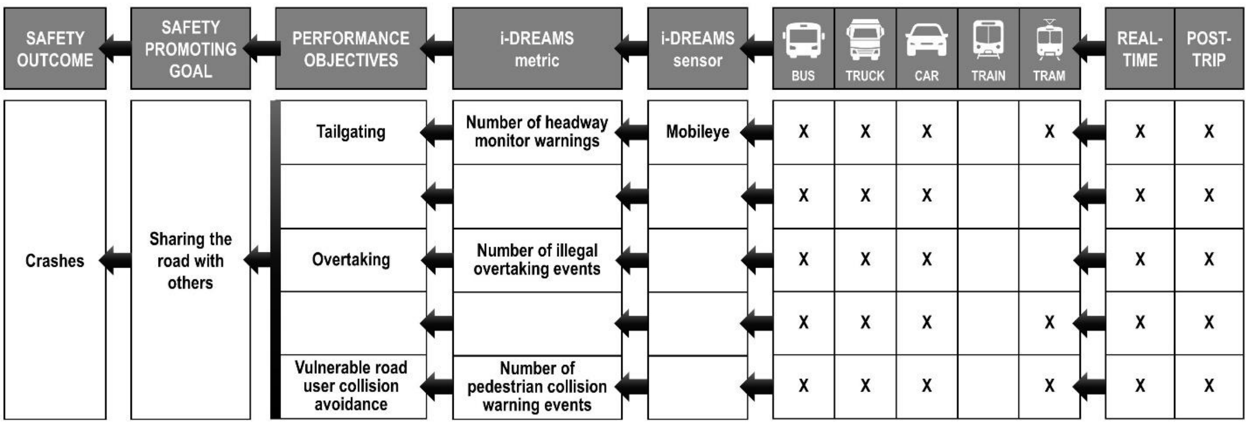

Fig. 1. Overview of (a selection of) performance objectives, metrics, and sensors for the SPG ‘sharing the road with others’

Once the safety promoting goals and their related performance objectives were defined, the COM-B model was used as a guideline to define and select relevant socio-cognitive determinants to be included as to-be-targeted change objectives in the i-DREAMS interventions. The COM-B Model is actually a holistic summary of more than thirty different psychological theories that explain which factors determine human behaviour (Michie et al., 2011). The central tenet behind the model is that for any behaviour to occur, one or more of the following three concepts are required: *capability* (i.e., a person's ability to perform a certain behaviour), *motivation* (i.e., a person's willingness to perform a certain behaviour), and *opportunity* (i.e., facilitators or inhibitors that enable or prevent a person to perform a certain behaviour). Within each of these three theoretical domains (i.e., capability, motivation and opportunity), more specific socio-cognitive variables were identified for inclusion as targets for the real-time and post-trip interventions. To illustrate, for the real-time interventions, the variables 'attention' and 'understanding' were selected as to-be-targeted change objectives inside the capability domain since vehicle operators should be mentally ready to react when necessary (i.e., attention), and knowledgeable of how to appropriately adapt their behaviour (i.e., understanding). For the post-trip interventions, 'attitude' and 'self-efficacy' were selected as to-be-targeted change objectives in the motivation domain because without a favorable disposition towards safety (i.e., attitude) and sufficient confidence in the ability to drive safely under challenging conditions (i.e., self-efficacy), vehicle operators will probably not demonstrate safe driving behaviour. For more details on how we used the COM-B Model and selected socio-cognitive determinants, see Brijs et al. (2020).

3.2. Behaviour change techniques

Behaviour change techniques (BCT) can be defined as the active components of an intervention designed to change behaviour (Michie et al., 2013). The selection of BCTs was based on the Behaviour Change Taxonomy v1 (BCTTv1), i.e., a taxonomy containing 93 BCTs clustered into 16 groups. For instance, 'instruction on how to perform a behaviour' is a BCT that falls within group 4, i.e., 'shaping knowledge'. The rationale behind the BCTTv1is that BCTs should be selected in function of whether they match with the socio-cognitive determinant they are meant to change. For example, BCTs in group 8, i.e., 'repetition and substitution' are especially useful in case the objective is to change a bad 'habit'. Returning to the i-DREAMS real-time interventions, 'prompts/cues' was the specific BCT selected to achieve the change objective related to 'attention', and 'feedback on behaviour' was the BCT selected to achieve the change objective related to 'understanding'. For the post-trip interventions, 'pros and cons' were one BCT selected to achieve the change objective related to 'attitude' and 'focus on past success' was one of the BCTs selected to achieve the change objective related to 'self-efficacy'. For more information on the selection BCTs, see Brijs et al. (2020).

