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D7.1
Methodology for the evaluation of interventions

Safe tolerance zone calculation and interventions for driver-vehicle-environment interactions under challenging conditions

iDREAMS

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Glossary and Abbreviations

Abbreviation	Description	Abbreviation	Description
ABA	Aggregation Based Analysis	PI	Performance Indicators
ACC	Adaptive Cruise Control	PO	Performance Objectives
ADAS	Advanced Driver Assistance System	PRM	Physical Risk Modelling
AIDE	Adaptive Integrated Driver-vehicle Interface	PW	Pedestrian Warning
BLIS	Blind Spot Information System	RE-AIM	Reach, Effectiveness, Adaption, Implementation and Maintenance
CO	Change Objectives	RMS	Root Mean Square
COM-B	Capability, Opportunity, Motivation - Behavior	SA	Situational Awareness
CTW	Cross Traffic Collision Warning	SL	Speed Limit
CSW	Curve Speed Warning	SO	Safety Outcomes
EASY	Effects of Automated Systems on Safety	SPAD	Signal Passed AT Danger
EBA	Event Based Analysis	SPG	Safety Promoting Goals
euroFOT	European Field Operational Test	SRR	Steering Wheel Reversal Rate
FCW	Forward Collision Warning	STZ	Safety Tolerance Zone
GW	Generic Warning	SW	Stop Sign Warning
HASTE	Human Machine interaction And the Safety of Traffic in Europe	TDF	Theoretical Domains Framework
HFC	High Frequency Component	TET	Time Exposed-TTC
IM	Intervention Mapping	TLC	Time-To-Line Crossing
ISA	Intelligent Speed Adaptation	TLW	Traffic Light Warning
ISPS	Intelligent Speeding Prediction System	TPB	Theory of Planned Behavior
IVDR	in-Vehicle Data Recorder	TTC	Time-To-Collision
KPIs	Key Performance Indicators	UFOV	Useful Field Of View
LDW	Lane Departure Warning	UFCW	Urban Forward Collision Warning
OHS	Occupational Health and Safety	UMDA	Unified Model of Driver Acceptance
OTW	Oncoming Traffic Warning	VRU	Vulnerable Road Users

Executive summary

This deliverable aims to provide the methodology for the evaluation of both real-time and post-trip safety interventions, which will be developed to improve driver safety through keeping the driver within the boundaries of the 'Safety Tolerance Zone'. In particular, the methodology will cover all the features and particularities of each one of the interventions examined, as well as the statistical issues involved in effectiveness assessment of interventions.

In order to evaluate the effectiveness of the safety interventions, the logic model of change behind the *i*-DREAMS interventions (comprising of Safety Outcomes (SO), Safety Promoting Goals (SPG), Performance Objectives (PO) and Change Objectives (CO) is presented and the dependency among the different levels was highlighted. Moreover, it was sought to link the SO, SPG, PO, and CO with driving behavior and safety critical indicators, in order to identify the potential measurements to be provided from the *i*-DREAMS platform and will be utilized for intervention assessment. For the interventions taking place in a professional work setting, data analysis and interpretation of results will have to take companies' safety climate into account, as this can be expected to be a crucial environmental factor influencing intervention effectiveness. In line with corporate safety climate, individual user acceptance is also to be included in the analysis and interpretation of intervention effectiveness.

In addition, an overview of past methodologies and frameworks from literature that have been used to assess interventions was described. It was revealed that safety promoting goals and performance objectives had the greatest effect on the assessment of interventions. Although safety constitutes the cornerstone of the *i*-DREAMS project, little evidence for safety outcomes was identified, due to the limited time framework of interventions and the fact that the crashes were rare events. Safety promoting goals (i.e. driver fitness, vehicle control, speed management) appeared to have an influence in a great extend for the assessment of interventions. Moreover, performance objectives, and especially, speeding, harsh acceleration, harsh braking, lane deviation and left turns had the strongest impact on the evaluation of interventions, while driver related characteristics such as distraction, stress, fatigue, drowsiness, attentions, concentration and blind spot appeared to have lower impact.

The final section of the deliverable deals with the evaluation methodology, based on the aforementioned different safety levels of the logic model of change. The ultimate purpose of the methodology is a summative assessment focusing on outcome and process evaluation. At the beginning of the evaluation, appropriate research questions need to be defined and indicators, measures and determinants need to be outlined. The criteria, KPIs and user acceptance, acceptability and reliability factors, which will support the assessment are also thoroughly described in this document.

Methodologically, three different methods are proposed: before-after analysis, case-control trials and questionnaires. With regards to before-after analysis, both quantitative (i.e. safety outcomes, safety promoting goals, performance objectives) and observed qualitative (i.e. change objectives) indicators can be utilized, and comparisons can be drawn using before-after or case-control study designs. Questionnaires, will be exploited mostly for the evaluation of qualitative indicators (i.e. change objectives)

Finally, following the design of the assessment methodology, the crucial next step within the *i*-DREAMS project is connected with the organization of the back-office database, which will provide all necessary data for the realization of the individual evaluations as well as the comparisons between different countries and transportation modes.

1 Introduction

The goal of this section is to provide a brief outline of the objectives of the specific deliverable, how those are aligned and relevant with the overall project, and which approach was followed in order to achieve them.

1.1 About the project

The overall objective of the *i*-DREAMS project is to setup a framework for the definition, development, testing and validation of a context-aware safety envelope for driving ('Safety Tolerance Zone'), within a smart Driver, Vehicle & Environment Assessment and Monitoring System (*i*-DREAMS). Taking into account driver background factors and real-time risk indicators associated with the driving performance as well as the driver state and driving task complexity indicators, a continuous real-time assessment will be made to monitor and determine if a driver is within acceptable boundaries of safe operation (i.e. Safety Tolerance Zone). Moreover, the to-be-developed *i*-DREAMS platform will offer a series of in-vehicle interventions, meant to prevent drivers from getting too close to the boundaries of unsafe operation and to bring them back into the safety tolerance zone while driving. The safety-oriented interventions will be developed to inform or warn the driver real-time in an effective way as well as on an aggregated level after driving through an app- and web-based gamified coaching platform, thus reinforcing the acquisition of safer driving habits/behaviors. Consequently, the *i*-DREAMS platform will allow the implementation of the two aforementioned safety interventions, meant to motivate and enable human operators to develop the appropriate safety-oriented attitude.

Specifically, the in-vehicle interventions are meant to assist and support vehicle operators in real-time (i.e. while driving). Depending on how imminent crash risks are, a distinction can be made between a 'Normal driving' phase, a 'Danger' phase, and an 'Avoidable Accident' phase. In the normal driving phase, no abnormalities in a vehicle operator's driving style are detected by the monitoring pillar of the *i*-DREAMS platform, and no sign of a crash course initiating is present. Consequently, no real-time intervention is required. In the danger phase, abnormal deviations from the vehicle operator's driving style are detected by the *i*-DREAMS monitoring module, and the potential for a crash course to unfold is present. A warning signal is to be issued in that case. In the avoidable accident phase, deviations from normal driving have evolved even further, and the risk for a crash to occur will become imminent if the vehicle operator does not adapt appropriately to the present circumstances. A more intrusive warning signal is to support vehicle operators in avoiding a collision.

With regards to post-trip interventions, these are not operational while driving, but they are based on what happens during a trip. They hinge upon all the raw data that is captured by the *i*-DREAMS sensors, which is further processed and fused into information about a vehicle operator's driving style, how it evolved during a trip, how many (safety-critical) events occurred, and in which circumstances these events happened. This information can be further translated into feedback consultable for vehicle operators via an app in a pre- or post-trip setting. To establish a longer-term relationship with individual vehicle operators, app-supported feedback can be combined with the use of a web-based coaching platform, containing so-called gamification features meant to motivate drivers to work on a gradual and persistent improvement of their driving.

Figure 1 summarizes the conceptual framework, which will be tested in a simulator study and three stages of on-road trials in Belgium, Germany, Greece, Portugal and the United Kingdom with a total of 600 participants representing car, bus, truck and tram/train drivers.

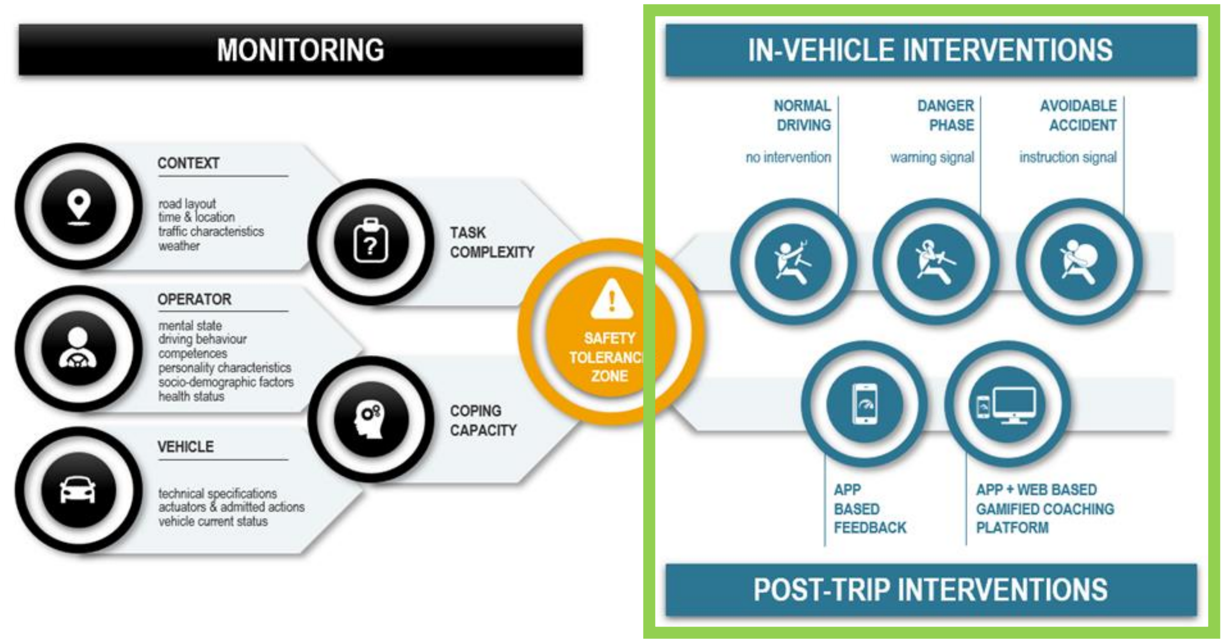


Figure 1: Conceptual framework of the i-DREAMS platform. The green frame indicates the thematic scope of this deliverable (see section 1.2)

Expected by the end of the project in 2022, the key output of the project will be an integrated set of monitoring and communication tools for intervention and support, including in-vehicle assistance and feedback and notification tools as well as a gamified platform for self-determined goal setting working with incentive schemes, training and community building tools. Furthermore, a user-license Human Factors database with anonymized data from the simulator and field experiments will be developed.

1.2 About this report

The work presented in this deliverable relates to the right part of Figure 1 (see green box), i.e. the intervention pillar of the to-be-developed *i*-DREAMS platform. As can be seen, one of the key-targets of the *i*-DREAMS platform is to keep vehicle operators as much as possible within the Safety Tolerance Zone (STZ) while driving. In order to do so, a methodology for both real-time and post-trip interventions evaluation will be developed and presented in this document. In particular, the methodology will attempt to convey all the features and particularities of each one of the interventions examined, and specify the approach with which the efficiency of the intervention will be assessed. A variety of methods and study designs will be overviewed in order to estimate the safety effects of interventions as efficiently as possible. Furthermore, an appropriate framework for comparing results among different modes and different countries will be outlined.

After combining the previously determined factors, the expected outcomes can be stated. To illustrate, for the *i*-DREAMS project, it has to be decided which behavioral factors in the targeted populations have to change in order to positively influence the targeted safety outcomes. For instance, to reduce the number of forward collisions, it is necessary vehicle operators share the road safely with other road users. An improvement in terms of how vehicle operators share the road with others would be a to-be-targeted safety promoting goal. Additionally, so-called performance objectives are to be formulated. These actually indicate what performance is required from both the members of the primary target groups (i.e. private car drivers and professional bus, truck, tram and train drivers), and the relevant environmental agents. In other words, performance objectives specify what members of the primary target groups and relevant environmental agents more specifically need to do in order for the planned interventions to be able to achieve the expected safety promoting goals. For example, to improve interaction with other road users, vehicle operators would have to reduce risk-prone manoeuvres like tailgating. A reduction of tailgating incidents (by maintaining a safe headway distance) would be a to-be-targeted performance objective.

Then, it is necessary to identify the underlying determinants that explain why current performance on the relevant behavioral factors is not satisfying. Typically, these determinants rest within individuals (e.g. mental or physical capabilities, motivation-oriented variables like beliefs, attitudes, norms, self-efficacy, et cetera) or relate to factors in the physical or social environment that currently encourage (or discourage) continuation of behavior or facilitate (or hinder) behavioral change. To illustrate, tailgating might be explained in function of biased risk perception (e.g. a driver underestimating the danger of a too short headway distance). Correction of such a biased risk perception would be the so-called change objective to be targeted.

Aims and objectives

The main purpose of the current deliverable is to provide a methodology for safety intervention evaluation in order to keep driver behavior within the boundaries of the STZ. In more specific terms, the deliverable aims to address the following objectives:

- Identify the appropriate assessment variables from the i-DREAMS platform, which are related to safety outcomes, safety performance goals, performance objectives and change objectives.
- Define the crucial indicators and measurements for the quantification of the impact of real-time and post-trip safety interventions.

The key research question the task is addressing

- Which are the crucial aspects that the intervention assessment methodology should tackle in order to keep the driver within safe boundaries?

Structure

The structure of this deliverable is presented as follows. Chapter 2 provides the *i*-DREAMS intervention strategy specifications, along with the main targets, features and particularities of interventions. The purpose and philosophy as well as the logic model of change behind the real-time and post-trip *i*-DREAMS interventions are analysed. Moreover, the outcome variables needed for assessment and considerations/modifications per different modes, are also presented. Then, Chapter 3 highlights and demonstrates the assessment of interventions in order to identify strengths and weaknesses that could be exploited for the *i*-DREAMS intervention methodology, based on the logic model of change. Different methods, specific criteria, perspectives, key performance indicators (KPIs) and thresholds constitute the key factors of this section. Chapter 4 addresses the evaluation methodology, where the hypothesis testing, research questions, indicators and measures along with the methodological design are given in order to turn the available measurements into meaningful information on the level of driving safety. Finally, Chapter 5 draws practical conclusions and gives recommendations on the following steps of the project.

2 *i*-DREAMS intervention strategy specifications

2.1 Targets, Features and particularities of interventions

2.1.1 Purpose and philosophy behind the *i*-DREAMS interventions

The purpose of the *i*-DREAMS interventions is to effectively **increase driver safety** by supporting the driver in his driving task. As it was stated in the introduction section, the purpose of the *i*-DREAMS interventions is to keep a driver as long as possible within the first phase or, in case this is not possible, to prevent a driver from transitioning between dangerous and avoidable accident phase.

In order to achieve this purpose, information that will be used within the interventions will be provided by a risk monitoring instrument. The intervention mechanism needs to be based on the Safety Tolerance Zone (STZ) concept. According to the STZ, a driver can be in three different phases:

(1) Normal Driving phase,

(2) Danger phase,

(3) Avoidable Accident phase.

In case a driver is within the first phase (i.e. normal driving), no real-time interventions are necessary. On the contrary, in case a driver is within the phase of danger, an alert should be offered, while in the case of the avoidable accident phase, an intrusive warning signal (either or not accompanied by an instruction) should be offered.

As mentioned in previous deliverables of the project, two different types of interventions will be offered: real-time interventions and post-trip interventions. Within **real-time interventions**, signals are given to the driver while driving with the help of an **in-vehicle warning system**. Within **post-trip interventions**, signals are given to the driver after driving, with the help of a **smartphone application**. This smartphone application has two versions: one version with only **scores** based on driving performance, and a second version including **gamification elements** (e.g. points and goals). Key-stakeholders (i.e. company management, i.e. CEO or fleet safety manager, outdoor service providers, and indoor coaches, i.e. planner or buddy) that are actively involved in the process of coaching professional drivers to improve their driving style will have access to a **web platform**. In order to increase the impact of interventions on driver safety, both kinds of interventions will be combined, since both are complementary.

In addition to the way that the interventions are delivered (i.e. in-vehicle warning system vs. smartphone application for drivers, and web platform for key-stakeholders that are actively involved in the process of coaching professional drivers), both kinds of interventions also differ in terms of the time that a driver has to undertake an action. With real-time interventions, drivers have almost no time to think about their actions, hence, a **nudging approach** is going to be utilized for these kinds of interventions. Within this approach, heuristics (i.e. mental shortcuts) and manipulations of cues within a social or physical environment are being used in order to activate non-conscious thought processes involved in human decision making. For *i*-DREAMS, the context is also related to the in-vehicle warning system. With post-trip interventions, drivers have time to think about their future actions, hence, a **coaching approach** will be used. Within this approach, there is a focus on helping/guiding the driver in order to drive more safely by boosting their competences. As a result, conscious thought processes involved in human decision making can be activated. In this way, **two mutually reinforcing approaches for behavioral change** are going to be used: the nudging approach aims to improve driver safety by manipulating the driving context, while the coaching approach aims to improve driver safety by manipulating the driver himself.

Since *i*-DREAMS not only focuses on non-professional drivers (i.e., private car drivers), but also on professional drivers (i.e., bus drivers, truck drivers, train operators and tram operators), particular concern will also be given on **'virtual coaching'** (i.e. coaches working via the web) in addition to **'e-coaching'** (i.e. coaching fully web-mediated).

2.1.2 The logic model of change behind the *i*-DREAMS interventions

Since the *i*-DREAMS interventions aim to improve driver safety, four different levels of driver safety need to be targeted as presented in Figure 2. The highest level targeted by the *i*-DREAMS interventions consist of the **safety outcomes** (e.g. the likelihood of crash occurrence, for example, frontal crashes, side crashes or rear crashes). The second highest level consists of the **safety promoting goals**. These are the behaviors that need to change in order for the safety outcomes to be realized. The second lowest level refers to the **performance objectives**. These are the more specific actions or behavioral parameters that need to change in order for the safety promoting goals to be achievable. The lowest level consists of the **change objectives**. These are the underlying behavioral determinants that need to change for the performance objectives to become realizable. For a detailed description, see deliverable 3.3 (Brijs et al., 2020).

From Figure 2, it can also be concluded that safety outcomes are dependent upon safety promoting goals, which are dependent upon performance objectives, which in turn are dependent upon change objectives. As a result, outcomes will be evaluated at different levels and various steps in the process/causation chain that are supposed to be causally linked with each other. Since this deliverable concentrates on the methodology for the evaluation of interventions, there will not be a focus on change methods and practical applications. Nevertheless, a brief description of the safety outcomes, safety promoting goals, performance and change objectives will follow.

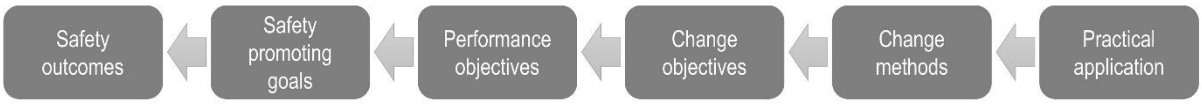


Figure 2: Structural overview of various steps in the process/causation chain

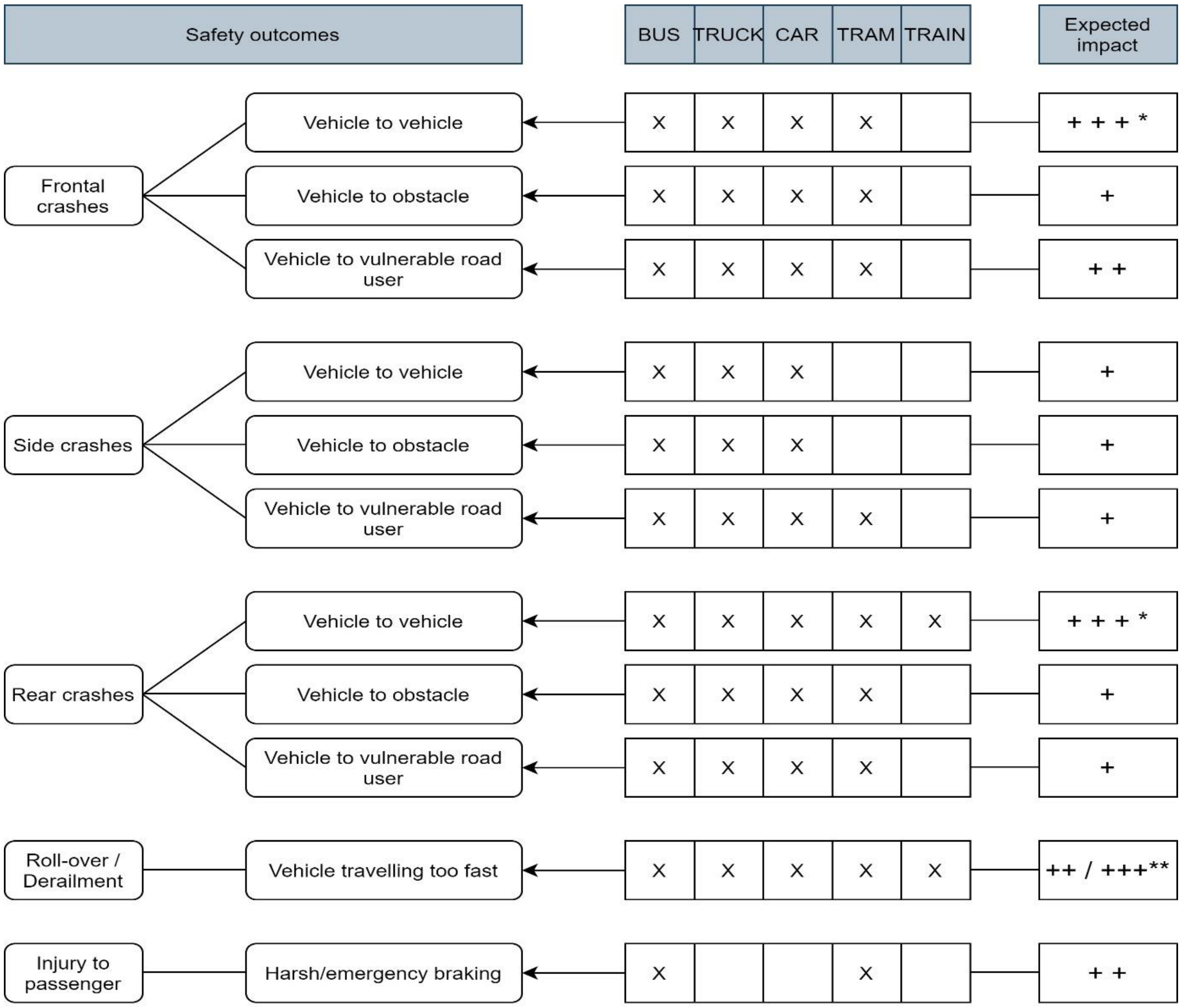
<u>*Safety outcomes (SO)*</u>

The aim of the real-time and post-trip interventions provided by the *i*-DREAMS platform is to reduce the likelihood of crash occurrence. Crashes are categorized in function of the impact type as **frontal crashes** (i.e. the operator's vehicle hitting another crash subject or object in the front side), **side crashes** (i.e. the operator's vehicle hitting another crash subject or object in the side), and **rear crashes** (i.e. the operator's vehicle hitting another crash subject or object in the rear side). The categories '**roll-over/derailment'** and '**injury to passenger'** are more typical for rail modes. As a result, the *i*-DREAMS platform targets five safety outcomes:

- **SO1**: The likelihood of cars, buses, trucks, or trams equipped with and exposed to the *i*-DREAMS interventions to be involved in a **frontal crash** will significantly reduce.
- **SO2**: The likelihood of cars, buses, trucks, or trams equipped with and exposed to the *i*-DREAMS interventions to be involved in a **side crash** will significantly reduce.
- **SO3**: The likelihood of cars, buses, trucks, trams or trains equipped with and exposed to the *i*-DREAMS interventions to be involved in a **rear crash** will significantly reduce.
- **SO4**: The likelihood of trams and trains equipped with and exposed to the *i*-DREAMS interventions to be involved in a **roll-over/derailment crash** will significantly reduce.

- **SO5**: The likelihood of trams equipped with and exposed to the *i*-DREAMS interventions to be involved in a **crash with injury for passengers** will significantly reduce.

These safety outcomes are depicted in Figure 3.



+ + +	High impact
+ +	Medium impact
+	Low impact
*	For trains this is achieved through prevention of signal passed at danger (SPAD) events
**	For road the expected impact is + +, for rail + + +

Figure 3: Safety outcomes to be addressed in i-DREAMS technology by mode

It can be seen that the different crash types apply as safety outcomes to each of the three road transport modes (i.e. car, bus, and truck), while they do not apply necessarily to the rail transport modes.

Safety promoting goals (SPG)

Safety promoting goals refer to behaviors that can be logically linked to the safety outcomes. Behaviors that are typically monitored in the context of safety promoting interventions relate (but are not necessarily limited) to vehicle control, sharing the road with others, speed management, driving fitness, and use of safety devices. As a result, the *i*-DREAMS platform targets five safety promoting goals:

- **SPG1**: Performance in terms of **vehicle control** (expressed as a numerical score) will significantly improve for cars, bus, trucks, trams and trains equipped with and exposed to the *i*-DREAMS interventions.
- **SPG2**: Performance in terms of **sharing the road with others** (expressed as a numerical score) will significantly improve for cars, bus, trucks, and trams equipped with and exposed to the *i*-DREAMS interventions.
- **SPG3**: Performance in terms of **speed management** (expressed as a numerical score) will significantly improve for cars, bus, trucks, trams and trains equipped with and exposed to the *i*-DREAMS interventions.
- **SPG4**: Performance in terms of **driving under conditions where one is fit enough** (expressed as a numerical score) will significantly improve for cars, bus, trucks, trams and trains equipped with and exposed to the *i*-DREAMS interventions.
- **SPG5**: Performance in terms of **using safety devices** (expressed as a numerical score) will significantly improve for cars, bus, trucks, trams and trains equipped with and exposed to the *i*-DREAMS interventions.

These safety promoting goals are visualized in Figure 4.

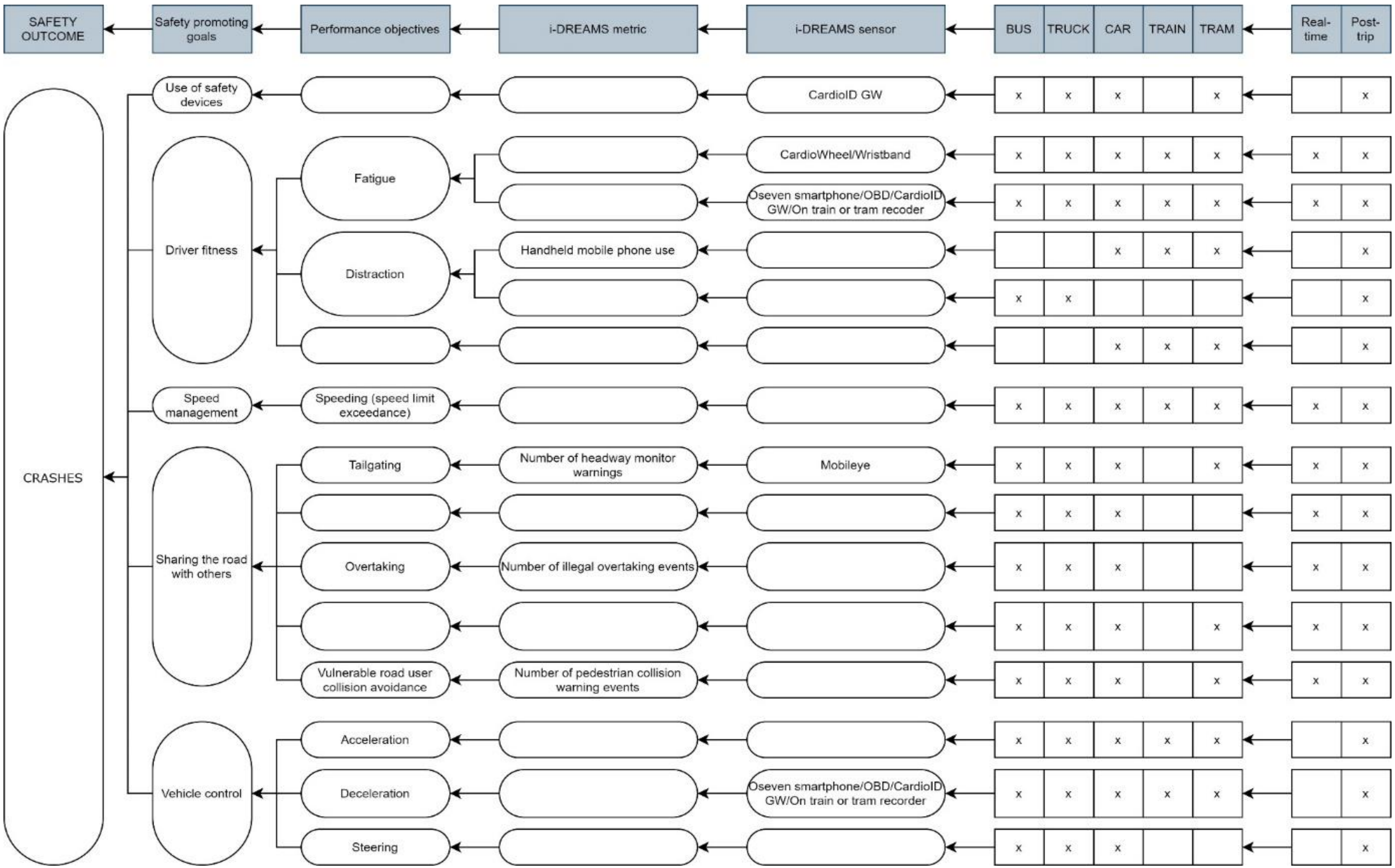


Figure 4: Safety promoting goals and performance objectives which will affect the safety outcomes

Performance objectives (PO)
Performance objectives are the more specific actions or behavioral parameters that need to change in order for the safety promoting goals to be achievable. More specific and suitable (surrogate) measures will have to be proposed to appropriately operationalize objectives set at this highest level of impact. As it can be derived from Figure 4, one safety promoting goal can relate to several performance objectives. For example, the safety promoting goal “vehicle control”, consists of three performance objectives:

- PO1: **Accelerate** appropriately
- PO2: **Decelerate** appropriately
- PO3: **Steer** appropriately

Change objectives (CO)
Change objectives are the underlying behavioral determinants that need to change for the performance objectives to become realizable.

The change objectives are based on components of the **COM-B model** (Michie et al., 2011; Michie et al., 2014). The selected components differ between real-time interventions and post-trip interventions. The COM-B model focuses on **Capability, Opportunity, Motivation and Behavior**. The central tenet of the model is that for any behavior to occur, one or more of these three concepts are required:

- **Capability** refers to a person’s ability to perform a certain behavior, or not. The capability concept further splits up into two dimensions that represent the two human resources that determine a person’s overall capability, i.e. **psychological capability** (e.g. having the knowledge, psychological skills, strength or stamina to perform the behavior), and **physical capability** (e.g. having the physical skills, strength or stamina to perform the behavior).
- **Motivation** relates more to a person’s willingness to perform a certain behavior (or not). Depending on which system of thinking (i.e. the ‘automatic’ system or the ‘reflective’ system) generates motivation, a distinction is made between **automatic motivation** (e.g. processes involving wants and needs, desires, impulses and reflex responses) and **reflective motivation** (e.g. self-conscious planning and evaluations such as beliefs about what is good or bad).
- **Opportunity** refers to whether there is a facilitator or inhibitor present that enables or prevents a person to perform a certain behavior or not. **Physical opportunity** relates to what the environment allows or facilitates in terms of time, triggers, resources, locations, physical barriers. **Social opportunity** refers to whether there are interpersonal influences, social cues or cultural norms present that could facilitate or inhibit performance of a certain behavior.

The COM-B Model is visualized in Figure 5.

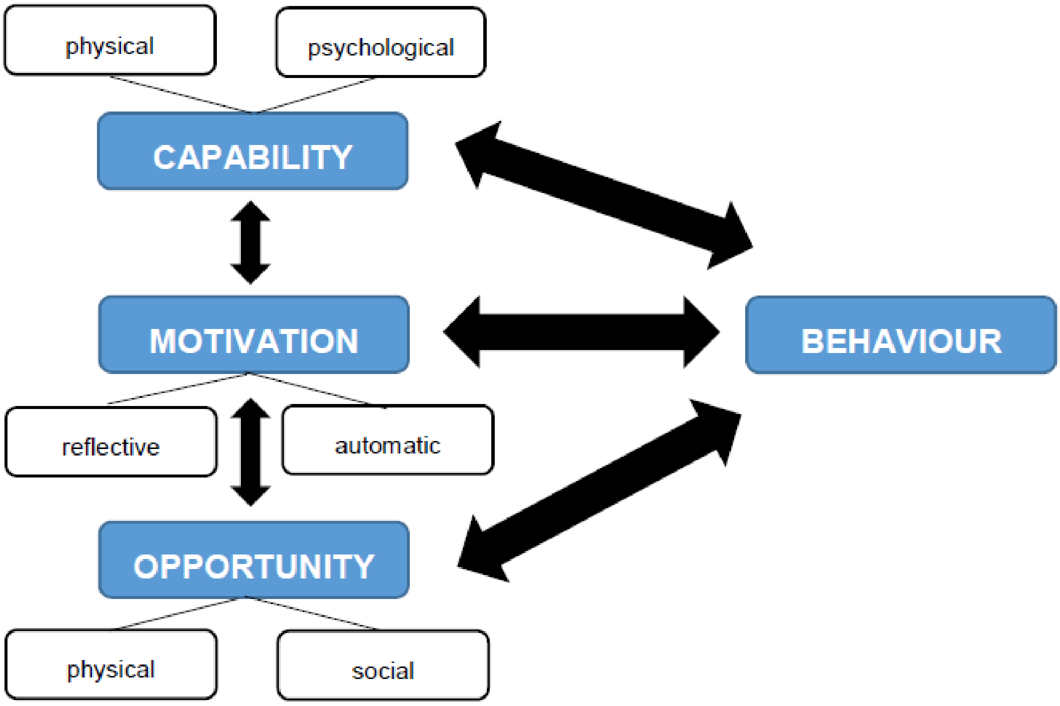


Figure 5: The COM-B Model. Source: adapted from Michie et al. (2014)

To simplify the multitude of candidate-variables that could be used to operationalize each of the six above mentioned concepts (i.e. psychological and physical capability, automatic and reflective motivation, physical and social opportunity), an interdisciplinary panel of experts selected 14 so-called theoretical domains, i.e. **the Theoretical Domains Framework (TDF):**

- Theoretical domains within the concept 'psychological capability':
  - Knowledge
  - Cognitive and interpersonal skills
  - Memory, attention, and decision processes
  - Behavioral regulation
- Theoretical domains within the concept 'physical capability':
  - Physical skills
- Theoretical domains within the concept 'automatic motivation':
  - Reinforcement
  - Emotion
- Theoretical domains within the concept 'physical opportunity':
  - Social/professional role and identity
  - Beliefs about capabilities
  - Optimism
  - Intentions
  - Goals
  - Beliefs about consequences
- Theoretical domains within the concept 'social opportunity':
  - Social influences

2.1.3 Real-time interventions

Components from the COM-B model that were identified as relevant for the real-time interventions since they align best with the idea of nudging are **(1) psychological capability, (2) automatic motivation, and (3) physical opportunity**. As can be derived from Figure 6:

(1) Psychological capability is relevant in the context of real-time interventions, as drivers should be mentally ready to act when necessary, and knowledgeable of how to appropriately adapt their behavior. For this component, the determinants selected for inclusion are '**attention'** and '**understanding'**. Drivers have to cope with various attention-demanding tasks while driving. To keep drivers sufficiently situation aware, attention regulation is a key-determinant for real-time interventions. It is also important that drivers are knowledgeable of how to appropriately adapt their behavior. Without clear and precise enough understanding of what particular aspect(s) of current driving need(s) correction, it remains difficult for drivers to make accurate decisions, and take appropriate action, especially under challenging conditions and without much time.

(2) Automatic motivation (i.e., reflex responses and impulses) is selected instead of reflective motivation (i.e., conscious reasoning) in the context of real-time interventions, since the window of opportunity for decision-making is often limited to (milli)seconds. For this component, the determinants selected for inclusion are '**emotion'** and '**punishment sensitivity'**. Triggering emotion (e.g. fear) can be a very powerful leverage to initiate immediate action whenever required, even though it needs to be implemented with care. Punishment sensitivity (i.e., the degree to which an individual's behavior is inhibited by punishment-relevant stimuli, Carver & White, 1994) is another potentially relevant determinant that can facilitate motivating the drivers to adapt their behavior.

(3) Physical opportunity refers to factors situated in the cockpit environment that steer the driver's decision-making while driving, thereby facilitating safe behavior. For this component, the determinant selected for inclusion, is labelled '**environmental context and resources'**, i.e. any circumstance of a person's situation or environment that discourages undesirable behavior or encourages the desired (adaptive) behavior (Michie et al., 2014). Environmental context and resources refers to any kind of technological device inside the cockpit (e.g., dashboards, head-up displays, centre console displays) that is meant to discourage risky behaviors and/or encourage safe behaviors while driving.

These five factors (i.e., attention, understanding, emotion, punishment sensitivity and environmental context and resources) constitute the conceptual basis of the change objectives to be targeted by the real-time interventions.

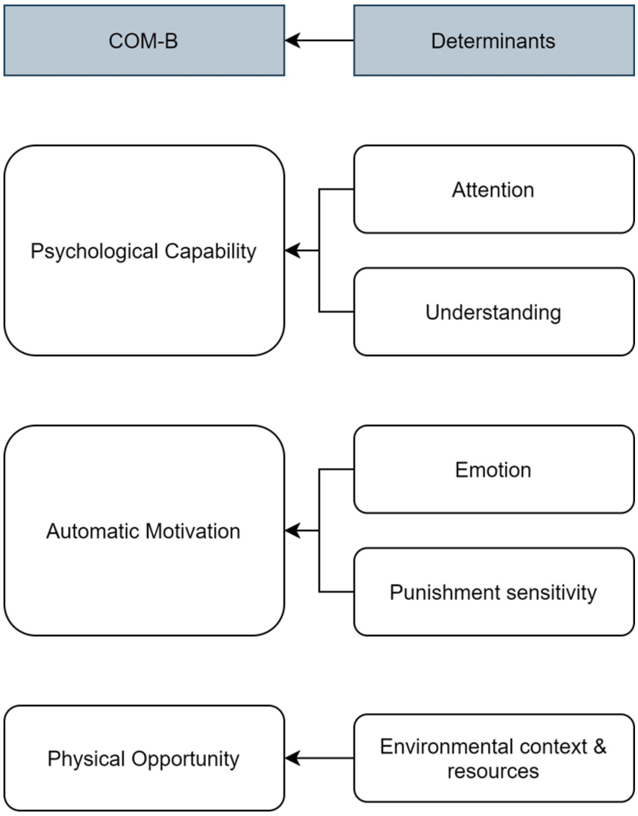


Figure 6: Determinants for real-time interventions

2.1.4 Post-trip interventions

Components of the COM-B model that were identified as relevant for the post-trip interventions since they align best with the idea of coaching are: **(1) psychological capability, (2) physical capability, (3) reflective motivation, (4) automatic motivation, and (5) social opportunity.** As it can be derived from Figure 7:

(1) Psychological capability is a first objective targeted by post-trip interventions in order to coach drivers to become safe(r) drivers. Two determinants fall under this component, i.e. **knowledge and implementation intention**. Different from the real-time interventions where understanding is to be interpreted as an ephemeral and momentarily triggered conscious recognition of the need to adapt behavior, for the post-trip interventions, knowledge refers to more stable and elaborate mental schemes referring to factual information. For instance, concerning the advantages and disadvantages of safe and unsafe behavior respectively, to codes and rules that apply to traffic, or to procedures on how to cope with challenging driving conditions. Implementation intention relates to volition and has already been explained as a self-regulatory strategy in the form of an ‘if-then’ plan that increases the likelihood for an individual to act upon motivation. It is in other words, that aspect of psychological capability that refers to an individual’s capacity to turn good intentions into behavior.

(2) Physical capability is important since drivers should be physically ready to act when necessary. The determinant associated with this component is **skills** (i.e., an ability or proficiency acquired through practice, Michie et al., 2014). Due to the fact that the post-trip interventions run over wider time episodes, they lend themselves much better to building up the skills needed to master the behavioral parameters that are causally linked to the safety promoting goals targeted by the *i*-DREAMS interventions.

(3) Reflective motivation (i.e., motivation that results from conscious thought processes) is suitable for post-trip interventions, since these interventions are not bound to a (milli)second time window. The determinants that fall under this component are: **attitude, personal norm, subjective norm, self-efficacy, and goals**. Attitude (i.e., the thought process behind motivation) is mainly focused on outcome expectancies (i.e. beliefs about what will be the consequences of performing a certain behavior), and their affective evaluation (i.e. whether one appraises the expected consequences as positive or negative). Personal norm is when the motivation to perform a certain behavior (or not) is dependent upon one's own personal value system. Before engaging in a particular behavior, an individual will consider the potential consequences for his or her self-image. In the case of subjective norm, motivation is believed to be dependent on the extent to which a person complies (or not) with the opinion of important social referents (e.g. colleagues, friends, partner) about performing a particular behavior. Self-efficacy is to be understood as a person's judgment of his or her ability to cope effectively in different circumstances. Goals direct people's attention, evaluations, consideration of actions/alternative actions, and the cognitive accessibility of knowledge and attitudes. Goals are mental representations of outcomes or end states that an individual wants to achieve. Goals are thus to be seen as important behavioral regulators.

(4) Automatic motivation is not only important in the context of real-time interventions, but also in the context of post-trip interventions, since rewarding desirable behavior and penalizing undesirable behavior are popular methods. Therefore, the determinants associated with this component are **punishment sensitivity and reward sensitivity**. As explained above, punishment sensitivity is a potentially relevant determinant that can facilitate motivating the drivers to adapt their behavior. Reward sensitivity can be defined as the tendency to detect, pursue, learn from, and derive pleasure from positive stimuli (Goodnight, 2018). It is included since post-trip interventions frequently use motivation strategies to motivate people to show the desired behavior.

(5) Social opportunity refers to agents in the individual's social environment that can facilitate the desired behavior. The determinant associated with this component is **group identity**. Group identity can be defined as the portion of an individual's self-concept derived from perceived membership in a relevant group (Turner & Oakes, 1986).

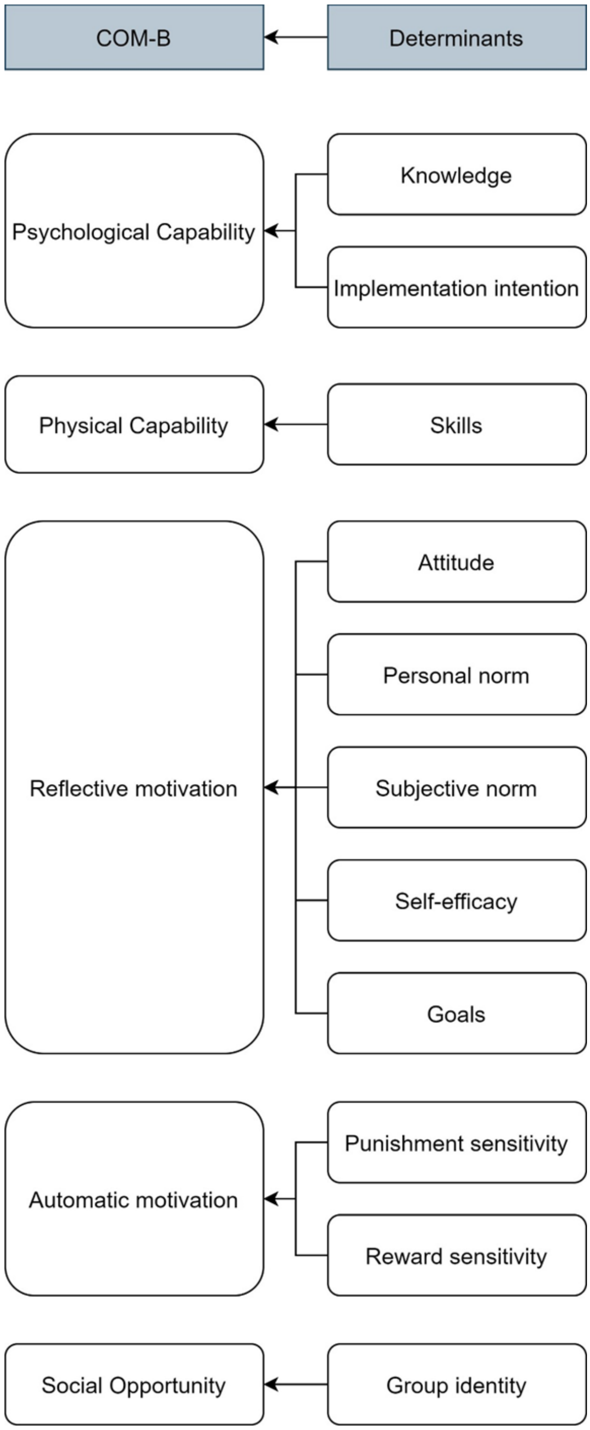


Figure 7: Determinants for post-trip interventions

Within the logic model of change that will be applied in the real-time and post-trip interventions, the selected determinants are causally linked to the selected behavioral parameters, and these in turn are causally linked to the selected safety promoting goals.