3.3. Practical applications

For the practical design of the i-DREAMS interventions, the Persuasive Systems Design (PSD) Model from Oinas-Kukkonen and Harjumaa (2009) was consulted. From that model, it can be derived that gamification is a suitable way to practically apply the selected BCTs in the i-DREAMS interventions. Gamification refers to the application of game-specific design elements, mechanisms and features in a non-gaming context (Deterding et al., 2011) and is generally aimed at increasing intrinsic motivation. Following Rigby and Ryan (2011), intrinsic motivation requires the fulfilment of three basic human needs, i.e., competence (the feeling that one is capable of doing a certain task), autonomy (the feeling that one is in control over doing a certain task) and relatedness (the feeling that engagement in a certain task is meaningful to oneself and to important social referents). Put differently, gamification is overall aimed at influencing what according to the COM-B Model are the main determinants of behaviour. To translate the selected BCTs into gamification features, the Periodic Table of Gamification Elements was used (see Marczweski, 2018). To illustrate, for the real-time interventions, the game mechanic 'signposting' (i.e., just in time cues to point people who are stuck into the right direction) was used to practically apply the BCT 'prompts/cues'. For the post-trip interventions, the game mechanics 'points', 'badges' and 'leaderboard' were used to practically apply the BCT 'focus on past success'. For more information on the application of gamification in the i-DREAMS interventions, see Brijs et al. (2020).

3.4. Critical design parameters

Practical applications of BCTs can only be effective if their design accounts for so-called ‘critical design parameters’, i.e., design characteristics that determine whether the practically applied BCTs will result in their intended effect.

For the real-time interventions, an in-vehicle display device installed on top of the dashboard was used as message carrier (see Figure 2). The messages were designed based on guidelines as proposed by the Eco-feedback Design-Behaviour Framework (see Sanguinetti et al., 2018). According to this framework, for real-time messages to be effective, these should be salient (i.e., they must attract attention), precise (i.e., they should trigger a learning process), and meaningful (i.e., they should induce the appropriate motivation). These three requirements are primarily dependent upon three specific design features, i.e., display, timing, and information. As for the *display device*, the 20-items checklist for the design of Human-Machine Interfaces as proposed by Naujoks et al. (2019) was used as a guideline during the design process. As for *timing*, we followed up on literature where dynamic issuing of in-vehicle warnings based on flexible thresholds was found to increase effectiveness and user acceptance (e.g., Panou, 2018). More in detail, the timing of messages for tailgating, fatigue and speeding were made situationally adaptive in a sense that timing was dependent upon specific aspects of available operator capacity and/or imposed task complexity. For instance, a message for ‘tailgating’ indicating entrance of the ‘danger phase’ inside the Safety Tolerance Zone is triggered sooner than normal, in case vehicle operators are fatigued or distracted, or in case of rainy weather. As for *information*, formal visual properties of message signs (e.g., colour, size, font, shape or level of animation) often carry a typical figurative meaning (e.g., ‘danger’, ‘safe’, ‘obligation’, ‘restriction’, ‘prohibition’, ‘urgent’, ‘important’). These connotative values can be further reinforced by means of the acoustic properties of sounds (i.e., pitch, loudness, and tone). More specifically, the intention was to design easily ‘guessable’ messages, i.e., messages that convey their meaning almost instantly and that can be processed, understood and reacted upon in milliseconds. According to Ng and Chan (2007), this requires the following semiotic criteria to be met: familiarity, concreteness, simplicity, meaningfulness and semantic closeness (see Figure 2).