2.2 Assessment variables

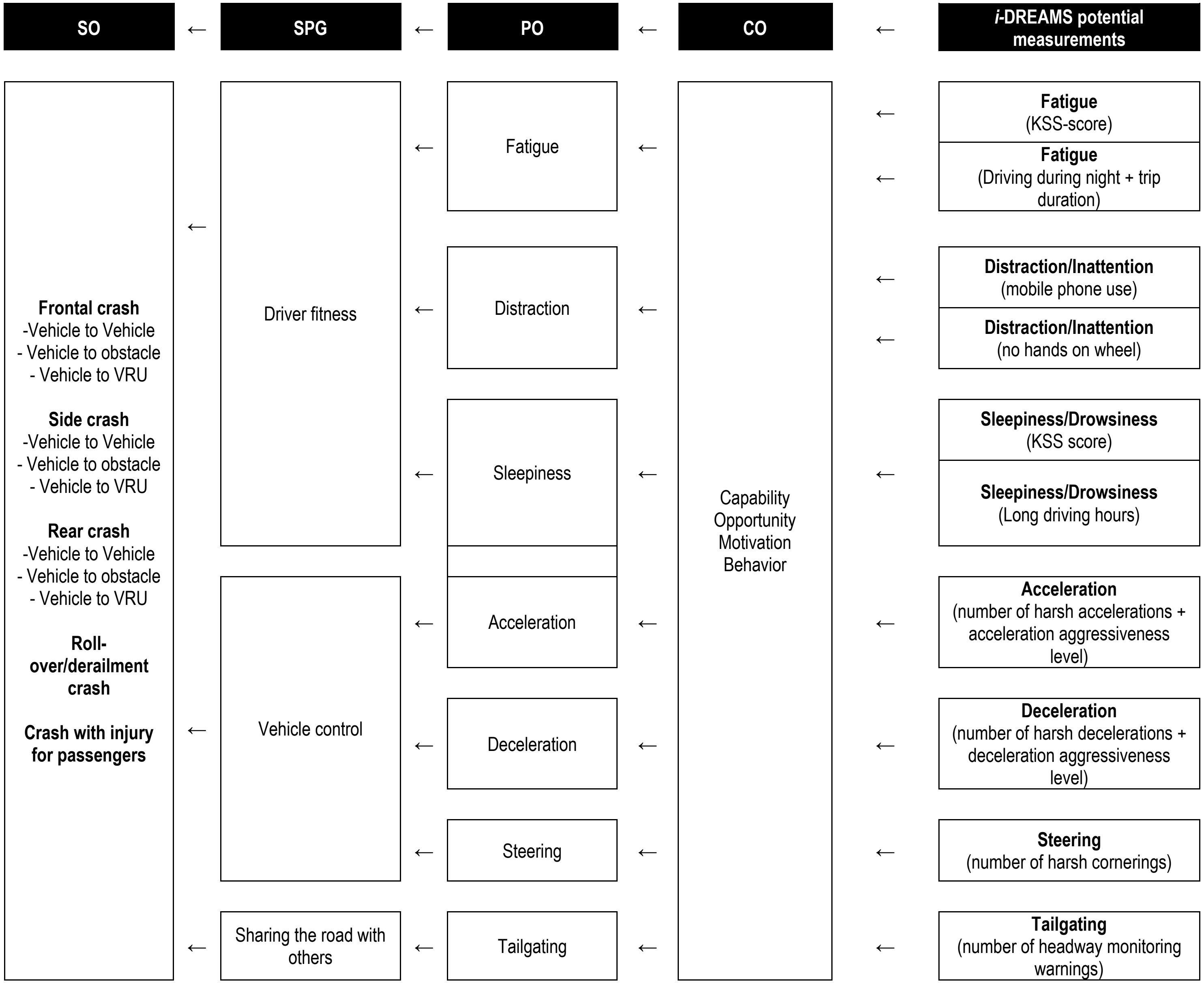
In order for the assessment to take place, the SO, SPG, PO, and CO need to be linked with appropriate variables from the *i*-DREAMS platform. The key task is to determine which **behavior** (e.g. prevalence, incidence, etc.), **environmental** (e.g. weather conditions, roadway infrastructure, traffic conditions, societal factors, etc.) and related **personal determinants** (i.e. what factors cause or modify the behavior and environment of the at-risk group) are relevant in the context of crash evolution. In order to come to a full understanding, the **available assets, capacities and abilities** are also to be determined (i.e. which leverages for a successful intervention are present or needed?). After combining the previously determined factors, the expected outcomes can then be assessed.

Within the *i*-DREAMS project, a list of outcome variables have been addressed in Work Package 2, where a state-of-the-art has been summarized in terms of which factors related to the vehicle operator, the environmental context in which that operator is situated, and the vehicle being operated, determine crash risk (Deliverable 2.1 by Kaiser et al., 2020). Furthermore, potential assets, capacities and abilities of interventions to address road safety problems have been reviewed (Deliverable 2.2 by Katrakazas et al., 2020). Table 1 lists the variety of *i*-DREAMS safety outcomes, safety performance goals, performance objectives and change objectives along with potential measurable variables from the *i*-DREAMS platform that could be used for assessment. Figure 8, re-visits Figure 4, by adding measurements that can be used for determining the different SO, SPG and PO and CO.

Table 1: Different levels of driver safety (SO, SPG, PO, and CO) along with the appropriate variables from the i-DREAMS platform

SO	SPG	PO	CO	Potential measurements
Frontal crash -Vehicle to Vehicle - Vehicle to obstacle - Vehicle to VRU	Driver fitness	Fatigue	Capability	**Distraction** (Handheld mobile phone use, Hands on wheel)
Side crash -Vehicle to Vehicle - Vehicle to obstacle - Vehicle to VRU	Vehicle control	Distraction	Opportunity	**Inattention** (Handheld mobile phone use, Hands on wheel)
Rear crash -Vehicle to Vehicle - Vehicle to obstacle - Vehicle to VRU	Sharing the road with others	Sleep deprivation	Motivation	**Fatigue** (KSS score, Long driving hours, Time driving)
Roll-over/derailment crash	Speed management	Acceleration	Behavior	**Sleepiness** (KSS score, Long driving hours)
Crash with injury for passengers	Use of safety devices	Deceleration		**Drowsiness** (KSS score, Long driving hours)
		Steering		**Road layout** (FCW, UFCW)
		Tailgating		**Poor visibility/ darkness** (wiper on)
		Lane discipline		**Weather conditions** (wiper on)
		Overtaking		**Acceleration** (number of harsh accelerations and acceleration aggressiveness level)
		Forward collision avoidance		**Deceleration** (number of harsh braking and deceleration aggressiveness level)
		Lane departure avoidance		**Speeding** (percentage overspeeding and average speed over speed limit)
		Vulnerable Road User (VRU) collision avoidance		**Steering** (number of harsh cornerings)
		Speeding (speed limit exceedance)		**Overtaking** (number of illegal overtaking events)
				Risky hours (driving during 00:00-05:00)
				Lane discipline (number of lane departure warnings)
				Forward collision avoidance (number of FCW, UFCW)
				Lane departure avoidance (number of lane departure warnings and dashcam video)
				Vehicle blind spot[1] (SPAD/SPAS)

[1] Exclusive of rail modes


SO
SPG
PO
CO
i-DREAMS potential measurements
Fatigue
(KSS-score)
Fatigue
(Driving during night + trip duration)
Distraction/Inattention
(mobile phone use)
Distraction/Inattention
(no hands on wheel)
Sleepiness/Drowsiness
(KSS score)
Sleepiness/Drowsiness
(Long driving hours)
Acceleration
(number of harsh accelerations + acceleration aggressiveness level)
Deceleration
(number of harsh decelerations + deceleration aggressiveness level)
Steering
(number of harsh cornerings)
Tailgating
(number of headway monitoring warnings)
Capability
Opportunity
Motivation
Behavior
Fatigue
Distraction
Sleepiness
Acceleration
Deceleration
Steering
Tailgating
Driver fitness
Vehicle control
Sharing the road with others
Frontal crash
-Vehicle to Vehicle
- Vehicle to obstacle
- Vehicle to VRU
Side crash
-Vehicle to Vehicle
- Vehicle to obstacle
- Vehicle to VRU
Rear crash
-Vehicle to Vehicle
- Vehicle to obstacle
- Vehicle to VRU
Roll-over/derailment crash
Crash with injury for passengers

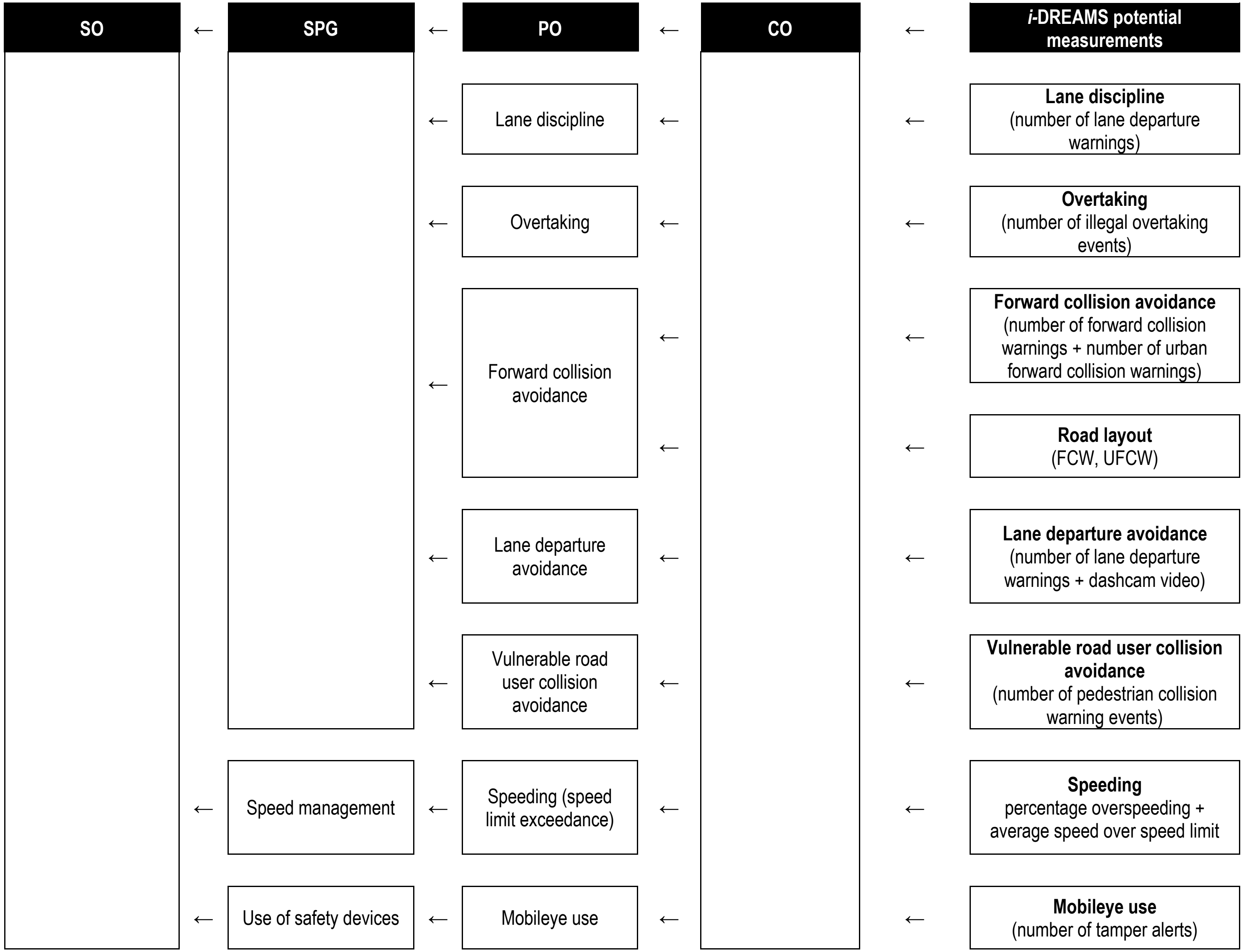


Figure 8: Re-visiting intervention logic with potential measurements

Taking into account the variety and combination of the aforementioned levels of driver safety (SO, SPG, PO and CO), a link with the potential measurements should be made in order to assess them. As already mentioned, SO are dependent upon SPG, which by extension are dependent upon PO, which therefore are dependent upon CO. In order not to lose the logic strength of the change strategy (i.e. change objectives → performance objectives → safety promoting goals → safety outcomes), it is important that suitable measures for each of the links in this causal chain to be considered in relation to each other when assessing intervention effects. Consequently, the assessment variables will be evaluated at different levels where there exist a causally link with each other. For instance, for the different safety outcomes (i.e. type of accident, conflicts and other safety-critical events) or safety promoting goals (i.e. driver fitness, vehicle control etc), specific corresponding measurement from the *i*-DREAMS platform will be chosen for evaluation.

From the description of Figure 8, it is observable that change in safety outcomes and safety promoting goals and performance objectives can potentially be assessed quantitatively as the respective indicators are continuous measurements, while change objectives might need the use of qualitative assessment or an appropriate scoring to be evaluated as they refer to more psychological or behavioral aspects.

2.3 Modal considerations/modifications

Within the *i*-DREAMS project, attention is given to several modes, i.e., cars, trucks, buses, trains, and trams. Although all modes target safety outcomes, i.e., crash occurrence, the specific safety outcomes (i.e. types of crashes) targeted vary between modes. As a consequence, also the safety promoting goals, performance objectives, and change objectives may vary between modes.

2.3.1 Trucks

In Deliverable 2.2 (section 2.3) it was discussed already that one of the crucial and consistent findings in the field of Occupational Health and Safety (OHS), is that building and sustaining employee health and safety is to a large extent dependent on how the workplace environment is oriented towards health and safety. This of course, is a crucial difference with a private driver context, where individual behavior is less bound to rules, guidelines or protocols that regulate personal conduct. Organizations can differ greatly in terms of how strong (or weak) their safety culture and safety climate is developed. Research shows that management commitment, fleet safety management, and communication regarding fleet safety are strategically important actions that can positively contribute to a prosperous safety culture and climate.

Actual involvement of other agents within the workplace setting (besides the targeted end-users), is of essential importance for the success of the *i*-DREAMS interventions, most particularly, for those modes that are operational in a professional context (i.e. bus, truck, tram, and train). Especially in the case of the post-trip interventions where a coaching approach will be adopted as a basic strategy for behavioral change, the proposed *i*-DREAMS platform (i.e. both app and web-based dashboard) will not operate as a stand-alone solution or a full replacement of human interaction. Rather, the *i*-DREAMS platform will function as kind of automated expert system, meant to provide support to the different key-stakeholders that are actively involved in the process of coaching professional vehicle operators to improve their driving style.

In Deliverable 3.3 (see section 6.3.2.2) it was discussed that stakeholders can take up three specific roles in the context of intervention uptake, i.e. adoption, implementation, and consumption. Adoption relates to the decision to use an intervention. Implementation refers to the execution of the intervention. Consumption stands for the actual exposure to and use of the intervention by the targeted end-users. Based on exploratory consultancy of stakeholders in the sectors of professional (public and private) transportation of persons and goods (see for instance, Deliverable 9.1), it has become clear that four stakeholder parties have an important role to play in the context of fleet safety management. These four stakeholder parties are: company management (i.e. CEO or fleet safety manager), outdoor service providers, indoor coaches (i.e. planner or buddy) and employees and will be further elaborated in the subsequent paragraphs.

1. Company management usually takes the decision to use a fleet safety intervention program, or not. This means company management is the stakeholder party taking up the role of intervention adoption. In addition to that, it is clear from the literature on safety culture and climate, that company management is also an important party to involve in the execution of a fleet safety intervention. In other words, company management is also taking up the role of intervention implementation. More specifically, demonstrated commitment and a good employer-employee relationship contribute to the success of fleet safety interventions. The *i*-DREAMS post-trip intervention platform will support company management in staying committed throughout the whole intervention duration, for instance, via a user-friendly and company-tailored reporting system that allows to monitor progress on a regular basis (for more technical details on this, see Deliverable 4.3).

2. Outdoor service providers: more and more, transport companies call on specialized outdoor services to organize, implement, and follow-up their fleet safety management due to the fact that they do not have the necessary expertise in-house, or because of time constraints. The *i*-DREAMS platform (especially the web-dashboard) is designed to support such fleet safety service providers in setting up and managing intervention programmes that are tailored to the specificities of the companies they work with. This outdoor service provider is thus to be seen as the intervention's coordinating supervisor, and makes use of the *i*-DREAMS platform as a kind of super-administrator. He or she is in other words involved in intervention implementation. More specifically, the super-administrator is allowed to and provided with the opportunity to set all sorts of configurations (e.g. to define projects, create different user groups, configure functionalities offered by the back-end gamification engine, draw reports, et cetera). Accordingly, the super-administrator acts as a support for the in-company coaches via the *i*-DREAMS platform. Furthermore, the super-administrator can use the *i*-DREAMS platform and all the analytics behind it, to persuade company management to step in and stay committed to a fleet safety-promoting program.

3. Indoor coaches: these are people inside the company that collaborate with employees on an almost day-to-day basis, such as a planner or a dedicated in-company mentor (i.e. a 'buddy'). As for the latter, transport companies often rely on and appoint such in-company mentors to support individual colleagues to work on an improvement of their driving style. Most often, these are the more experienced employees who have the expertise and the skills to coach less experienced colleagues. Moreover, in-company mentors have the advantage of personally knowing their coachees, which is important in the context of building up mutual trust and a relationship where coach and coachee are treated and seen as equals. The in-company coach as well as the planner can consult the *i*-DREAMS web-dashboard to follow-up on coachees' performance and progress in a very low-effort and user-friendly way. This in turn, allows the coach to provide better tailored and personalized feedback, and become more adequate in timely identifying opportunities for improvement, and scheduling in personal appointments whenever necessary. The planner can derive important information from those reports as well to tailor and optimize driving schedules. For instance, whether and how often fatigue or sleep deprivation-related events have been registered for particular drivers. The indoor coaches are thus also involved in intervention implementation.

4. Employees: the individual vehicle operator him/herself is of course the ‘coachee’ or ‘end-user’. End-users will remain in close contact with an in-company coach, but can consult the *i*-DREAMS app as an additional support tool on a day-to-day basis. Gamification mechanics integrated in the app serve to keep end-users motivated to work on a stepwise improvement of their driving style, and to identify relevant opportunities to achieve that purpose. Employees thus act in the role of intervention consumption.

For the interventions taking place in a professional work setting, data analysis and interpretation of results will have to take companies’ safety climate into account, as this is expected to be a crucial environmental factor influencing intervention effectiveness. Table 2 presents an example of the sample matrix of change for the real-time interventions, while

Table 3 depicts the sample matrix for the post-trip interventions.

Table 2: Example matrix of change for the real-time interventions for truck drivers

Safety promoting goal: Truck drivers improve the way they share the road with others					
Determinants					
Performance objective	*Attention*	*Understanding*	*Emotion*	*Punishment sensitivity*	*Environmental context & resources*
Truck drivers reduce risky tailgating events	Identify headway time	Recognize the need to adjust headway time in case a risky tailgating event is imminent	Demonstrate worry when receiving a headway time warning	Adjust headway time when receiving a headway time warning	Have a nomadic device inside the cockpit providing continuous feedback on headway time
Survey items					
Number of headway monitor warnings (Mobileye)	Was the *i*-DREAMS system able to keep you aware of headway time while driving? (Never/ Always)	Maintaining a large enough headway time is important to avoid tailgating. (Agree/disagree)	How worried did you feel when the *i*-DREAMS system triggered a headway time warning? (Almost not worried/very worried)	How often was the *i*-DREAMS system able to motivate you to adapt headway time? (Never/Always)	How often did you actively use and follow up on the warnings generated by the *i*-DREAMS system? (Never/ Always)

Table 3: Example matrix of change for the post-trip interventions for truck drivers

Safety promoting goal: Truck drivers improve the way they share the road with others											
Determinants											
Performance objective	*Knowledge*	*Implementation intentions*	*Skills*	*Attitude*	*Personal norm*	*Subjective norm*	*Self-efficacy*	*Goals*	*Punishment sensitivity*	*Reward sensitivity*	*Group identity*
Truck drivers reduce risky tailgating events	State the safety related risks of an inappropriate headway time	Plan when and how to adopt an appropriate headway time	Demonstrate ability to adopt an appropriate headway time	Express positive feelings about an appropriate headway time	Express self-regret when they adopt an inappropriate headway time	Recognize that important others think it is important to adopt an appropriate headway time	Express confidence in their ability to adopt an appropriate headway time	State what performance level they want to achieve in terms of an appropriate headway time	Express sorrow when they are penalized for adopting an inappropriate headway time	Express joy when they are rewarded for an appropriate headway time	Express shame in case they adopt an inappropriate headway time when important others do not
Survey items											
Number of headway monitor warnings (Mobileye)	Small headway time substantially reduces the time to react safely (Agree/disagree)	Was the *i*-DREAMS system helpful in learning when and how it is important to adopt an appropriate headway time? (Not very helpful at all/very helpful)	Gently releasing the gas pedal for a moment is a way to increase your headway time. (Agree/disagree)	Maintaining an appropriate headway time is important to avoid crashes (Agree/disagree)	How acceptable is it for you personally to maintain a too short headway time (Totally unacceptable/ totally acceptable)	Do you think that important others find it important to adopt an appropriate headway time? (Not at all/very)	Do you think you are able to adopt an appropriate headway time? (Not at all able/very able)	What performance level do you want to achieve in terms of an appropriate headway time?(Very high level/very low level)	How sorrowful did you feel when receiving a headway time warning from the *i*-DREAMS-system? (Not sorrowful at all/very sorrowful)	How satisfied did you feel when the *i*-DREAMS-system informed you that you appropriately adapted your headway time? (Not satisfied at all/very satisfied)	How shameful towards important others did you feel when receiving a headway time warning from the *i*-DREAMS-system while important others not? (Not shameful at all/very shameful)

2.3.2 Rails

The rail transport mode differs from the road-based modes in that trams' and trains' lateral movement is determined by the track and that interaction with other road users is limited on segregated sections of track. For trains this segregation is for the entire route but for trams some route sections are in areas of mixed traffic (motorized vehicles, cyclists, pedestrians). In addition for trains, track management determines the separation between trains on the same track and large stopping distances mean that trains do not travel within close proximity to each other and the driver is very unlikely to be able to stop in time once they have observed an object or road user on the track. Within this context the focus for trains and trams is use of safety systems, speed management, fatigue and sleepiness. For trams, the avoidance of vulnerable road users (i.e cyclists, pedestrians) is also a focus.

The context within which the *i*-DREAMS interventions will be tested differs between the trains and the trams. For trains most, if not all, the testing of interventions will occur within in a simulator and the driver experience and acceptance will be the focus. Trains already have a variety of intervention technology fitted to ensure speed limits are not broken and to intervene if signals are passed at danger. Therefore, for trains, behavior change as a result of the existing technology will also be studied as well as any intervention provided by the *i*-DREAMS technology (i.e. fatigue, sleepiness, possibly speeding). The possibilities of using more theoretical intervention triggers such as track based object/person on the line alerts and speed on approach to a signal set at danger in a simulator using a pseudo version of the *i*-DREAMS intervention platform will also be investigated. It is unlikely that behavior change as a result of post trip feedback can be examined in a simulator study. User and operator evaluation of the feedback tool and contents will be collected. A series of simulator studies are planned for trains with supplementary focus groups and manager/operator interviews.

For trams similarly to the road transport modes both a simulator study and an on-rail trial is planned. For the simulator trial interventions relating to the proximity of vulnerable road users, speeding and fatigue/sleepiness are planned. For the on-rail trial, subject to operator approval, it would be possible to provide real time interventions if the time headway was too small for vehicles (including other trams?) on the track and vulnerable road users ahead or in close proximity to the tram (measured by MobilEye Shield with additional cameras to cover areas to the side of the cab), for sleepiness/fatigue, and for travelling over the speed limit (still under investigation). Post trip feedback will also be given to the drivers (and operators).

2.4 Summary

Within this chapter, a summary description of the purpose and philosophy behind the *i*-DREAMS interventions was developed (i.e. a complementary platform where real-time interventions (e.g. nudging) and post-trip interventions (e.g. coaching) are meant to mutually reinforce each other).

Then, the logic model of change behind the *i*-DREAMS interventions (i.e. Safety Outcomes, Safety Promoting Goals, Performance Objectives and Change Objectives) was presented and the dependency among the different levels was highlighted. In particular, SOs are dependent upon an underlying set of SPG, then SPG are dependent upon PO, and finally PO are dependent upon CO. It was also clearly mentioned that outcomes will be evaluated at different 'levels' that are supposed to be causally linked with each other.

The SO targeted by the *i*-DREAMS interventions are related to the classification of road vehicle collisions. As a result, collisions that are going to be examined are frontal collisions (i.e. the operator's vehicle hitting another collision subject or object in the front side), side collisions (i.e. the operator's vehicle hitting another collision subject or object in the side), rear collisions (i.e. the operator's vehicle hitting another collision subject or object in the rear side), roll-over/derailment collisions and injury to passenger collisions. With regards to the first three crash categories, a distinction was made in terms of whether the subject or object colliding with is a vehicle, an obstacle or a vulnerable road user. However, the other two categories were more typical for the rail modes in *i*-DREAMS.

The SPG refer to improving behaviors that can be logically linked to the SO, based on existing empirical evidence. As was elaborately discussed in section 2.1.2, behaviors that are typically monitored in the context of safety promoting interventions related (but are not necessarily limited) to one of the five behaviors that appear as safety promoting goals: vehicle control, sharing the road with others, speed management, driving fitness, and use of safety devices.

A so-called ‘matrix’ technique was developed, where SPG are coupled to Performance Objectives (PO: i.e. objectives that apply to behavioral parameters), and where Performance Objectives are crossed with their related determinants (e.g. acceleration, deceleration, steering).

The CO (i.e. objectives that apply to determinants) were based on the components of COM-B model, and in particular attention was given in the behavioral change, where the individual needs to have the opportunity to do so, possess the necessary capabilities, and be sufficiently motivated.

Moreover, the COM-B components and the respective determinants that will be targeted by the real-time and the post-trip interventions were analysed. Three determinants (e.g. psychological capability, automatic motivation, and physical opportunity), which will become the change objectives to be targeted by the real-time interventions, were mentioned. In addition, with regards to post-trip interventions, as this kind of feedback aimed at coaching vehicle operators to become safer drivers, five COM-B components and the respective determinants that will be targeted by the post-trip interventions (e.g. psychological capability, physical capability, reflective motivation, automatic motivation, and social opportunity) were proposed. It should be noted that these five components and the more specific determinants associated with them are thus also to be seen as causally linked with the behavioral parameters previously mentioned.

Furthermore, the SO, SPG, PO, and CO were linked with the appropriate variables, in order to identify the potential measurements which can be measured from the *i*-DREAMS platform. After the combination of the previously determined factors, the expected outcomes can then be assessed. It was found that distraction, inattention, fatigue, sleepiness, drowsiness, poor road layout, poor visibility, darkness, adverse weather conditions, harsh acceleration, harsh braking, speeding, steering, illegal overtaking, risky hours driving, lane discipline, forward collision and lane departure avoidance were all the assessment variables that can be practically measured from the *i*-DREAMS platform.

It is worth noting that both real-time and post-trip interventions apply for all modes in *i*-DREAMS, albeit the operationalization of the proposed logic model of change, vary between modes, in a sense that not the same metrics can be collected for all modes. For instance, all modes in the end (i.e. at the highest level of impact) target 'safety outcomes', but the specific safety outcomes (i.e. types of crashes) targeted can vary between the different modes.

With regards to professional operators, the *i*-DREAMS interventions that will be tested may be different. For example, within the rail transport mode, the assessment variables of speed/speeding, sleepiness, fatigue and blind spot will be available from the simulator processing. Post-trip feedback could be also provided and evaluated but it would be difficult to observe or assess whether any behavior change occurred due to post-trip in a simulator only study. In addition, particular focus is given on vulnerable road users (i.e. cyclists, pedestrians) but vehicles ahead of the train should be detected too. The time headway is likely to need to be greater for trams, but this is yet to be established. In theory VRUs could also appear on the segregated parts of the track.

Lastly, taking into account truck drivers, the point can be made that vehicle operators work embedded in a company context with a certain safety culture/climate present, and that this might be a potential moderator/mediator for the effects generated by the *i*-DREAMS interventions. Since truck drivers are professional drivers working for a company, key-stakeholder (i.e., company management (i.e. CEO or fleet safety manager), outdoor service providers, and indoor coaches (i.e. planner or buddy)) that are actively involved in the process of coaching professional drivers to improve their driving style, will have access to a web platform.

3 Assessment of interventions: Road Safety Background

In order to sketch out a methodology for the assessment of interventions, an overview of already utilized methodologies needs to be performed in order to identify strengths and weaknesses that could be exploited for the *i*-DREAMS intervention assessment methodology. This chapter is going to perform this task, by looking into methods, criteria for assessment, utilized KPIs and thresholds for measurement variables.

3.1 Methods

In recent decades, automotive telematics and driver monitoring systems were introduced in the industry in order to provide real-time and post-trip interventions and feedback to the driver. The assessment of the interventions should focus on the effectivity of the interventions, based on the logic model of change (i.e. safety outcomes, safety promoting goals, performance objectives and change objectives, which have been already described. In this section, an attempt is made to investigate methods that can be used to evaluate the aforementioned outcomes, goals and objectives.

3.1.1 Naturalistic driving studies

Several intervention studies occupy an important role in research due to the emphasis on crash prevention. To begin with, Payyanadan et al. (2017) monitored crash risk events in order to assess the interventions. It should be noted that a possible accident event was recorded when the accelerometer detected a change in speed of more than 15 mph in 1 s in any direction. However, due to a low occurrence rate of crash risks, directly measuring significant changes in crash risk required tens of thousands of drives observed over a very long time frame. In many cases, this type of study was impractical to pursue and implement. To address this problem, a route crash risk measure was developed in order to estimate changes in crash risk. As a result, the Trip Diary web-based feedback system reported and assessed basic indicators of driving behavior, such as the number of left turns, speeding, harsh braking, harsh cornering, and harsh accelerating events by a driver along a driven route. The events were annotated on the map to provide visual feedback of the areas that the driver had a risky driving behavior.

In addition, post-trip intervention technology improved safety outcomes for work-related drivers. The percentage of time drivers spent within the speed limit and exceeding the speed limit as well as the percentage of time exceeding the speed limit compared with other drivers participating in the intervention was evaluated (Newnam et al., 2014). Drivers also completed a brief demographic (e.g. age, gender) and driving exposure (i.e. kilometres driven per week) questionnaire and provided useful information about their speed violations.

Toledo et al. (2008) showed that the rates of harsh events, such as hard braking and acceleration, turns and lane changes can be used as indicators of the risk to be involved in road crashes. Summary statistics of the crash rates in the periods before and after the exposure to the IVDR feedback were provided and a comparison of driver performance indicators was made through a before-after analysis.

It was also concluded by another naturalistic driving experiment (Farah et al., 2014) that providing feedback on driving behavior along with parental training in vigilant care, led to a change in behavior in a great extent. Different types of excessive maneuvers were assessed and had been classified into five categories: harsh braking, harsh accelerating, turn handling, lane handling and speeding. The ANOVA analysis was conducted and participants were also requested to fill a web questionnaire, which was served as screening in order to evaluate their relevance to the study. Fujii et al. (2001) investigated the change objectives and discussed psychological and behavioral strategies that influence individual awareness and address other, various psychological factors to encourage voluntary behavior change. A before-after analysis was conducted and drivers were asked to answer a questionnaire about their driving habits.

In addition, how behavioral and emotional driver factors, such as fatigue, drowsiness or distraction can affect driving performance by providing post-trip interventions and alerts (Arumugam and Bhargavi, 2019) was investigated. Using post-trip intervention technology, drivers can reliably quantify the risk associated with a specific driving behavior, such as speeding, number and severity of harsh events (braking and acceleration), harsh cornerings even or driving aggressiveness. Driver behavior events, such as hard acceleration, hard braking, hard cornering and over speeding were used as reliable indicators to assess the interventions. Driver scores were collected through a web-platform and a before-after analysis was conducted in order to evaluate the interventions. In addition, physiological factors, such as fatigue, drowsiness and distraction were assessed and a before-after analysis was made to evaluate the different values or rates of physiological indicators. Toledo and Shiftan (2016) assessed data regarding safety related events and supplementary safety events, such as braking, lateral acceleration or speeding, were recorded, in three experimental phases: no feedback, limited feedback to the worst drivers, and full feedback. A before-after analysis was conducted and changes in the rate of events reflected safety (e.g. frequency of speeding, harsh accelerations and harsh braking) were identified in order to assess the interventions.

In other two studies (Hickman and Geller, 2003; Levick and Swanson, 2005), interventions came in the form of in-cab sounds, lights and/or summary reports to the driver, were available on vehicle performance measures only as effected by the driver, such as speeding, hard braking, and excessive idling. A meta-analysis was conducted in order to assess risk driving behaviors as well as the frequency of extreme braking incidents. The objective of another naturalistic driving study (Bell et al., 2017) was to evaluate whether two types of feedback from an in-vehicle monitoring system (IVMS) could reduce the incidence of risky driving behavior with a before-after analysis. The experiment included two periods: in the first period, the driver got feedback of warning lights from an in-cab device which notified drivers when they performed harsh driving maneuvers (i.e. hard braking, speeding, swerving that exceeds set accelerometer thresholds), and in the second period, drivers viewed video recordings of their risky driving behaviors with supervisors and were coached and motivated by them on safe driving practices. It was observed that both performance objectives as well as change objectives were assessed for the evaluation of interventions.

Moreover, the effects of a driver assistance system for keeping safe speed and safe distance (called as SASPENCE) on driver behavior, reactions and acceptance were evaluated in a real-life field study carried out by Adell et al. (2011). The SASPENCE is an advanced driver assistance system which assists the driver to keep a safe speed (according to road and traffic conditions) and a safe distance to the vehicle (obstacle) ahead. The “safe speed and safe distance” function informed/warned the driver: when the car was too close to the vehicle in front, when a collision was likely due to a positive relative speed, when the speed was too high considering the road layout and when the car was exceeding the speed limit. After each drive, the test drivers were asked to complete a questionnaire, in order to assess the drivers’ comprehension and experience of the system. Driving data was logged and the test drivers were observed by means of an in-car observation method, in this case by two observers riding along in the car with the driver. The findings revealed positive effects of the system in terms of fewer alarm situations, shorter alarm lengths, shorter reaction times, increased headway and better interactions with VRU at intersections. However, driver performance worsened slightly, the number of centre line crossings increased, there was worse facilitating behavior with regard to other drivers and harder braking at traffic lights. No major effect on driver's speed behavior, lane keeping/change, overtaking, red running, use of turning indicator and workload was found.

3.1.2 Simulator studies

With regards to driving simulator studies, critical situations can be highly controlled and trained within driving simulator experiences (Karthaus and Falkenstein, 2016). An important goal for simulator training is to provide feedback and help drivers to improve their driving performance. Several studies have shown positive effects of simulator training on driving competence in on-road real-time conditions. To begin with, Roberts et al. (2012) developed an interesting simulator study which was conducted to evaluate driver's distraction, through real-time and post-drive mitigation systems. It should be noted that change objective (i.e. motivation) was also used for the assessment of the interventions and a before-after analysis was conducted. The post-drive mitigation system consisted of coaching drivers on their performance and encouraging social conformism by comparing their performance to peers.

Another simulator experiment was conducted which assessed the differences in driving performance and eye-movement patterns between different drives and compared these across treatments (Donmez et al., 2008). Safety outcomes, such as collision with lead vehicle and collision with oncoming traffic as well as performance indicators, such as speeding, acceleration, too close to lead vehicle and lane deviation were evaluated in a meta-analysis method. An interesting finding of Toledo and Lotan (2006) indicated that the exposure to post-trip interventions had a positive effect on driver performance and therefore safety. The safety promoting goals of vehicle control and speed management were evaluated per their effectiveness and examples of these measurements/manoeuvres included lane changes, harsh acceleration, sudden braking and excessive speed. The quality of performance of the detected manoeuvres was also assessed in a before-after analysis.

Zhao and Wu (2013) conducted a driving simulator study to assess driving speed and compare the effectiveness and acceptance of the Intelligent Speeding Prediction System (ISPS) as well as the Intelligent Speed Adaptation (ISA) through a before-after analysis. System type served as a between-subjects variable with four levels: no speed assistance system, pre-warning system developed based on the ISPS, post-warning system ISA, and combined pre-warning and ISA system. Furthermore, Paredes et al. (2018) presented the first guided slow breathing intervention for drivers aimed at reducing stress. The experiment was conducted in two simulated driving environments (i.e. city, highway) and subjective stress metric (i.e. perceived stress level) as well as driving safety and performance metrics (i.e. harsh braking, lane-keeping violations, perceived ability to follow guidance, distraction, focus, and perceived concentration) were evaluated with a before and after methodology. Van der Heiden et al. (2018) investigated how quickly drivers responded to a visual in-car warning using a driving simulator. The driving task was combined with an audio task that assessed different levels of cognitive distraction, time reaction as well as lane change. Drivers requested to fill a questionnaire and results showed that the initial reaction time to in-car warnings was significantly larger for drivers that were distracted by the audio task. Moreover, it was proved that in-car warnings might be helpful as a last resort to prevent a crash; however, such warnings should be given timely.

Moreover, Wong et al. (2019) investigated how effective are voice commands in influencing people’s speed on a semi-autonomous vehicle regardless of how occupied the driver is with secondary task. Drivers were first given a warning at the approach of one of driving scenarios, such as roundabouts, lane changes, T-junctions. This was then followed by one of three different execution commands (indicate left/right, braking, speed), which varied both in tone and phrasing. Driving indicators, such as harsh braking and speed were assessed in a before-after methodology and assertive and non-assertive voice commands were given in an identical set of driving videos separately. The results showed that participants responded quicker to assertive voice commands despite how immersive the secondary task was. Roenker et al. (2003) compared simulator training and useful field of view (UFOV) functional training in older drivers. A before-after analysis was conducted and authors assessed safety promoting goals

goals of speed management (i.e. speeding) and driver fitness (i.e. attention) before training, immediately after training, as well as eighteen months after the training period, both in a driving simulator and on open-road traffic conditions. While the simulator training improved older drivers' behavior at left turns and traffic lights, the UFOV training improved divided attention.

Another study (Lavallière et al., 2012), aiming to evaluate the effectiveness of the video-based feedback training was conducted. To achieve this objective, ten older drivers who received a driving refresher course and feedback about lane change and blind spot were tested with an on-road standardized evaluation before and after participating to a simulator training program (Feedback group). All participants were given a general verbal questionnaire that included items on driving and a before-after analysis was implemented. Their results were compared to a Control group (twelve older drivers) who received the same refresher course and in-simulator active practice as the Feedback group without receiving driving-specific feedback. After attending the training program, the Control group showed no increase in the frequency of the visual inspection of three regions of interests (rear view and left side mirrors, and blind spot). In contrast, for the Feedback group, combining active training and driving-specific feedbacks increased the frequency of blind spot inspection by 100% (32.3 to 64.9% of verification before changing lanes). These results suggested that simulator training combined with driving-specific feedbacks helped older drivers to improve their visual inspection strategies, and that in-simulator training transferred positively to on-road driving.

To sum up, the majority of the examined studies, focusing on the assessment and the effectivity of the interventions, mostly used a before-after analysis, presenting the statistics of events' occurrences, as well as safety outcomes, safety promoting goals, performance objectives and change objectives. In addition, questionnaires were also assess the interventions, while the meta-analysis, for the assessment of interventions place, was a methodology which was implemented in fewer studies.

Table 5 presents an overview of the studies examined along with their driving performance indicators and the methods utilized.

Table 4: An overview of the studies examined along with their driving indicators and methods utilized

Studies	Indicators	Methods
Toledo et al., 2008	**crash rates**	before-after analysis
Toledo et al., 2008, Fujii et al., 2001, Arumugam and Bhargavi, 2019, Toledo and Shiftan, 2016, Bell et al., 2017, Roberts et al., 2012, Toledo and Lotan, 2006, Zhao and Wu, 2013, Paredes et al., 2018, Wong et al., 2019, Roenker et al., 2003, Lavallière et al., 2012	**driver performance** (i.e. harsh braking, harsh acceleration, speeding)	
Arumugam and Bhargavi, 2019, Paredes et al., 2018, Roenker et al., 2003	**physiological measurements** (i.e. fatigue, distraction, drowsiness)	
Payyanadan et al., 2017, Hickman and Geller, 2003, Levick and Swanson, 2005, Donmez et al., 2008	**crash risk events**	meta-analysis
Newnam et al., 2014, Farah et al., 2014, Fujii et al., 2001, Adell et al., 2011, Van der Heiden et al., 2018, Lavallière et al., 2012	**driver performance** (i.e. harsh braking, harsh accelerating, turn handling, lane handling and speeding)	questionnaires *(based on before-after analysis)*

3.2 Criteria/Perspectives

3.2.1 The Intervention Mapping framework

When developing interventions to change behavior (like in the case of the *i*-DREAMS project), numerous choices have to be made. These choices revolve around a series of important questions about which interventions work to create behavioral change like for instance: how to logically assess a health or safety problem? How to get from goals and objectives to intervention strategies? How to decide which intervention methods to use? How to link interventions design with implementation? According to Bartholomew Eldredge et al. (2016: p. 7) consultation of available theoretical and empirical evidence is necessary "to ensure that we can describe and address the factors that cause health problems and the methods to achieve change." Experts have argued that more guidance on how to use theory to understand and address health and social problems, would be very beneficial to the field of health & safety promotion and education (e.g. Glanz & Bishop, 2010; Glanz et al., 2015).

As highlighted by Bartholomew Eldredge et al. (2016), the key words in Intervention Mapping (IM) are planning, research and theory. IM provides a vocabulary for program planning, procedures for planning activities, and technical assistance with identifying theory-based determinants and matching them with appropriate methods for change. It maps the path from recognition of a need or problem to the identification of a solution. This process is iterative rather than linear, as intervention planners are supposed to move back and forth between tasks and steps. Moreover, the protocol is cumulative: each step is based on previous steps, and inattention to a particular step may lead to mistakes and inadequate decisions.

To sum up, IM is a framework for effective decision making at each step in intervention planning, implementation, and evaluation (Bartholomew Eldredge et al., 2016). The purpose of the IM is to provide planners of health and safety promotion interventions with a framework for effective decision making at each step in intervention planning, implementation, and evaluation. Specifically, IM is a six-step protocol:

(1) Logic model of the problem
(2) Program outcomes and objectives (Logic model of change)
(3) Program design
(4) Program production
(5) Program implementation plan
(6) Evaluation plan

It is worth mentioning that deliverable 3.3, provides a detailed overview. More specifically, within this deliverable, special attention is given to step 6 “Evaluation plan”. Within the current work, effect and process evaluation questions need to be formulated. The targeted objectives (i.e. safety outcomes, safety promoting goals, performance objectives, and change objectives) are going to be operationalized. This requires a categorization of specific indicators and a further translation into directly or indirectly observable measures. The next step is to specify the evaluation design. Both qualitative and quantitative measures should preferably be included when evaluating an intervention (Bartholomew Eldredge et al., 2016).

3.2.2 Different evaluation perspectives

There are several evaluation perspectives: formative vs. summative evaluation and outcome vs. process evaluation vs. cost-benefit analysis.

Whereas formative evaluation occurs during the development phase in order to improve a system iteratively until desired objectives are reached and weaknesses of the system are eliminated, hence ‘evaluate as you create’, summative evaluation focuses on a final system, hence ‘evaluate when you are finished’.