As for the post-trip interventions (i.e., a smartphone app and a supportive web-platform for coaching), two critical design parameters in particular were accounted for to increase user engagement and retention, i.e., individually tailored implementation of BCTs, and persuasive messaging (e.g., Kaptein and van Halteren, 2013). According to the Transtheoretical Model of Behaviour Change (Prochaska and DiClemente, 1983), people are different in terms of how receptive they are to the idea of changing their behaviour. Self-Determination Theory (Deci and Ryan 1985), adds to that the idea that people are motivated differently depending on where they are in the process of behavioural change. These differences in both the quantity (i.e., how much you want to change behaviour) and quality (i.e., why it is you want to change behaviour) of motivation plead in favour of a stage-matched selection and use of BCTs. As an illustration of how we adopted the principle of tailored implementation of BCTs in the i-DREAMS post-trip interventions: offering challenges and setting goals targeting an improvement of a person’s driving style does not motivate people that refuse to see or unwillingly ignore problems associated with their current driving style (i.e., so-called ‘precontemplators’). Making them aware of the present potential and importance of such improvement, and influencing their decisional balance so that the pros of engaging in behavioural change outweigh the cons, are more appropriate techniques to use in that stage of change.

Persuasive messaging was a second critical design parameter accounted for. This relates to the high rate of disengagement among individuals who choose to install an app: over 80% of app users use it only once and eventually delete it, and only 5% of the apps continue to be used beyond a month (see Bidargaddi et al., 2018). One factor affecting dropout in mobile app use, is the timing of messaging: users are likely to drop out if messages do not meet expectations and needs at the right time. Most app-based interventions adopt prompting as a strategy to encourage interaction and engagement. In apps, prompts are implemented as push notifications with both the content and timing of a push notification being programmable. In the Fogg Behavior Model (Fogg, 2009), three types of prompts are described, i.e., *sparks* (designed for those who need motivational support and meant to trigger a form of pleasure, a sense of hope, or social acceptance), *facilitators* (designed for those who lack capability, typically indicating that tasks are attainable and that people have the means to accomplish them), and *signals* (serving as reminders to perform a certain behaviour when capability and motivation are already in place). A set of decision rules was developed to intelligently manage a suit of push notifications consisting of a selection of sparks, facilitators and signals. An example of a spark notification is a message (‘Well done! Some of your colleagues already took up the next goal!’) that is automatically pushed when a driver has accomplished a goal.

3.5. Design mockups

The real-time interventions consisted of a series of warning messages displayed via a nomadic device (i.e., Nextion 2.4-inch display) able to prompt visual and auditory cues (see Figure 2). This device is installed on top of the dashboard. The icons and symbols selected are very well known and familiar to vehicle operators. To illustrate, for lane discipline and lane departure avoidance, two full white lines intuitively refer to the lane edges being detected. A dotted white line combined with a series of short sharp beeps represents an edge line being crossed (i.e., an unintended lane departure, or an intended one without use of the indicator). The colour codes used for some of the icons and symbols (green vs red) are also invested with well-known connotative meanings (safe vs dangerous). Moreover, animated (i.e., more intrusive) effects are proposed in potentially critical situations (e.g., flickering of an enlarged car icon in case of a critical forward collision avoidance warning). Acoustic properties of sound vary as well (e.g., changes in loudness and pitch) in function of how critical a warning is, with the level of intrusiveness increasing from danger phase to avoidable crash phase.

Fig. 2. Real-time intervention device: front view of the graphical user interface - main page

For the post-trip interventions, a smartphone app (Android and iOS) with a supportive web-based coaching dashboard were developed. The dashboard serves as a means for driver coaches to manage settings, define projects and groups, (de)activate gamification features, tailor gamification features (e.g., calibration of goals and challenges), post messages, et cetera. Gamification features are offered to drivers under the form of the following app functionalities (for more detailed descriptions, see Vanrompay et al., 2020): scores, trips (i.e., a GPS trace representation of a selected trip on a map, together with (a video of severe) events that happened during that trip), forum, pros & cons, tips, goals, challenges and badges, leaderboard, survey (i.e., a series of knowledge quizzes about safe driving), and shop. Below, the following screenshots are included: the home screen (Figure 3, panel a), the screen with GPS trace representations of a trip on a map (Figure 3, panel b), and the screen with goals and badges (Figure 3, panel c).