Outcome evaluation, also called effect evaluation, applies to whether targeted factors changed as a result of the intervention or not. Process evaluation aims to determine which parts of the intervention were effective and which not. Moreover, the quality of implementation and adoption of the intervention is investigated. A cost-benefit analysis compares the costs with the benefits of an intervention.

Within this deliverable, there is a focus on summative evaluation with an emphasis on outcome evaluation and process evaluation.

3.2.3 Outcome evaluation

As mentioned above, outcome evaluation focuses on the effectivity of the intervention. Within the outcome evaluation, there will be a focus on the outcomes proposed in the logic model of change (see Figure 2), hence, **“safety outcomes”, “safety promoting goals”, “performance objectives”, and “change objectives”**. Hence, it will be investigated whether the intervention had an impact on these variables. Although it would be ideal to detect statistically significant impact on safety outcomes (e.g. crash occurrence), this is not very likely, since crashes are rare events, and the total duration of the field trials covers only a few months. The occurrence of such impact can be expected as more likely for safety promoting goals, performance objectives and change objectives.

In addition, there will be a focus on **“user acceptance”** and “**user acceptability**” within this outcome evaluation, since both are important for the adoption and effectiveness of the interventions. While acceptability relates to whether drivers have the intention to and are open for using this system, acceptance has to do with how they experience the actual use of a new system.

Since the adoption of a new in-vehicle safety technology can only be successful if the technology is effective in reducing the target risk and when it is also used efficiently by the driver, user acceptability and acceptance will be measured during the outcome evaluation. If the driver does not accept the technology, misuse or disuse of the technology is evident (Parasuraman and Riley, 1997). It is therefore important to reach a high level of acceptability and acceptance and to measure the level of acceptability and acceptance.

User acceptance

Since user acceptability is related to the actual use of the system, the behavior of the driver will be investigated when receiving signals of the system during driving. For example, if a driver receives a signal, does he react to this signal? In case he reacts to the signal, how and when does the driver react?

User acceptability

Since user acceptance is related to the intention to use a system, it is based on individual **attitudes, expectations and experience**, obtained during actual use, as well as their **subjective evaluation of expected benefits** (Schade and Baum, 2007). Since these variables are latent concepts, a **survey** will be used in order to investigate this.

User acceptance will be evaluated for the two tools that are used to offer the interventions to the **driver**: (1) the in-vehicle warning system for real-time feedback, and (2) the smartphone application, for post-trip feedback. In addition, user acceptance will be evaluated for the tool that is used to offer the post-trip intervention to the **key-stakeholder** (i.e., company management (i.e. CEO or fleet safety manager), outdoor service providers, and indoor coaches (i.e. planner or buddy)) that is actively involved in the process of coaching professional drivers to improve their driving style, namely the web platform.

The **Unified Model of Driver Acceptance (UMDA)** proposed by Rahman et al. (2018), will be used as a conceptual framework for the identification of the key-variables that determine user acceptance. Among these variables, a selection will be made to incorporate in the evaluation. As illustrated in Figure 9:, the model consists of attitude, perceived usefulness, perceived ease of use, subjective norm, perceived behavioral control, compatibility, trust, endorsement, and affordability. **Attitude** stands for an individual’s positive or negative assessment about performing a certain behavior, in this case, using a new technology system in a real-time or post-trip setting. **Perceived usefulness** refers to the degree to which a person believes that using a particular system would enhance his or her performance, in this case, how safely he or she operates a vehicle. **Perceived ease of use** is the degree to which a person believes that using a particular system would be free of effort. **Subjective norm** relates to a person’s perception that most people who are important to him or her think he or she should or should not perform a particular behavior, in this case, using a new system in a real-time or a post-trip setting. **Perceived behavioral control** refers to the perceived ease or difficulty of performing a certain behavior, i.e. using a new system in a real-time or post-trip setting. **Compatibility** is the degree to which an innovative system is perceived as being consistent with the existing values, needs, and past experiences of potential adopters. **Trust** is the belief of users that the system would perform its intended task(s) with high effectiveness. **Endorsement** stands for the willingness to approve or recommend the purchase and/or the use of a new technology system. **Affordability** refers to the monetary amount people are willing to pay to purchase, install, and maintain the system. This set of factors is assumed to predict overall acceptance of new technology, with acceptance considered as the combination of **the intention for future use as well as the actual use experience**. Potential **moderators** of the relationship between user acceptance on the one hand, and its predictors on the other hand, are age, gender, user experience, and personal innovativeness (i.e., the willingness to adopt technological innovations earlier than others).

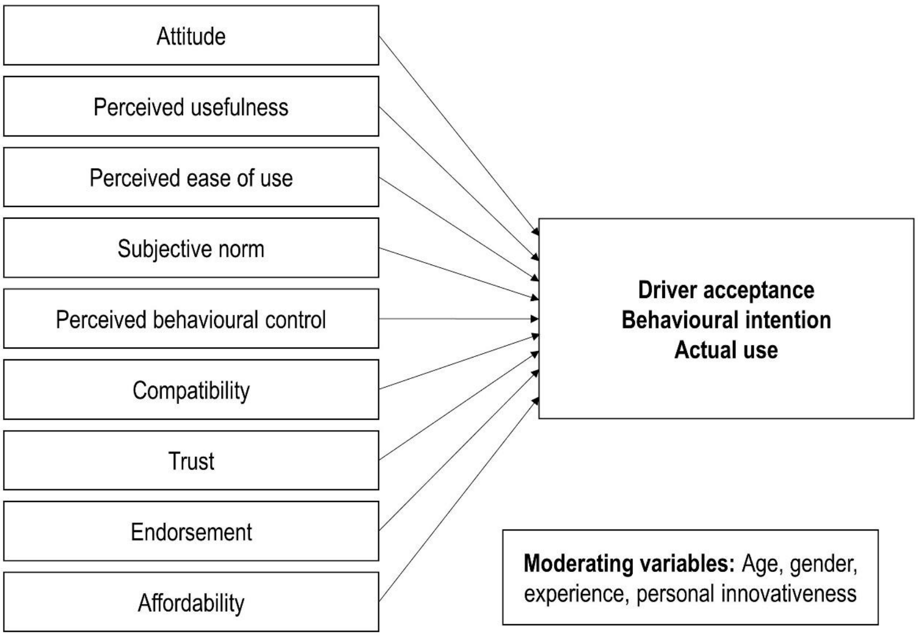


Figure 9: The Unified Model of Driver Acceptance

3.2.4 Process evaluation

As mentioned above, process evaluation focuses on the quality of material designs, the quality of implementation, and the adoption of the intervention. Within the process evaluation, there will be a focus on (a selection of) variables within the **RE-AIM Framework** (Glasgow, Vogt, & Boles, 1999). This is a widely known framework for process evaluation. As it can be derived from Figure 10: , the abbreviation "RE-AIM" stands for: Reach, Effectiveness, Adaption, Implementation and Maintenance. "**Reach**" is the absolute number, proportion, and representativeness of individuals who are willing to participate in a given initiative. "**Effectiveness**" is the impact of an intervention on outcomes, including potential negative effects, quality of life, and economic outcomes. "**Adoption**" is the absolute number, proportion, and representativeness of settings and intervention agents who are willing to initiate a program. "**Implementation**" refers to the intervention agents' "**fidelity**" to the various elements of an intervention's protocol. This includes consistency of delivery as intended and the time and cost of the intervention. "**Maintenance**" is the extent to which a program or policy becomes institutionalized or part of the routine organizational practices and policies. Maintenance also has referents at the individual level. At the individual level, it is defined as the long-term effects of a program on outcomes 6 or more months after the most recent intervention contact (Gaglio, Shoup, & Glasgow, 2013).

Figure 10: the RE-AIM Framework

Linnan and Steckler (2000) indicated seven components as 'key process evaluation components': **(1) Context, (2) Reach, (3) Dose delivered, (4) Dose received, (5) Fidelity, (6) Implementation, and (7) Recruitment**. Therefore, these components will be explained in detail:

(1) Context: Aspects of the larger social, political, and economic environment that may influence intervention implementation.

(2) Reach: The proportion of intended target audience that participates in an intervention. If there are multiple interventions, then it is the proportion that participates in each intervention or component. It is often measured by attendance. Reach is a characteristic of the target audience.

(3) Dose delivered: The number or amount of intended units of each intervention or each component delivered or provided. Dose delivered is a function of efforts of the intervention providers.

(4) Dose received: The extent to which participants actively engage with, interact with, are receptive to, and/or use materials or recommended resources. Dose received is a characteristic of the target audience and it assesses the extent of engagement of participants with the intervention.

(5) Fidelity: The extent to which the intervention was delivered as planned. It represents the quality and integrity of the intervention as conceived by the developers. Fidelity is a function of the intervention providers.

(6) Implementation: A composite score that indicates the extent to which the intervention has been implemented and received by the intended audience.

(7) Recruitment: Procedures used to approach and attract participants. Recruitment often occurs at the individual and organizational/community levels.

3.3 KPIs

Key Performance Indicators (KPIs) are measures that are monitored in order to determine the quality, resources, satisfaction, effectiveness, and efficiency (Dolence et al., 1994). According to Chan and Chan (2004), KPIs are general indicators of performance that focus on critical aspects of outputs or outcomes. For performance measurement to be effective, the measures or indicators must be accepted and totally understood. In addition, KPIs will need to evolve and it is likely that a set of KPIs will be subject to change and refinement. It should be noted that driver measures are measures which have direct influence on the outcome of the key performance indicators. Outcome of the KPIs are dependent on driver measures.

The safety outcomes of *i*-DREAMS are the same for both real-time and post-trip interventions, as depicted in Figure 3, delivered from deliverable 3.3. As these are the key factors the project is looking to prevent, they will form the basis of the KPIs, measuring whether the technology has been successful in each mode of transport. Figure 3, shows how the safety outcomes can be classified broadly as a need to address and measure the preventative effects on front, rear and side crashes; rollover/ derailment; and injury to passengers. Figure 3, also shows how these can be broken down further within each category to very specific types of accident or accident partner (such as vulnerable road users). These safety outcomes will apply to some modes and not others due to the differing nature in them, for example side impacts will not feature in rail mediums due to being track based but will be crucial to examine for cars, buses and trucks.

These safety outcomes (defined in terms of crashes) are causally dependent upon an underlying set of safety promoting goals, referring to behaviors which can be logically linked to the safety outcomes, based on existing empirical evidence. As fully detailed in deliverable 2.2 (see sections 3 and 4), behaviors that are typically monitored in the context of safety promoting interventions related (but are not limited) to one of the five behaviors that appear as safety promoting goals in Figure 4, i.e. vehicle control, sharing the road with others, speed management, driving fitness, and use of safety devices. How these safety promoting goals feed into the safety outcomes is covered fully in deliverable 3.3 and Figure 4 is taken from this.

The safety outcomes and safety promoting goals were used to inform the KPIs needed within the project to assure the technology has had a positive effect on each.

Table 5 shows each KPI and the type of intervention they will be measured in (real-time and/ or post-trip) and the vehicle modes they apply to.

Table 5: i-DREAMS KPIs as they apply to real-time and post-trip intervention and mode

Safety promoting goal	Performance objective	KPI/ *i*-DREAMS metric	Real-time	Post-trip	Mode
Driver fitness	Fatigue	Time driving	X	X	All
	Sleepiness	KSS Score	X	X	All
	Distraction	Hand-held phone use	[2]	X	Car/Bus/Truck
		No hands on wheel	[3]	X	Bus/Truck
Speed management	Speeding	Percentage time over speed limit + average speed over speed limit	X	X	All
Sharing the road with others	Tailgating	Number of headway monitoring warnings/ increased time headway	X	X	Car/Bus/Truck/Tram
	Overtaking	Number of overtakes in illegal area	X	X	Car/Bus/Truck
	Lane Discipline	Number of lane departure warnings	X	X	Car/Bus/Truck
	Vulnerable road user collision avoidance	Number of forward collision warnings	X	X	Car/Bus/Truck/Tram
Vehicle control	Acceleration	Number of harsh accelerations + acceleration aggressiveness level	X	X	All
	Deceleration	Number of harsh decelerations + deceleration aggressiveness level	X	X	All
	Steering	Number of harsh cornering events	X	X	Car/Bus/Truck

[2] Available in real-time but in vehicle computation needed for cars/trucks/buses/rails
[3] Available in real-time but in vehicle computation needed for cars/trucks/buses/rails

3.4 Thresholds

A key task in defining the *i*-DREAMS platform concerns the identification of adequate thresholds that are necessary to distinguish the different phases constituting the STZ. In order to evaluate the effect of a system or technology, a threshold for information-processing should be considered (Wong and Huang, 2013). This section, aims defining the basis of the already reviewed indicators and projects, which are their typical values and suitable thresholds that enable the identification as well as the assessment of the three different stages of the STZ.

To begin with, various projects, initiatives and publications can be found in literature, focusing on the issue of safety evaluation of Advanced Driver Assistance Systems (ADAS). Page et al. (2015) and Faulks et al. (2010) reported a large amount of projects dealing with the impact of ADAS on safety. In Table 6 the most relevant to this deliverable are briefly recalled.

Table 6: Projects focusing on safety evaluation of ADAS

Project name	Brief description
AIDE (Johansson et al., 2004)	Adaptive Integrated Driver-vehicle Interface – among the objectives it has the maximization of the efficiency and safety benefits of ADAS.
UK-ISA (Lai, Carsten, & Tate, 2012)	Intelligent Speed Adaptation Project - It investigates how car drivers behave when driving with ISA by means of set of field trials, it studies via driving simulator the overtaking behavior with ISA, it prepares an ISA design for motorcycles and large trucks and investigates the costs and benefits of such a system.
EASY (“Effects of Automated Systems on Safety (EASY) : University of Leeds Driving Simulator,” n.d.)	Effects of Automated Systems on SafetY – focusing on safety benefits from advanced driver assistance systems.
HASTE (“Human Machine interaction And the Safety of Traffic in Europe (HASTE) : University of Leeds Driving Simulator,” n.d.)	Human Machine Interface And the Safety of Taffic in Europe – it examines the influence of IVIS on the risk of crashing.
TRACE (“TRACE Walking and Cycling tracking services,” n.d.)	It focuses on the assessment of the potential of ICT-based tracking services to optimize the planning and implementation of such measures.
euroFOT (“euroFOT // The first large-scale European Field Operational Test on Active Safety Systems,” n.d.)	European Field Operational Test – it establishes a comprehensive, technical, and socio/economic assessment of the impact of intelligent vehicle systems on safety, the environment and driver efficiency.
ADVISORS (Wiethoff, n.d.)	Action for advanced Driver assistance and Vehicle control systems Implementation, Standardisation, Optimum use of the Road network and Safety – it has among all its objectives the one to develop an integrated assessment methodology and relevant criteria to reliably assess traffic safety, usability, interaction safety, user acceptance, road network efficiency and environmental impacts of ADAS.

Project name	Brief description
DaCoTa (Thomas et al., 2013)	It has as main aim to further develop the content of the ERSO with additional data types and ouput tools, belonging to 8 additional research areas.
IMVITER ("Final Report Summary - IMVITER (Implementation of virtual testing in safety regulations) | Report Summary | IMVITER | FP7 | CORDIS | European Commission," n.d.)	Implementation of virtual testing in safety regulations – it aims to promote the implementation of virtual testing in safety regulations.
InteractIVe ("interactive - Accident avoidance by intervention for Intelligent Vehicles," n.d.)	It focuses on the design, development, and evaluation of integrated ADAS applications.
PReVENT ("PReVENT :: Home," n.d.)	As primary objective it has the development, test and evaluation of preventive safety applications, using on-board systems for driver assistance.
ADAS&ME ("Homepage - ADAS&ME," n.d.)	Holistic impact assessment of automation opportunities to enhance safety by supporting the impaired driver/rider, as well as of handover transitions optimisation.
RESPONSE3 (Knapp, Neumann, Brockmann, Walz, & Winkle, 2009)	The goal is to obtain a Code of Practice for the development and testing of ADAS for the European industry.

Of all the projects, only the ones developing the assessment step of ADAS devices are considered, i.e. ADAS&ME, InteractIVe, TRACE, euroFOT, AIDE, RESPONSE3, DaCoTa and HASTE. What is generally pointed out by the research works, is that there is a lack of formalization in the evaluation procedure of safety systems (Page et al., 2015; Thomas et al., 2013), which leads to several assessments with different results (Thomas et al., 2013).

AIDE (Johansson et al., 2004), which has as general scope to determine the potential performance improvement resulting from ADAS support, indicates four categories of performance metrics: longitudinal and lateral metrics, event detection metrics and combined control and event detection metrics. Overlooking the fourth category, which is especially focused on IVIS performances, seven key variables are defined by AIDE: speed, headway and other vehicle following metrics, pedal movement and steering wheel metrics, lane-keeping metrics and event detection metrics.

For each of the recalled variables, specific indicators are defined. For the evaluation of Intelligent Speed Adaptation (ISA) and Adaptive Cruise Control (ACC) systems, mean speed, standard deviation/variance of speed, maximum speed and speed change are identified. In particular, this last metrics is defined by HASTE ("Human Machine interaction And the Safety of Traffic in Europe (HASTE) : University of Leeds Driving Simulator," 2020) and reported in AIDE, and is determined as the difference between the start and end value of a linear function fitted to the speed signal in a given interval by means of least squares.

As regarding headway, both distance and time headway, with their mean, minimum values and standard deviation, are considered metrics in AIDE. Time-To-Collision (TTC) is recalled, too, and specifically, minimum TTC, the mean of TTC local minima and TET (Time Exposed-TTC) are reported as useful in the evaluation of ADAS performances. Even lane keeping metrics are divided in distance and time based. In the first group, mean lane position, standard deviation/variance of the lane position and lane exceedances are listed. As well, lane Root Mean Square (RMS) deviation, peak lane deviation and mean lane exceedance duration are reported. As time-based metrics, Time-To-Line Crossing (TLC) is considered, specifically its median, 15% level- and minimum values. To these, HASTE adds the minimum values of TLC, with its mean value and the proportion of min TLC values lower than 1s.

Finally, event detection metrics for braking, acceleration and steering are summarized. These are response time and distance, respectively defined as the time/distance a driver needs to respond correctly to a given stimulus, errors of omission, i.e. the number of times a driver fails to respond to the stimulus, and number of commission, that is the number of time they incorrectly respond to the stimulus.

Regarding steering wheel metrics, although defined and described, their suitability is underlined more for IVIS assessment than for ADAS. Standard deviation of the steering wheel angle, High Frequency Component (HFC) of the steering wheel angle and steering wheel reversal rate and action rate are the recalled magnitudes. In addition to them, the maximum steering deflection, the steering velocity standard deviation, the number of steering holds, steering zero crossings and steering grip are also listed. Also, pedal movement metrics, although considered, are quite of rare use.

In AIDE (Johansson et al., 2004), not only metrics are reported, but for some of them also general thresholds are provided. They mainly refer to discarded values or to ranges to be considered in the evaluation and are summarized in Table 7.

Table 7: Metrics and thresholds as reported in Johansson et al., 2004 (with regards to safety promoting goals, red color refers to vehicle control, while green color refers to sharing the road with others)

Metrics	Thresholds
Steering Wheel Reversal Rate (SRR)	[0.5-10] degrees
Distance headway	If > 50 m, discarded
Time headway	If > 3 s, discarded
TTC	< 1,5 s, critical values
TTC	<1 s and > 15 s, discarded
HFC	[0-0.6] Hz dominant frequency band for steering activity
TLC	<1 s and > 20 s, discarded
Min(TLC)	< 1 s

EuroFOT (Faber et al., 2011) assesses eight ADAS functions, by considering six user-related aspects: driver behavior, driver workload, driver acceptance, trust, function usage and exposure.

The safety impact analysis is based on hypothesis testing and relies on three basic steps: the definition of the target crash population, the identification of the roles of safety-related measures before and after the interventions, and the interpretation of remarkable changes in terms of accidents, incidents and fatalities at European level.

As described in Faber et al. (2011), three different analysis typologies are employed in the assessment, Event Based Analysis (EBA), Aggregation Based Analysis (ABA) and Physical Risk Modelling (PRM). In relation to the kind of investigation, diverse metrics are used. In the case of EBA, frequencies of critical driving situations are considered; ABA evaluates changes between baseline and treatment measurements, while PRM esteems vehicle conflicts.

In Table 8 the indicators measured within euroFOT and the kind of situation they refer to (the target crash population, as it is defined in Faber et al. (2011) are summarized.

Table 8: Target crash population and metrics used in euroFOT (red color refers to safety outcomes, green color refers to safety promoting goals and blue color refers to performance objectives)

Target Crash population	Metrics
Rear-end crashes	forward accidents/incidents per mileage/time driven/n° of drivers
	risk and severity of crash involvement in car following situations with/without ACC+ Forward Collision Warning (FCW)
	n° of ACC+FCW activations/n° of driving hours
	ACC+FCW activation time/n°of driving hours
	average speed with/without ACC+FCW
	hard decelerations per mileage/time driven/n° of drivers
	mean time headway with/without ACC+FCW
	response time when reaching the brake pedal
	using of acceleration pedal
Crashes initiated by inadvertent lane departure	lateral accidents/incidents per mileage/time driven/n° of drivers
	exceeding a given offset to the lane markings per mileage/time driven/n° of drivers
	changes in steering wheel angle/velocity/frequency of movement with/without Lane Departure Warning (LDW)
	relation between lane change occurences and use of turn indicators with/without LDW
	n° of LDW activations/n° of driving hours
	LDW activation time/n°of driving hours
Lane change crashes	lane change accidents/incidents per mileage/time driven/n° of drivers
	frequency of lane change indicator use when on multilane roads with/without Blind Spot Information System (BLIS)
Speed Limit (SL)/CC	instances of time with speed larger than legal speed (with more than 10 s duration) per mileage/time driven/n° of drivers
	instances of jerks larger than a given threshold per mileage/time driven/n° of drivers
	instances of time headway/TLC/TTC shorter than a given threshold per mileage/time driven/n° of drivers
	SL activation occurences/n° of driving hours
Curve Speed Warning (CSW)	curve entrance speed selection with/without CSW

InteractIVe (Larsson et al., 2012) provides an evaluation framework to assess the technical performance, user-related one and safety impact, and it judges these areas using both subjective and objective data, e.g. questionnaire results and measured magnitudes, using before/after analysis.

Starting from the basic hypothesis that the provided intervention should not negatively influence driving behavior, the project supplies a very detailed overview of the performance indicators applied for each research question. Basically, they can be divided in factors related to the performance of the detection, and indicators linked to measurable driving behavior. With regards to performance factors, they include basic indicators, such as missed/false/correct alarm rates, false negative/positive detections, rate function "on" per environmental condition, function warning/intervention status, duration of the intervention, minimum/mean/maximum distance and time distance at the first detection (of an object for example), maximum difference in the detected and current speed limit.

The indicators employed to objectively evaluate driver behavior are surrogate safety measures, i.e. TTC, TLC and TET, at a point in time, which could be related to the alarm, start of an intervention or first detection, driver reaction in terms of speed reduction, braking and/or steering reaction after an alarm, i.e. brake pedal and steering wheel angle, maximum steering velocity, maximum longitudinal and lateral acceleration, vehicle speed and position, duration of speed exceeding, distance to speed limit at initiating deceleration, minimum/mean/maximum yaw rate, lateral position in lane.

In InteractIVe, also a table with ranges, frequency and description of the time signals logged during the tests is provided. In the following, Table 9: summarizes the main magnitudes triggered by InteractIVe system and their ranges.

Table 9: Ranges and accuracies of metrics applied in InteractIVe (red color refers to safety outcomes, green color refers to sharing the road with others and blue color refers to speed management)

Signal	Range lower value	Range upper value	Accuracy	Unit
Vehicle speed	-30	100	0.01	m/s
Longitudinal acceleration	-15	15	0.1	m/s2
Lateral acceleration	-15	15	0.1	m/s2
Yaw rate	-3	3	0.001745	°/s
Wheel speed	-30	100	0.1	m/s
Lateral velocity	-10	10	0.1	m/s
Lateral position in the lane (left/right)	-12	12	0.01	m
Steering wheel angle	-720	720	0.1	°
Steering wheel velocity	-360	360	1	°/s
Brake/accelerator pedal position	0	100	1	%
Brake pressure	0	205	1	bar
ACC set speed	0	70	0.278	m/s

Signal	Range lower value	Range upper value	Accuracy	Unit
Longitudinal range to target	0	200	0.1	m
Lateral range to target	0	200	0.1	m
Longitudinal relative speed of target	-50	50	0.1	m/s2
Lateral relative speed of target	-50	50	0.1	m/s2
GPS position (latitude, longitude, altitude)	-	-	-	-
Speed limit of current/next road section	0	250	1	km/h
Curve radius of current road section	0	5000	1	m
Distance to obstacle (curve/intersection/roadwork/hill)	0	5000	1	m
Type of warning	0	1111	binary	
Function intervention status	0	1111	binary	
Recommended speed	0	70	0.01	m/s
Lane number	1	7		
Lane direction	0	2		
Number of lanes	1	5		
Lane width	0	6	0.1	m

In TRACE (Kessler et al., 2016) both a quantitative and qualitative evaluation was worked out. Data for the assessment were collected via surveys, focus groups and interviews, as well as before and after measurements of travel behavior were made. Unfortunately, only general information about the indicators and their statistics is given in the deliverable, focusing deeper on the evaluation methodology and its application to the developed app.

DaCoTa (Thomas et al., 2013) is more focused on providing a formalization of safety systems evaluation, therefore it does not propose indicators and thresholds, rather it suggests guidelines to be followed during safety assessment attempts.

RESPONSE3 (Knapp et al., 2009) is a part of PReVENT project and aim at providing a code of practice for the evaluation of ADAS, where controllability is the main concept.

A practical description of the evaluation framework for ADAS divided per case studies is provided in ADAS&ME. Interestingly, it splits the analysis per modes, highlighting systems applied to long-haul trucks, motorbikes and busses. In all cases, the evaluation is run on measurements taken before, during and after driving test, and the analysed data are technical, behavioral as well as subjective. The main objective metrics reported by the project's deliverable are speed, automation status, steering wheel angle, brake pedal position vehicle position and visual behavior.

In addition to projects, also research articles have been scanned in relation to performance indicators and their possible thresholds. In (Cafiso and Di Graziano, 2012) attention is paid to heavy vehicles and to the effect of ACC system in rear-end collisions. Though thresholds are not given, reaction time, tyre performance, braking deceleration and vehicle time gaps are the indicators considered in the analysis.

Page et al. (2015) highlights two groups of metrics, which are necessary to determine the effectiveness of in-vehicle safety functions: absolute ones, to which it belongs avoidance of accidents/injuries/critical situations, and relative ones, where percentage of triggered critical events and changes in injury severity distribution are contained.

Suzuki et al. (2017) considered a system made by ACC and FCW. The ACC was designed to keep a distance headway so that THW equals 1s, and a maximum deceleration of 3 m/s^2, the FCW turns a warning when TTC equals 2.5s. They assessed it by evaluating the changes in braking reaction time and in the average deceleration with and without the system.

In correct/incorrect responses and drivers' reaction times are measured to assess six intersection assistance systems, i.e. Forward Collision Warning (FCW), left/right cross traffic collision warning (CTW), oncoming traffic warning (OTW), pedestrian warning (PW), red traffic light warning (TLW), stop sign warning (SW), generic warning (GW).

In conclusion, it can be said that – though existing general methodological guidelines (Page et al., 2015) and though being event detection and driver behavior performance indicators often considered evaluation metrics– each project has its own needs. Therefore, performance Indicators (PI) are customized on the specific project outcomes and on the specific hypotheses that the project would like to verify.

3.5 Summary

In this chapter, an overview of past methodologies and frameworks from literature that have been used to assess the interventions was described. According to the literature, these are the findings of the outcome evaluation which focuses on the effectivity of the intervention and its great impact on other variables. Specifically, the evaluation was conducted in terms of the outcomes proposed in the logic model of change, and it was revealed that safety promoting goals and performance objectives had the greatest effect on the assessment of interventions. With regards to safety outcomes, collision with lead vehicle and collision with oncoming traffic were mostly used in order to evaluate the effectiveness of interventions. Although it would be ideal to detect statistically significant effect on safety outcomes (e.g. crash occurrence, conflicts, or other critical events), this was not found in the examined methodology, since accidents were rare events, and the total duration of the field trials covered only a few months. Undoubtedly, the occurrence of such impact can be expected as more likely for safety promoting goals, performance objectives and change objectives. Actually, safety promoting goals (i.e. driver fitness, vehicle control, speed management) appeared to have an influence in a great extend for the assessment of interventions. Performance objectives, and especially, speeding, harsh acceleration, harsh braking, lane deviation and left turns had the strongest impact on the interventions evaluation, while driver related characteristics such as distraction, stress, fatigue, drowsiness, attentions, concentration and blind spot appeared to have lower impact. Table 10 depicts the outcome variables which were found from the current literature in order to assess the interventions – they are classified in terms of the current study model. Lastly, change objective indicators (i.e. behavior change, motivation and capability) were rarely used for the assessment of interventions.

Table 10: Outcome variables for the assessment of interventions

Safety Outcomes	Safety Promoting Goals	Performance Objectives	Change Objectives
crash risk (Payyanadan et al., 2017)	**driver fitness** (Arumugam and Bhargavi, 2019, Roberts et al., 2012, Paredes et al., 2018, Van der Heiden et al., 2018, Roenker et al., 2003)	**speeding** (Payyanadan et al., 2017, Donmez et al., 2008, Newnam et al., 2014, Farah et al., 2014, Arumugam and Bhargavi, 2019, Toledo and Shiftan, 2016, Hickman and Geller, 2003, Levick and Swanson, 2005, Bell et al., 2017, Adell et al., 2011, Toledo and Lotan, 2006, Zhao and Wu, 2013, Wong et al., 2019, Roenker et al., 2003)	**behavior change** (Fujii et al., 2001)
collision with lead vehicle (Donmez et al., 2008, Adell et al., 2011)	**vehicle control** (Payyanadan et al., 2017, Donmez et al., 2008, Toledo et al., 2008, Farah et al., 2014, Arumugam and Bhargavi, 2019, Toledo and Shiftan, 2016, Hickman and Geller, 2003, Levick and Swanson, 2005, Bell et al., 2017, Toledo and Lotan, 2006, Paredes et al., 2018)	**harsh acceleration** (Payyanadan et al., 2017, Donmez et al., 2008, Toledo et al., 2008, Farah et al., 2014, Arumugam and Bhargavi, 2019, Toledo and Shiftan, 2016, Bell et al., 2017, Toledo and Lotan, 2006)	**motivation** (Bell et al., 2017, Roberts et al., 2012)
collision with oncoming traffic (Donmez et al., 2008)	**speed management** (Payyanadan et al., 2017, Donmez et al., 2008, Newnam et al., 2014, Farah et al., 2014, Arumugam and Bhargavi, 2019, Toledo and Shiftan, 2016, Hickman and Geller, 2003, Levick and Swanson, 2005, Bell et al., 2017, Adell et al., 2011, Toledo and Lotan, 2006, Zhao and Wu, 2013, Wong et al., 2019, Roenker et al., 2003)	**harsh braking** (Payyanadan et al., 2017, Toledo et al., 2008, Farah et al., 2014, Arumugam and Bhargavi, 2019, Toledo and Shiftan, 2016, Hickman and Geller, 2003, Levick and Swanson, 2005, Bell et al., 2017, Toledo and Lotan, 2006, Paredes et al., 2018, Wong et al., 2019)	**capability** (Paredes et al., 2018)
	sharing the road with others (Donmez et al., 2008, Payyanadan et al., 2017, Farah et al., 2014, Toledo et al., 2008, Wong et al., 2019, Lavallière et al., 2012)	**harsh cornering** (Payyanadan et al., 2017, Arumugam and Bhargavi, 2019)	
		left turns (Payyanadan et al., 2017, Farah et al., 2014, Toledo et al., 2008, Wong et al., 2019, Roenker et al., 2003)	
		lane deviation (Donmez et al., 2008, Farah et al., 2014, Toledo et al., 2008, Toledo and Lotan, 2006, Paredes et al., 2018, Van der Heiden et al., 2018, Lavallière et al., 2012)	
		idling (Hickman and Geller, 2003, Levick and Swanson, 2005)	
		distraction (Arumugam and Bhargavi, 2019, Roberts et al., 2012, Paredes et al., 2018)	
		fatigue (Arumugam and Bhargavi, 2019)	
		drowsiness (Arumugam and Bhargavi, 2019)	

Safety Outcomes	Safety Promoting Goals	Performance Objectives	Change Objectives
		focus/concentration (Paredes et al., 2018)	
		stress level (Paredes et al., 2018)	
		inattention (Roenker et al., 2003)	
		blind spot (Lavallière et al., 2012)	

In addition, a brief presentation of the different evaluation perspectives that can be adopted (i.e. outcome evaluation vs process evaluation vs cost-benefit analysis) was made and a summative perspective with particular emphasis on outcome evaluation and process evaluation was presented. The safety outcomes and safety promoting goals were used to inform the Key Performance Indicators needed within the project to assure the technology has a positive effect on each and the KPIs that can be measured, were described. Lastly, based on various projects, initiatives and publications which were found in the literature, focusing on the issue of safety evaluation, corresponding thresholds, ranges and accuracies of metrics were provided. However, it was clearly mentioned that performance indicators are customized on the specific project outcomes and on the specific hypotheses the project would like to verify, so it is somewhat difficult to draw common boundaries or thresholds.

4 Evaluation Methodology

4.1 Methodological design

Below within Figure 11, a conceptual framework in order to develop research questions for the intervention assessment methodology is displayed. At the top of the Figure 11, the different components (i.e. safety outcomes, safety promoting goals, performance objectives and change objectives) together constituting the logic model of change behind the interventions are shown. The three intervention formats all are linked to these outcomes of the *i*-DREAMS model of change (i.e., safety outcomes, safety promoting goals, performance objectives and change objectives). It is important to take into account potential moderators and/or mediators. Moderators affect the relation between two variables, while mediators explain the relation between two variables. Possible variables that could moderate or mediate the impact of the intervention format on the outcomes appearing in the *i*-DREAMS model of change (i.e., safety outcomes, safety promoting goals, performance objectives and change objectives) are technology acceptability, safety culture/climate and participant profile. Technology acceptability can be defined as “the degree to which an individual incorporates the system in his/her driving”. Safety culture/climate can be defined as “an organization’s approach to safety”. This is applicable to professional drivers like truck and bus drivers and train and tram operators. While “safety culture” mostly refers to individual and group values, attitudes, perceptions, competencies regarding safety, “safety climate” is mainly used to describe the expressed ideas, the tools and techniques used in general by the organization in order to confirm its compliance to safety. Participant profile can be defined as “the characteristics of a person”.

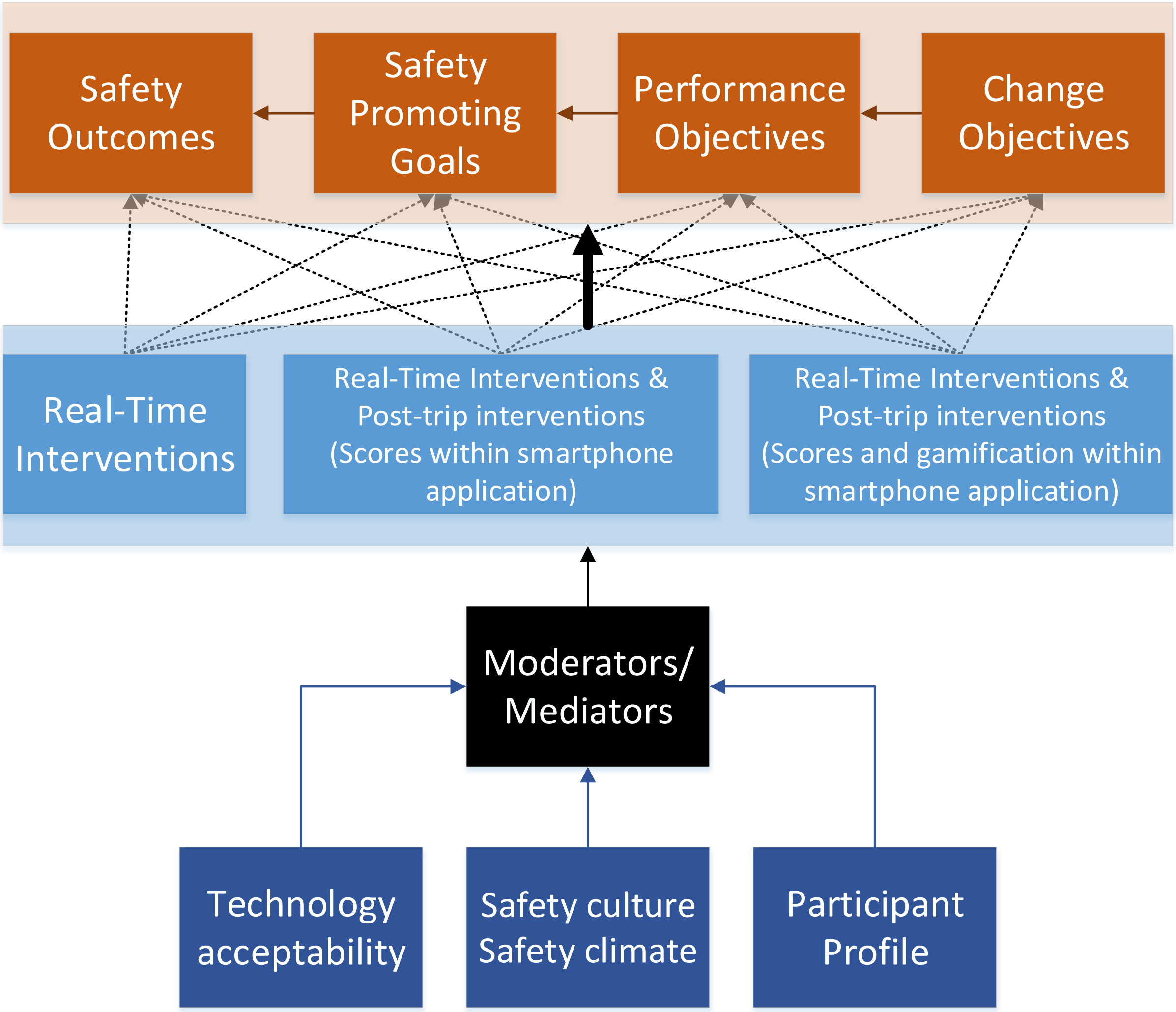


Figure 11: Conceptual framework for research questions

The vehicle operators will receive three different intervention formats:

1. Real-time intervention via an in-vehicle warning system
2. Real-time intervention via an in-vehicle warning system and post-trip intervention via a smartphone app consisting of scores
3. Real-time intervention via an in-vehicle warning system and post-trip intervention via a smartphone app consisting of both scores and gamification elements

4.2 Research questions

Within this section, research questions are proposed for both the outcome and process evaluation among all drivers. After this, the evaluation plan can be developed.

Outcome assessment

There are four main research questions related to the interventions for drivers. Each main research question consists of one or multiple sub-questions. Within research question 1, particular focus is given on 'tailgating' as an illustration.

1. What is the impact of the 3 intervention formats offered to the driver on outcomes appearing in the *i*-DREAMS logic model of change (including driver acceptance)?
   1.1. What is the impact of the 3 intervention formats offered to the driver on safety outcomes? E.g., Does the performance in terms of frontal crashes significantly improve for equipped with and exposed to the *i*-DREAMS interventions?
   1.2. What is the impact of the 3 intervention formats offered to the driver on safety promoting goals? E.g., Does the performance in terms of sharing the road with others significantly improve for equipped with and exposed to the *i*-DREAMS interventions?
   1.3. What is the impact of the 3 intervention formats offered to the driver on performance objectives? E.g., Do drivers reduce risky tailgating events?
   1.4. What is the impact of the 3 intervention formats offered to the driver on change objectives for real-time interventions? E.g., Do drivers recognize the need to adjust headway time in case a risky tailgating event is imminent?
2. Are there variables that moderate/mediate the impact of the 3 intervention formats offered to the driver on outcomes appearing in the *i*-DREAMS logic model of change?
   2.1. Does technology acceptability moderate/mediate the impact of the 3 intervention formats offered to the driver on outcomes appearing in the *i*-DREAMS logic model of change?
   2.2. Does safety climate moderate/mediate the impact of the 3 intervention formats offered to the driver on outcomes appearing in the *i*-DREAMS logic model of change?
   2.3. Does participant profile moderate/mediate the impact of the 3 intervention formats offered to the driver on outcomes appearing in the *i*-DREAMS logic model of change?
3. Is there empirical support for the causal links inside the *i*-DREAMS logic model of change?
   3.1. Are there causal links between the safety promoting goals and the safety outcomes?
   3.2. Are there causal links between the performance objectives and the safety promoting goals?
   3.3. Are there causal links between the change objectives and the performance objectives?
4. How do users evaluate the *i*-DREAMS interventions offered to them in terms of acceptability (with inclusion of the intention to use the interventions)?
   4.1. How do drivers evaluate the 3 intervention formats offered to them in terms of acceptability (with inclusion of the intention to use the interventions)?
   4.2. How do key-stakeholders (i.e., company management (i.e. CEO or fleet safety manager), outdoor service providers, and indoor coaches (i.e. planner or buddy)) evaluate the web-platform offered to them in terms of acceptability (with inclusion of the intention to use the interventions)?

Process evaluation

Based on the criteria (excluding ‘implementation’) proposed by Linnan and Steckler (2000), the following six research questions can be asked related to the process evaluation:

1. What are the aspects of the larger social environment that may affect implementation? (i.e., context)
2. What is the proportion of drivers to whom the intervention is actually delivered? (i.e., reach)
3. What is the amount of intended units of each intervention component that is delivered? (i.e., dose delivered)
4. What is the extent to which drivers engage with the intervention? (i.e., dose received)

5. Was the extent to which the intervention was delivered as intended? (i.e., fidelity)
6. What kind of approach was used in order to attract drivers? (i.e., recruitment)

4.3 Indicators and measures

Within this section, based on the aforementioned research questions, indicators and measures are proposed for both the outcome and process evaluation among all drivers. After this, the evaluation plan can be developed.

Outcome evaluation

With regards to outcome evaluation, some examples of indicators and measures are proposed.

Related to research question 1: "What is the impact of the 3 intervention formats offered to the driver on outcomes appearing in the *i*-DREAMS logic model of change (including driver acceptance)?", some indicators and measures are proposed for the safety outcomes, safety promoting goals, performance objectives and change objectives:

1. Safety outcomes will not only be measured by means of crash occurrence, but by additional surrogate safety measures like Time-To-Collision (TTC) as well, to allow robust enough statistical analyses.
2. Safety promoting goals will be measured by scores provided by the *i*-DREAMS platform. These scores will be based on the detection of events while driving.
3. Performance objectives will be measured by score provided by the *i*-DREAMS platform. These scores will be based on the detection of events while driving.
4. Change objectives will be measured by survey items.

As mentioned in chapter 2, Table 2: Example matrix of change for the real-time interventions for truck drivers and Table 3: Example matrix of change for the post-trip interventions for truck drivers, provide an illustration of survey items used in order to measure the change objectives within the real-time and post-trip interventions for truck drivers. Most survey items are statements accompanied by a 5 point scale in Likert or semantic differential format, for instance ranging from “Never” to “Always”. These items will not be questioned for the real-time interventions, since these items are quite abstract for a participant. Instead, the items of the ‘Technology acceptance questionnaire’ will be used as indicators for the change objectives during real-time interventions. As a result, these items will only be questioned for the post-trip interventions, hence, only during the field trials, and not during the simulator trials. A larger effect is expected on the items related to the post-trip interventions like knowledge compared to the items related to the real-time interventions, since the post-trip interventions are related to the principle of ‘coaching’. These items will be asked both at the start of the field trials and at the end of the field trials. Although the purpose is to ask these items during (de-)installation of the equipment, a selection needs to be made, since there will be a lot of items if every possible change objective is questioned. Moreover, participants, already need to answer a lot of questions, hence, a selection should also be made in order to prevent “respondent fatigue” (i.e., a phenomenon that occurs when respondents become fatigued by answering surveys). Therefore, items will focus on ‘safe driving’ in general. The purpose is to investigate whether an effect on change objectives can be translated in an effect on performance objectives. Minimum 2 items per concept will be questioned, in order to still check the internal consistency.

Related to research question 2: "Are there variables that moderate/mediate the impact of the 3 intervention formats offered to the driver on outcomes appearing in the *i*-DREAMS logic model of change?", the same indicators and measures will be used in combination with some additional ones. For example, safety culture/climate will be investigated with a short survey. One well-known survey to capture the level of variety in this regard, is the so-called Safety

Culture Ladder (see Taylor, 2010), where more information can be found concerning this survey. Specifically, it should be mentioned that The Safety Culture Ladder is an assessment method for measuring safety awareness and conscious safe acting (culture & behavior). Particular focus is given on the safety culture. The higher the safety awareness, the higher the assigned ladder step.