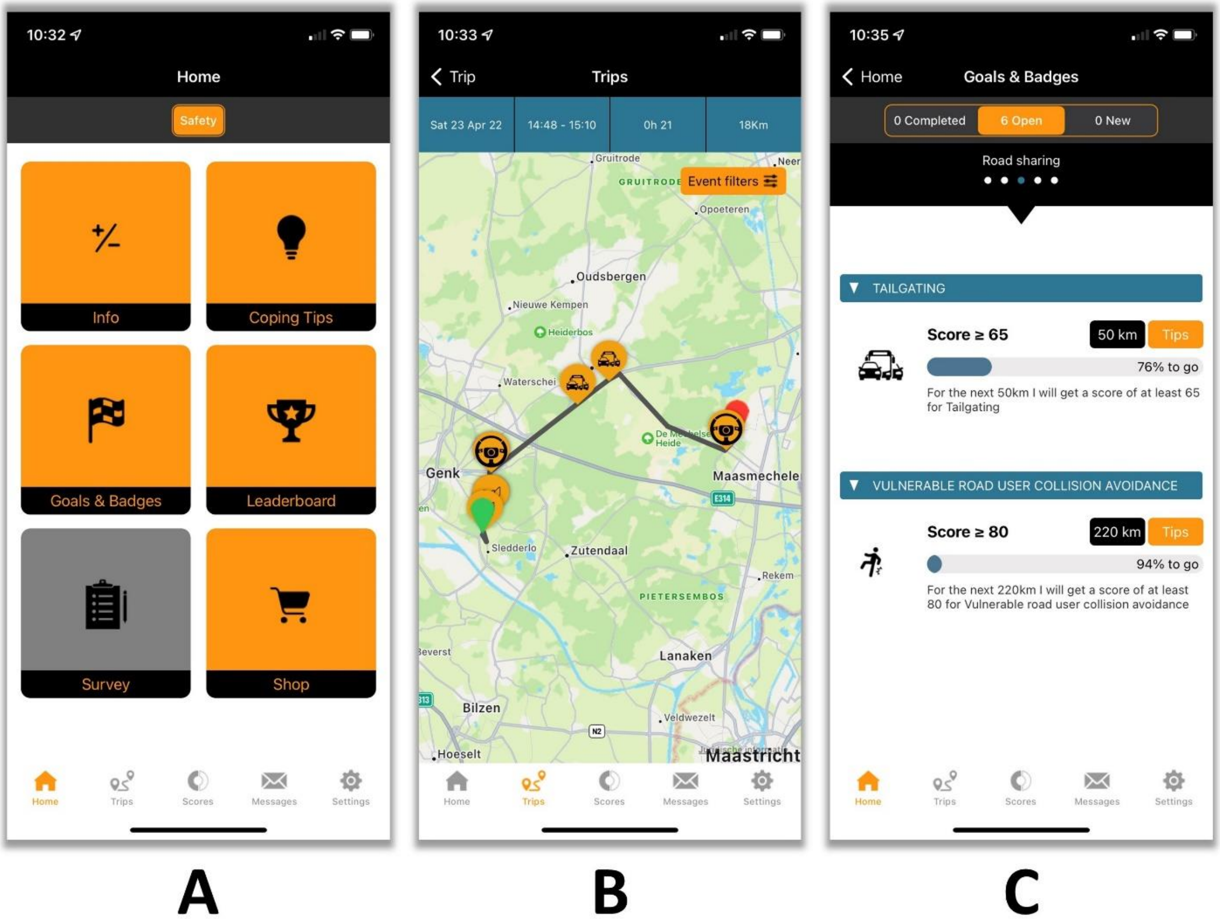

Fig. 3. (a) Home screen; (b) trip on map; (c) goals & badges

4. Conclusion

Intervention Mapping served as the main guideline for development of the i-DREAMS interventions. For the creation of a logic model of change, as well as for the selection of suitable BCTs, and the translation of BCTs into suitable practical applications, use was made of the most recent theoretical- and empirical insights coming from the field of behaviour change. Currently, the i-DREAMS project is in step 5 of IM, i.e., intervention implementation. Based on a naturalistic field trial, the real-time and post-trip interventions are tested for their effectiveness. The final step of IM will be to evaluate the impact of the interventions on the targeted outcomes, as well as the quality of the implementation process with a focus on user experience-related factors such as usability, usefulness, comprehensibility, attractiveness, trust, learnability, etc.

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