Related to research question 3: "Is there empirical support for the causal links inside the *i*-DREAMS logic model of change?", the same indicators and measures as mentioned above will be used.

Related to research question 4: "How do users evaluate the *i*-DREAMS interventions offered to them in terms of acceptability (with inclusion of the intention to use the interventions)?", Annex 1 for an overview of indicators and measures is available.

Process evaluation

With regards to process evaluation, some examples of indicators and measures are proposed.

Related to research question 1: An example of an indicator and measure for '**context'** related to professional drivers is the safety culture/climate of the organization, in a sense that it might moderate/mediate the effect of the *i*-DREAMS interventions on the targeted outcomes (i.e., safety outcomes, safety promoting goals, performance objectives, change objectives).

Related to research question 2: An example of an indicator and measure for '**reach'** is the dropout rate at the end of the intervention, preferably, in combination with the reasons to drop-out, which could be inventoried during the field trials.

Related to research question 3: An example of an indicator and measure for '**dose delivered**' is the number of warnings and goals that a driver has received during the period where participants were exposed to the real-time intervention and the post-trip interventions.

Related to research question 4: An example of an indicator and measure for '**dose received**' is the number of times participants appropriately reacted to warnings triggered by the *i*-DREAMS in-vehicle warning system; or the number of tips that were consulted by the driver in case of the post-trip interventions.

Related to research question 5: Technical failures or system deficiencies that possibly might occur during the field trials can be inventoried, and considered as an indicator for '**fidelity**' in a sense that they undermine the implementation of the *i*-DREAMS real-time and post-trip interventions as originally planned.

Related to research question 6: An example of an indicator and measure for '**recruitment**' could be the extent to which the originally foreseen objectives in terms of sample size and composition have been realized (or not).

4.4 Criteria

The evaluation as well as the adoption of safety interventions can only be successful if the technology is effective in reducing the target risk and when it is also used efficiently by the driver. If the driver does not accept the feedback technology, misuse or disuse of the interventions is evident (Parasuraman and Riley, 1997). The safety-related measures and criteria appropriate to the methodology for the evaluation of interventions within the *i*-DREAMS are separated per two categories; these which are related to the user and the others which are related to safety.

In order to make the evaluations reach their full potential, their quality should be as high as possible. Three quality requirements are important in this respect: user acceptance, user acceptability, reliability/validity (Van Berkel et al, 2014). It should be noted that user acceptability is related to the actual use of the system, so the behavior of the driver will be investigated when receiving signals of the system during driving. In addition, since user acceptance is related to the intention to use a system, it is based on individual attitudes, expectations and experience, obtained during actual use, as well as their subjective evaluation of expected benefits. Lastly, to work on reliability, a specific model, called as model answer, can be designed, which allows to assess as accurately and objectively as possible. Specifically, a model answer indicates which elements should be given particular focus on the assessment processing. When there are several evaluators for the same exam an appropriate model is highly recommended: this creates a consensus on the criteria that must be used to assess and makes sure that everything is evaluated from the same point of view.

Taking into account the aforementioned three quality important requirements, user based indicators, such as user acceptance, user acceptability and reliability are going to be analyzed in detail in the sections 4.4 and 4.5.

User based indicators:

- **User acceptance and user acceptability**

  Acceptance can be defined as the degree to which an individual incorporates the system in their driving, or in case of acceptability, if the system is not available, intends to use it (Adell, 2010). Hence, acceptance and acceptability do not only relate to the degree of actual usage, but also relates to the intended use (e.g. in a purchase decision). In other words, user acceptance and acceptability refer to the degree of approval by the users as well as the change observed in driver performance. In addition, the acceptance of real-time and post-trip interventions is based on individual attitudes, expectations and experience, obtained during actual use, as well as their subjective evaluation of expected benefits (Schade and Baum, 2007).

- **Trust**

  It should be noted that the evaluation of the interventions by the user could be very different before and after use of the system. With regards to trust, a distinction should be made between initial trust and dynamic trust. For instance, initial trust refers to the evaluation by the driver on how the system would help the driver to reach goals in a situation characterized by uncertainty and vulnerability, whereas dynamic trust refers to the same evaluation after having the opportunity to experience or use the system.

- **Perceived Usefulness**

  Perceived usefulness refers to the degree to which a person believes that using a particular system would enhance his or her performance, in this case, how safely he or she operates a vehicle. Qualitative feedback on the users' perception of usability of the platform, this includes interface designs, interactions, fitting and maintenance.

- **Satisfaction**

  Satisfaction refers to the appraisal of the intervention's process and outcome attributes. It is worth mentioning that subjective assessment of drivers will be valuable additional information to keep improving the system. The main characteristics that are essential for the success of an intervention tool are its performance along with driver's satisfaction (Yardley et al., 2015). The more these criteria are fulfilled, the better the effect on safety is. This was derived from the fact that if an objectively effective intervention is not easily useable or accepted by one driver, its effect would not be appreciated or demonstrated. It should be noted that perceived usefulness relates to aspects such as the perceived (in-)effectiveness of the system. However, a high perceived usefulness does not necessarily imply a high satisfaction of the system: if the system didn't work well (e.g. it was confusing or irritating), the driver would try to ignore it. As a result, finding a balance between maximizing effectiveness and driver satisfaction at high levels, during and after the trip, is beneficial for operators as well as the whole traffic ecosystem.

- **Reliability/Validity**

  Both reliability and validity of the different interventions consist a major concern for all drivers. The reliability/validity assessment will help to inform on the extent to which the technology was perceived to be useful or not and provide detailed feedback from users which the project can use to build upon and explain findings.

- **Effectiveness**

  For an intervention to be deemed effective, it must be shown to achieve the desired outcomes in the target groups. Additionally, the target groups must be considered sufficiently representative to allow for the outcomes to be considered replicable in larger target populations. It is also important to ensure that the appropriate indicators have been used to study the effects to ensure that these indicators are relevant to the target population in terms of their well-being.

- **Motivation**

  Motivation is related to a person's willingness to increase their capability or opportunity to perform, adopt or change a certain behavior and improve their current driving style (or not). For instance, motivation-oriented variables are beliefs, attitudes, norms, or self-efficacy. The level of motivation/impetus to use the platform- linked to behavioral intention (level of intention to use the platform) which can be collected prior to testing for comparison. In the case of attitude, the thought process behind motivation, is mainly focused on outcome expectancies (i.e. beliefs about what will be the consequences of performing a certain behavior), and their affective evaluation (i.e. whether one appraises the expected consequences as positive or negative).

- **Obtrusiveness**

  The potential problem with obtrusive assessment of feedback is that it may be reactive, i.e. affect drivers' performance. Reactivity refers to the influence that the assessment procedure exerts on the user's driving reactions.

- **Knowledge**

  More specific knowledge, attitudes and beliefs of the driver with respect to interventions constitute another useful aspect. In particular, if the driver does not know about the benefits and limitations of the feedback system, this could lead to a wrong evaluation of the system by the user.

- **Social influence**

  Social influence can also play an important role in the evaluation of a feedback technology. Social influence refers to the degree to which the driver thought that other important people believe they should use the new system. It also refers to those interpersonal processes that can cause individual drivers to change their thoughts, feelings, or behaviors about a specific intervention strategy. If other important people or relatives perceive the system to be important, then the driver would be more inclined to believe in using the system. This drive actually includes all social elements that stimulate people, going from mentorship, acceptance, social responses, and companionship to envy and competition as well. Behind all these drives, is the basic idea to naturally feel attracted by and want to draw closer to people, places, events or behaviors which can be related to.

Safety goals:

- **Safety**

  Safety indicators show the impact of the intervention formats on the outcomes appearing in the *i*-DREAMS model of change, moderators/mediators, and causal links. Information about health consequences (in the case of *i*-DREAMS, health relates to road safety), have been selected as the techniques for implementation of natural consequences as a change method. Comparable to the technique 'self-monitoring of outcomes of behavior', information about health (i.e. safety) consequences is a technique meant to influence the cognitive component of attitudes, but different from self-monitoring of outcome(s) of behavior, information about health consequences is specifically focused on the safety-related impact (e.g., crash likelihood, or crash severity) of particular behaviors (e.g. speeding, harsh acceleration, harsh decelerations, illegal overtaking). Safety outcomes will not only be measured by means of crash occurrence, but by additional surrogate safety measures like Time-To-Collision (TTC) etc.

- **Technological efficiency**

  It is also important to ensure that the intervention is useful, efficient and suited to the local context and requirements. These external criteria include training-related considerations, cost-effectiveness and the potential offered by the intervention to meet local needs. Implementation is also a key factor when assessing the usefulness and suitability of an intervention

- **Cost-benefit**

  Cost-benefit has been described as determinant in the formation of the driver's attitude with respect to an intervention system. It is evident that when the cost-benefit ratio is considered weak, the user would not be willing to purchase the system.

- **Ease of use**

  Ease of use is the degree to which a person believes that using a particular system would be free of effort. It relates to aspects such as how pleasant the system is to use or to the level of effort needed by the driver to use the system.

- **Companies' safety climate**

  For the assessment of interventions taking place in a professional work setting, companies' safety climate must be taken into account, as this can be expected to be a crucial environmental factor influencing intervention effectiveness.

4.5 KPIs and Surrogate Safety

As crashes could be triggered by multiple factors, Key Performance Indicators (KPIs) should take into account **not only qualitative but also quantitative indicators.** KPIs can be determined in order to compare the efficiency of the interventions with considerations on the implementation with on-board devices to be used to recognize episodes of specific driving behavior in real-time and post-trip. Qualitative measures may also be used to answer the research questions related to user acceptance, acceptability and reliability. Based on the methodology of the outcome evaluation for the interventions, the performance objectives that appeared to have the greatest effect on the assessment of interventions are presented below. A distinction is made between performance and physiological indicators. In addition, change objectives that are going to be assessed within the *i*-DREAMS platform are also mentioned. It should be noted that the available KPIs, which are going to be evaluated, can be delivered as rate, absolute values, numerical scores, absolute number of warnings or a binary variable. Key

Performance Indicators that can be measured in *i*-DREAMS platform, based on the findings of Table 1 in section 2.2, are presented below:

1. Performance objectives

Performance indicators (frequency, rates)

- speeding
- harsh acceleration
- harsh braking
- harsh cornering
- lateral and longitudinal movement
- lane deviation
- left turns
- blind spot
- Time-To-Collision

Physiological indicators (numerical scores, rates)

- fatigue
- distraction
- drowsiness
- inattention
- sleepiness
- emotions (i.e. stress)

2. Change objectives (scores)

- Capability
- Motivation
- Behavior Change

It is worth mentioning that the numerical scores, found in change objectives, as well as the rates, numerical scores and frequency of performance objectives, will have a direct impact on the frequency, rates, and numerical scores of safety promoting goals, and therefore safety outcomes (i.e the probability of crash risk as well as the frequency of conflicts) will be influenced in a great extent.

With regards to quantitative variables, these measures are especially used to answer the research questions which are related to the impact of the intervention formats on the outcomes appearing in the *i*-DREAMS model of change, moderators/mediators, and causal links. For example, tailgating behavior of vehicle operators can be measured by parameters recorded by Mobileye (e.g. number of headway monitor warnings). Within the evaluation conducted in terms of the outcomes proposed in the logic model of change, it was revealed that safety outcomes and safety promoting goals had a strong impact on the interventions evaluation. However, little evidence on safety outcomes information was identified in the current literature. The quantitative variables are summarized below:

3. Safety outcomes (frequency, probability)

- crash risk (i.e. collision with lead vehicle, collision with oncoming traffic)
- conflicts

4. Safety promoting goals (frequency, rates, scores)

- driver fitness
- vehicle control
- speed management
- sharing the road with others

4.6 User acceptance and user acceptability

As discussed within section 3 of this deliverable, there will be a focus on **"user acceptance"** and "**user acceptability**" within the outcome evaluation. The success of the *i*-DREAMS technology depends on whether drivers find the technology beneficial for their driving and safety. If drivers do not accept the interventions, the technology will not increase the safety of drivers.

User acceptance

The change (or absence of change) in driver behavior in response to the interventions will be an indication of acceptance. As a result, **observational techniques** will be used.

By observing the behavior of a driver, conclusions about acceptance can be derived, e.g. if a driver presses or does not press the brake when receiving a warning about braking, or if the brake response time when receiving a warning is too large.

User acceptability

It is important to gather information on how the drivers feel about the *i*-DREAMS technology. Hence, the subjective assessment of drivers will be valuable additional information to keep improving the system. As a result, **survey techniques** will be used. Several studies propose standardized survey scales to measure aspects of acceptability.

The items in Annex 1 are suggested to evaluate the *i*-DREAMS participants' acceptability of the technology. The items were adapted from Osswald et al. (2012) and Ghazizadeh et al. (2012) with the aim to better account for the *i*-DREAMS context. Since not all of the items are applicable for the real-time and the post-trip intervention, a respective indication is provided. The surveys can be applied at the end of each trial, or additionally in the first half of each trial, to trace how acceptability value change over time and with longer term use of the *i*-DREAMS technologies.

The items within the survey in Annex 1 have a five point Likert scale ranging from "Strongly Disagree" to "Strongly Agree". There is a focus on eleven constructs: "Performance expectancy", "Ease of use / effort expectancy", "Attitude towards using technology", "Social influence", "Facilitating conditions", "Self-efficacy", "Anxiety", "Perceived safety", "Perceived Usefulness", "Trust", and "Behavioral Intention to Use". Some items are only applicable to the real-time interventions (seventeen items), while other items are only applicable to the post-trip interventions (eleven items) and still other items are applicable to both the real-time interventions and the post-trip interventions (seventeen items). These items will be questioned both at the end of the simulator trials, as at the end of the field trials. For the field trials, all 45 items will be questioned. If possible, during the de-installation of the equipment, since participants then need to wait. For the simulator trials, a selection of items will be made. The selection will be made, due to 2 main reasons: 1) there is only limited time available per participant to conduct the simulator study (i.e., approximately 1.5h), hence, priority should be given to the most important items; 2) in order to prevent "respondent fatigue" (i.e., a phenomenon that occurs when respondents become fatigued by answering surveys), since participants already invested approximately 1.5h in the study. A selection will be made, based on the most interesting items for the simulator trials. Minimum 2 items per concept will be questioned, in order to still check the internal consistency. Hence, still minimum 22 items will be questioned (instead of 34 items).

4.7 Reliability

A search of the literature revealed little in the way of detailed reliability testing techniques for technology other than very comprehensive reliability audits. Such audits are used in safety critical industries like the aerospace and nuclear sectors, the process of these audits would be far too detailed for *i*-DREAMS to replicate as they use a highly complex systems perspective approach and are a whole discipline in themselves. However, it should be noted that end of the scale product development audits give managers a tool for tracing how well their concept products are being developed. In that case, the reliability assessments recommended are too simplistic for *i*-DREAMS needs. For example, the guide created by Crucible Design (2014) consisting of a single question on reliability with a 4 point scale rating from 'unreliable- regularly fails to work correctly' to 'A work horse- 100% reliable' can be taken into consideration. Similarly simplistic ratings of reliability have been used in academic literature such as by Wiegmann et al. (2001) who measured perceived reliability of a diagnostic aid by administering a post-experimental questionnaire rating the reliability using a scale that ranged from 0% (completely unreliable) to 100% (completely reliable).

Upon further reflection, reliability in its most basic form i.e. how many times did the technology objectively cease to work or encounter problems is not necessarily what is of most value to assess in *i*-DREAMS. Instead a reliability assessment looking into whether the technology served its purpose, added value and allowed the user to depend on it in all situations will be more useful to gather and is not covered in any other of the assessments detailed in this deliverable. Looking at reliability in this way relates to the well documented and validated Technology Acceptance Model, Davis et al. (1989), specifically the reliability assessment will be used to cover the top box in Figure 12 'Perceived Usefulness'. The above section on usability covers the 'Perceived Ease of Use' part of the model but still leaves the issue of whether the technology was deemed useful enough to try in the first place and then consistently use throughout the study, as shown in the attitudes, intentions and actual use parts of the model. The reliability assessment will help to inform on the extent to which the technology was perceived to be useful or not and provide detailed feedback from users which the project can use to build upon and explain findings.

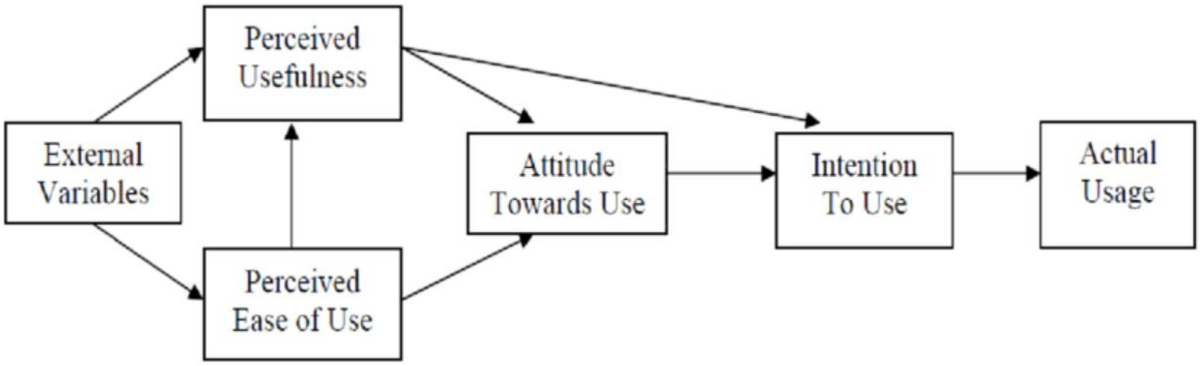


Figure 12: Technology Acceptance Model (Davis et al., 1989)

This insight is important as without such information users' choice to engage with the technology fully, partially or switch it off entirely cannot be explained or explored. This evaluation of reliability could also be considered to cross into validity and trust. Reliable is defined by the Cambridge Dictionary as "Someone or something that is reliable **can be trusted or believed** because he, she, or it **works or behaves well in the way you expect**." Similarly, the Cambridge Dictionary defines trust as: "to believe that someone is good and honest and will not harm you, or that **something is safe and reliable.**" This shows how trust, reliability and usability are all inherently inter-linked with each other.

As an evaluation involving trust and perceived usefulness of the system makes the evaluation more subjective than a simple objective count of how many times components failed, it is important to understand how the interaction between user and technology may influence their perception of the technologies' reliability. This can be affected by many elements such as the expectations they bring to the technology, previous technology use, mental models of the technology, potential risks to new technology (limiting their willingness to trust it and therefore try it in the first place). Due to his highly complicated interplay between the user and the technology and the many elements that can affect users' perceptions of reliability and trust that they put in the technology, some models around user interaction and trust first need to be understood.

Stanton and Marsden (1996) in early research looking into automation and drivers' interaction with vehicle systems concluded that there are many interrelated and complex correlation among variables, as shown in Figure 13.

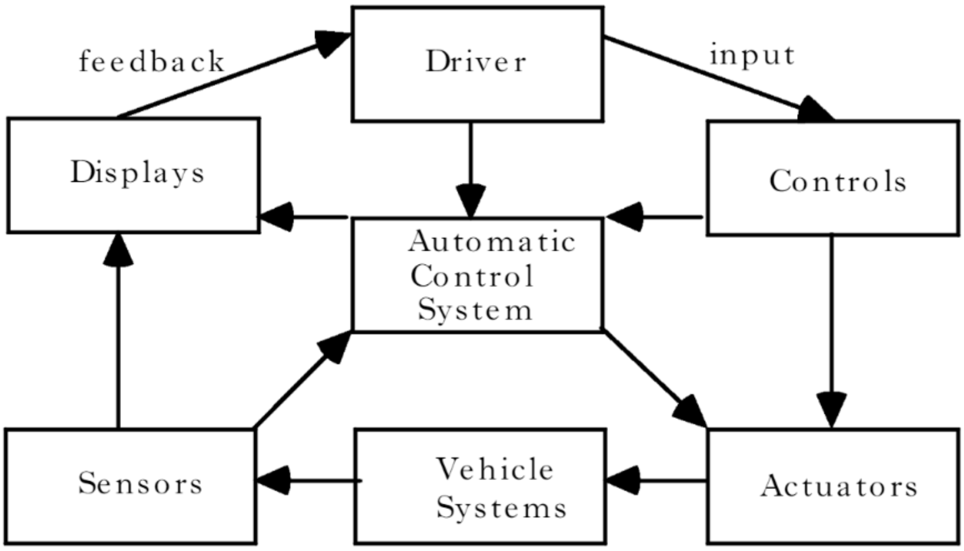


Figure 13: Information flow between driver, automation and sub-systems from Stanton and Marsden (1996)

Figure 13 shows how the amount of feedback desired by the driver is inherently related to the trust they have in the system. This model is based on automation but it stands to reason that a very similar interplay and set of vehicles will occur with the current in-vehicle technologies and those used in the *i*-DREAMS technology suite with the driver giving input into controls and sensors then feeding back to the driver through displays of various types and the amount of feedback the user desires will be affected by their trust in the system. This interplay of psychological factors is shown in Figure 14.

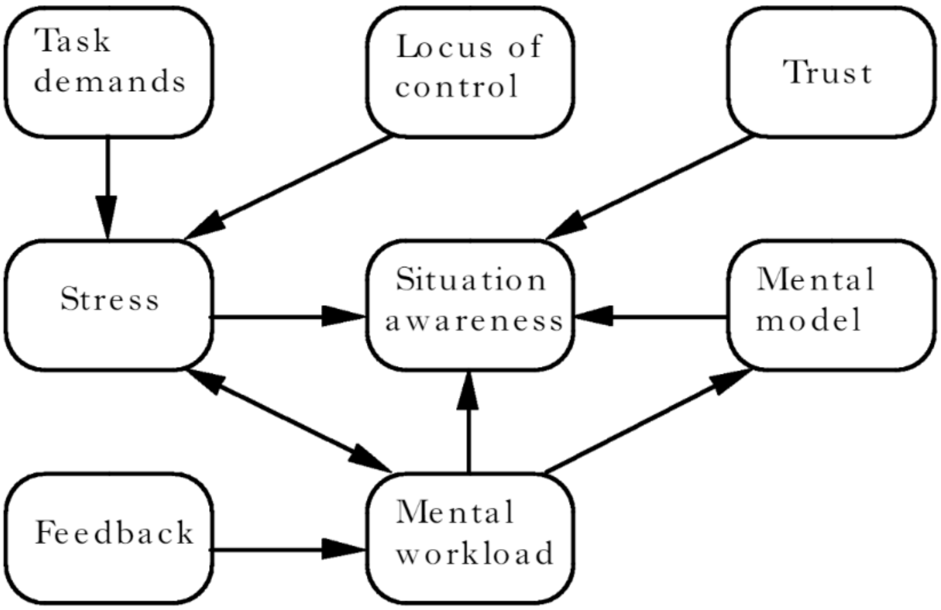


Figure 14: Hypothesised relationship between psychological factors from Stanton and Marsden (1996)

In Figure 14 Stanton and Marsden (1996) map out a hypothesised interplay of psychological factors when using systems in vehicles. Again, this was based on vehicle automation, but automated systems have the same goals as *i*-DREAMS technology suite of reducing workload and enhancing the driver's situational awareness. It is clear to see in the model where trust comes into this, directly affecting situational awareness (SA) and also, how feedback from the system affects mental workload which in turn affects SA. This relationship is intuitive to understand as if the system is perceived as giving insufficient feedback, such as making a noise but not being clear what the noise represents, then the driver will have to seek out what the meaning of the auditory alarm is, thus increasing workload, taking the drivers mind and eyes off the road and thus, reducing situational awareness. Similarly, too many warnings will lead the driver to be distracted by the system, increasing workload and reducing SA.

It could be argued that trust and feedback could also be directly linked in a system which is not aiming for full automation. It is feasible to imagine that too much or too little feedback will lead to a loss of trust in the system, leading to it be turned off or ignored if it is giving too many warnings and greatly reducing the impact it can have on driver safety. For this reason, it is very important to have some way to collect information on, and perhaps even measure, trust in the *i*-DREAMS systems which extends beyond the usability aspects. In this way, it is essential to ascertain if the system behaved in a way that was useful to the driver, giving feedback that they expected and that they desired at the correct time with consistency. Lastly, it can be identified whether the system was providing too little or too much information and how the design could be amended to work around any issues encountered. This all relates to reliability and validity, ensuring that is clear whether users experienced the system as being consistent and measuring and giving feedback on what they expected in the way they expected.

In their book on designing for situational awareness, Endsley and Jones (2011) noted the relationship between SA and reliability when systems, like those in *i*-DREAMS, are designed to give alarms, saying "*A significant issue affecting their interpretation of the alarm is its reliability. High false alarm rates, leading to cry wolf syndrome, lead operators to have a low confidence in the alarm*," page 149. They further note that "*The problem of false alarms is a difficult one for system designers. The degree to which a system produces false alarms must be weighed against the likelihood that it will have missed alarms*," page 150. They also establish just how accurate alarms may need to be for users to interpret the system as giving reliable alarms, "*One source showed that reliability needs to be above 95% for systems to be considered useful, although identifying a precise number for acceptability appears to be elusive,*" page 151. To get perfect reliability judgements is not just a case of ensuring the algorithms behind the technology is perfect, as unfortunately the circumstances that the use of a system in the real world will impose upon the system is unlikely to be completely controlled and predictable and therefore, very hard to design for. Endsley and Jones note this saying, "*The condition underlying false alarms is often not the functioning of the algorithms themselves, but the conditions and the factors that the alarm system cannot detect or interpret.* The fact that such electronics and computerised alarm signals are limited in their awareness of the situation (low system SA) leads to an <u>experienced false alarm rate</u> that is often much higher than that expected by the designers. In terms of the effect on human responsiveness to alarms, it is this <u>experienced false alarm rate that matters</u>" page 151-152.

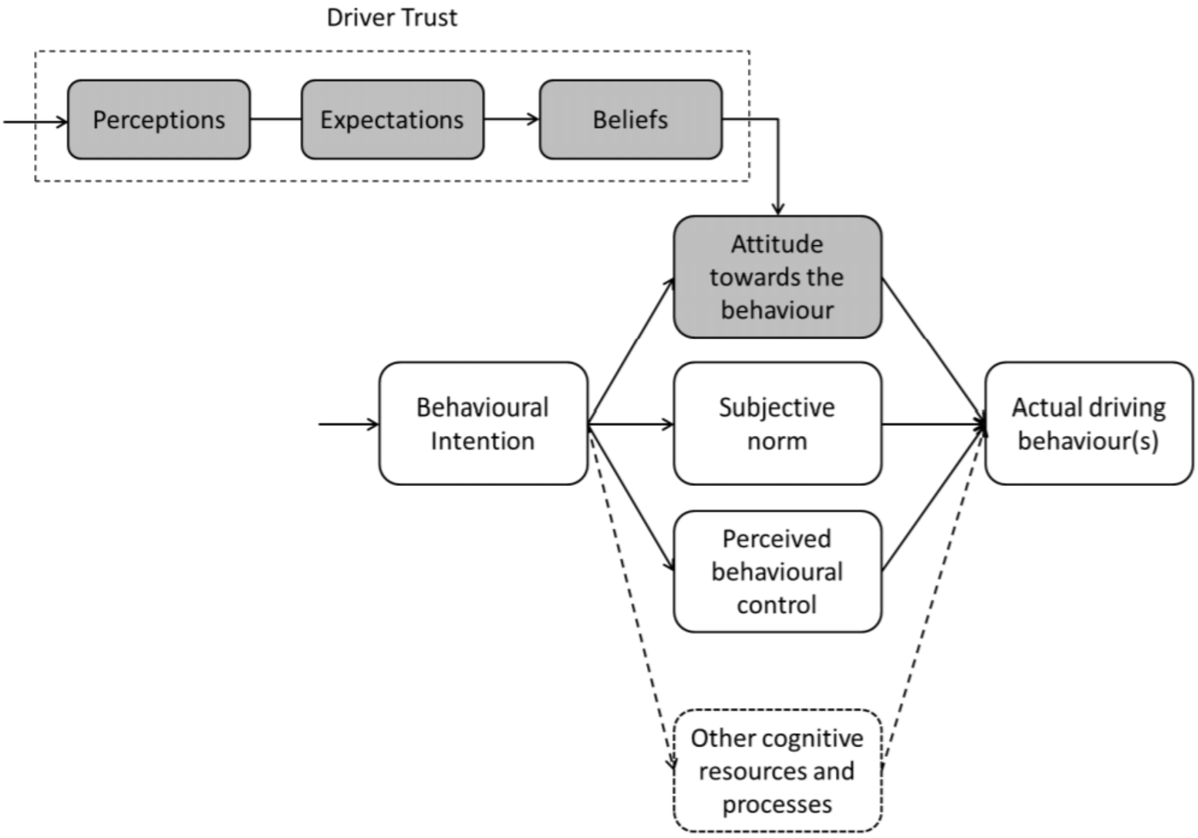


Figure 15: How driver trust influences behavior, from Walker et al., 2016

Walker et al. (2016) pose that the Theory of Planned Behavior (TPB; Ajzen 1991- Figure 15) could help explain why trust is such a vital element when looking at why driver does or does not interact with a system both immediately and in the long term. Figure 15 shows the elements that go into trust and how perceptions, expectations and beliefs can in turn explain intentions around technology engagement. This shows the importance of collecting not just the objective reliability of a system, i.e. how many times it had a known fault, but the users' perception of its reliability and the extent to which it met their needs and expectations, as this is what will ultimately affect their intentions around system usage. Walker et al. (2016) break down trust based on the findings of Rempel et al. (1985) finding that three main measurable components make it up, namely: predictability, dependability and faith. Predictability is important as it looks at the way the system performs and can be hard to refine as some elements of predictability will be brought to the system from the driver's previous experience and inbuilt assumptions and mental models, which can be hard to predict and may vary from person to person. This aspect can also be context sensitive. For example, in an environment where the user has experience of a system which failed a lot and a new system fails less, then, even though the new system is not perfect, this mixture of previous experience and context may lead to overall acceptance and satisfaction with a system that is inherently flawed.

Dependability is what will affect the users overall view of the system, humans are not perfectly rational and often base their judgments of reliability or dependability on the most visible and memorable interactions. Therefore, users may lose trust in a largely well-designed system because one part of it, especially if it is very visible, such as too many alarms going off, especially if they seem to be for no reason (false positives). Even if the rest of the system works perfectly, a loss of trust in one element could lead to entirely failure of the system as a whole.

Faith is the third part of the model, user can develop faith in systems when, over time, they have seen that it is predictable and reliable and then start to monitor the system's behavior less and put faith in the fact that it will do what they need it to do when they need it to do it. Faith is different from predictability and dependability in the future orientation of its scope. Walker, et al. (2016) note that some drivers will have faith in a system from the start while others will be far less trusting, sometimes to the point where they refuse to even use it in the first place so they are not able to see its predictability and dependability and allow these to influence their system use. It is also important to note that there is a relationship between trust and confidence; if a driver feels they can perform the task better than the technology then they will be unlikely to use it in the first place. Overcoming this and demonstrating its superiority in a supportive manner can be difficult when drivers are known to often be over competent in their own abilities.

Based on the above information it is not surprising that measuring trust in a system is inherently difficult, taking into account different individual, context sensitive and illogical aspects, as well as drivers' beliefs, intentions and actions around system. However, there have been a few proposed ways of attempting to collect such information.

4.7.1 Measuring reliability/ trust

As it has been established, reliability of a system is a lot more than just measuring the number of times a system has gone wrong objectively or even subjectively, with simple rating scales. The way the user interacts with a system and indeed if they do in the first place and continue to do will be affected by how reliable the system is perceived to be, which, in turn, will be influenced by how much they trust it. Walker et al. (2016) give a thorough review of the possible measurement method sub-categories, applicable ones will be briefly examined and then discussed with regards to the *i*-DREAMS system context and the final proposed methodology for use in the project will then be proposed.

Primary Task Measures observe the predictability of the system through seeing how the user interacts with the system and if it matches the way it was designed to be used for. For *i*-DREAMS this focus would be less on observing the way the user interface is used for each task and more whether, after a long period of familiarisation and use in daily life, participants are using all the features which the systems provide. For example, are they using the lane keeping assist function, the pedestrian detection function, are they still having the wearable every journey, etc. If it is determined that they have not stopped using the suite, then it could be examined whether they are using it to the full extent of its capabilities. For example, with the volume on as opposed to muted, are they still setting new targets on the gamified interface, etc.

Primary Task Measures could be measured in a number of ways, firstly observation, there are no internal facing cameras in the project technology suite, so an observer would have to sit on board for a number of journeys and take note of what is used and what not, and how (volume on, etc.). This has validity issues as the participants will be aware that they are being monitored so may be more likely to change their behavior, in order to perform in a smoother and quite manner. It may be possible to look at the data on the gateway and see what has been enabled and disabled, but this would require a great deal of analysis and would be unlikely to give a full picture such as adaptions made to using the system, for example covering the system if it is annoying. Therefore, it is likely that the best way is to self-report at multiple points in the project or at the end only, which asks about the frequency of use of each individual part of the system (wearable, interface, gamified web application etc.) as well as individual functions such as lane keeping assist, pedestrian detection etc. There should be a way to report any adaptions made (muting or covering the system for example) and the reasons why, to allow rationale behind decisions and important system improvement knowledge to be gained. Self-report would have the drawback that cannot be ascertained if it represents their true use of the system. Nevertheless, if a pre-designated time, which leads to greater inconvenience for the project and participants, is taken into consideration, then it can be concluded that the self-report questionnaire is the optimal method.

Subjective scales can be used to gather more than just frequency of use etc. but also provide more detailed breakdown of information on trust. There are ten sub-components of trust, such as the validated scale by Muir and Moray (1996) which measures: competence, predictability, dependability, responsibility, responsibility over time, faith, accuracy, trust in display, overall degree of trust, and confidence in own ratings. This has also been used in vehicle technology domain before, e.g. by Stanton and Young (2005). The scale measures trust through a series of questions with a rating scale anchored from 'not at all' to extremely high'. The questions that were written based on rating trust in a pump, but can be easily adapted, are:

1) Competence (i.e. to what extent does the pump perform its function properly?) [A further verbal clarification was given: 'To what extent does it produce the requested flow rates?']

2) Predictability (i.e. to what extent can the pump's behavior be predicted from moment to moment?)

3) Dependability (i.e. to what extent can you count on the pump to do its job?)

4) Responsibility (i.e. to what extent does the pump perform the task that it was designed to do in the system?) [A further verbal clarification was given: 'To what extent does it maintain system volume?]

5) Reliability over time (i.e. to what extent does the pump respond similarly to similar circumstances at different points in time?)

6) Your degree of faith that the pump will be able to cope with other system states in the future

7) Your degree of trust in the pump to respond accurately

8) Your degree of trust in the pump's display

9) Your overall degree of trust in the pump

These may need to be asked for each component of the technology, providing more feedback than the quantity of usage self-report questionnaires alone.

Similar to the subjective scales a semi-structured interview may be used instead of, or as well as, the above methodologies to gather in-depth data of whether systems were used, to what extent, what adaptions were made on the part of the participant or to the system directly and what led to a feeling of trust or distrust in the system. These could draw upon many of the models detailed already in order to ensure that they address the elements known to influence intentions to the *i*-DREAMS technology.

The *i*-DREAMS reliability/ trust methodology includes:

- All participants will be asked to complete a self-report questionnaire at the end of the study rating how frequently they used each component and the extent to which they think they used the component to its full capacity.
- All participants will be asked to complete a self-report questionnaire adapted from the questions in Muir and Moray (1996) about their trust in each component of the system.
- For both questionnaires there will be blank boxes below the questions to provide insights behind their answers.
- Each partner will conduct in-depth interviews with at least 5% of their on-road trial participants with questions around perceived usefulness of the technology, their trust in each component and function and the extent to which it met their expectations. These

will help to expand on the results of the self-report and trust questionnaires and add insights into the reasons behind the perceived reliability/ usefulness of the *i*-DREAMS technology suite. Further incentivisation (e.g. a small value voucher) may be needed to incentivise participation in these interviews over and above the on-road trial participation.

4.8 Methods

In order to analyze intervention processes, two methodological approaches have widely been used: before-after analysis and questionnaires. All the aforementioned methods are established tools, but their distinct epistemological properties enable them to illuminate different aspects of interventions.

4.8.1 Before-after analysis

With regards to the methods that are going to be used for the evaluation of interventions, before-after analysis is proposed. In particular, “before” refers to a measurement being made before an intervention is introduced to a group and “after” refers to a measurement being made after its introduction. Equivalent terms for “before” and “after” are “pre” and “post”. It should be noted that the before-after design offers better evidence about intervention effectiveness than the other non-experimental designs. The before-after analysis is most useful in demonstrating the immediate impacts of short-term programs. However, it was revealed that it is less useful for evaluating longer term interventions. This is because over the course of a longer period of time, more circumstances can arise that may obscure the effects of an intervention. These circumstances are collectively called threats to internal validity.

Before-after analysis can be used for **both quantitative** (i.e. safety outcomes and safety promoting goals) and observed **qualitative** indicators (i.e. performance objectives, change objectives). For instance, repeated measures analyses of variance (ANOVA) will be conducted in order to compare pre-test data with post-test data. Specifically, safety outcomes can be measured by means of crash occurrence, conflicts as well as by additional surrogate safety variables, like Time-To-Collision (TTC). Safety promoting goals as well as performance objectives will be based on the detection of events while driving. Lastly, change objectives (i.e. attention, understanding, emotion, punishment sensitivity and environmental context and resources) will be measured with a survey, and a comparison will be made before and after receiving warnings.

4.8.2 Questionnaires

Lastly, a key indicator of qualitative measurement of questionnaires (i.e. performance objectives, and change objectives), is that researchers can gain valuable information about key issues from a large proportion of drivers, using few but reliable resources. If intervention outcomes are measured using pre- and post-intervention questionnaires, one should not overlook the practicality of also measuring process using questionnaire items. Compared to conducting lengthy interviews, it is convenient for respondents to also answer a number of process questions that measure key constructs known to be relevant for implementation and that can be linked to quantitative outcome evaluation of interventions (Murta et al., 2007; Semmer, 2011; Nielsen and Abildgaard, 2013).

Qualitative indicators such as change objectives (i.e. capability, motivation, behavior change, understanding, emotion, punishment sensitivity and environmental context and resources) as well as performance objectives (i.e. speeding, harsh acceleration, harsh braking, distraction, fatigue, inattention etc.) will be measured by survey items.

Apart from before-after analyses and questionnaires, case-control designs, where cases are represented by drivers who operate with intervention assistance, and controls are drivers who operate without interventions can be utilized to assess intervention efficiency.

4.9 Summary

Within Chapter 4, a conceptual framework was presented. To begin with, research questions, indicators and measures were proposed for both the outcome and process evaluation among all drivers. Three different intervention formats were highlighted: real-time intervention via an in-vehicle warning system, real-time intervention via an in-vehicle warning system and post-trip intervention via a smartphone app consisting of scores as well as real-time intervention via an in-vehicle warning system and post-trip intervention via a smartphone app consisting of both scores and gamification elements.

It is worth mentioning that the evaluation of safety interventions will be based on specific criteria (i.e. user acceptance and user acceptability, trust, satisfaction, reliability, validity, effectiveness, motivation, usefulness, obtrusiveness, knowledge, social influence, safety, technological efficiency, cost-benefit, ease of use and companies' safety climate. Acceptance-related aspects (i.e. user acceptance, user acceptability), as well as technical reliability were explained in detail. Furthermore, Key Performance Indicators were taken into account both qualitatively and quantitatively.

For the intervention evaluation processing, three different methods were proposed: before-after analysis and questionnaires. Furthermore, the RE-AIM framework can be used for process evaluation. After applying the different scoring techniques on a specific transportation mode use case, a summative scoring on the performance of an intervention can be derived.

Figure 16 illustrates the overall processing and methodology for the evaluation of interventions.

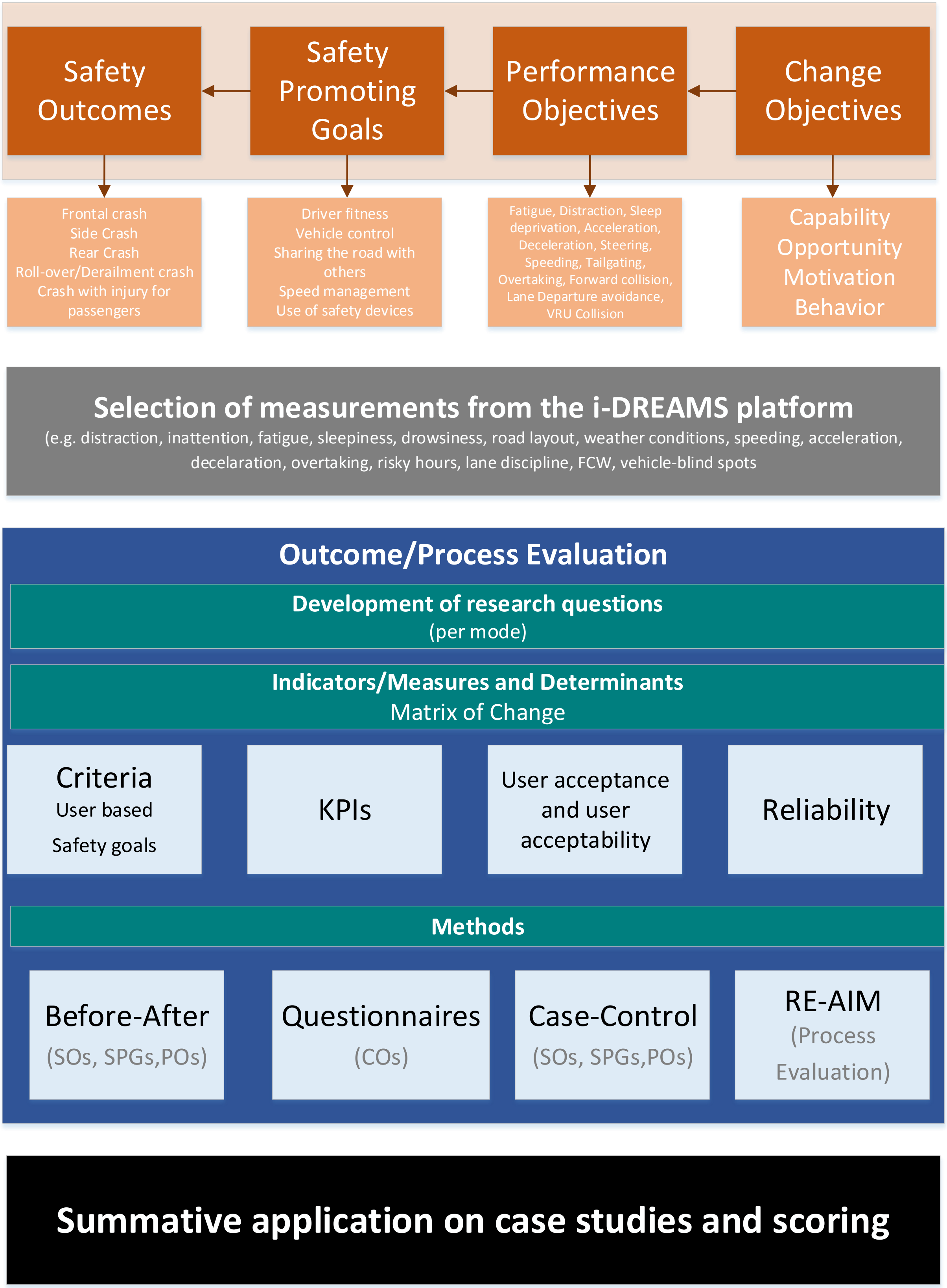


Figure 16: The overall methodology for the evaluation of interventions

5 Conclusions and next steps

This deliverable aimed at providing the methodology for the evaluation of safety interventions within i-DREAMS. In order for the methodology to be designed, the specifics of the i-DREAMS interventions were overviewed and past experience on similar projects was exploited in order to derive a list of methods, indicators and evaluation criteria mostly suitable for evaluating the project's safety interventions. As the intervention logic is based on the quadruplet of safety outcomes, safety promoting goals, performance and change objectives, the evaluation methodology should be based on measurements that most accurately assess the performance of the intervention in terms of the four aforementioned parts. Furthermore, appropriate research questions for the evaluation of each intervention need to be initially formed, and suitable indicators, criteria and measures need to be selected as described in the previous chapters of the deliverable. In order to assess the performance of an intervention based on the corresponding research questions and the selected criteria, before-after studies, case-control trials and questionnaires can be utilized with regards to the safety outcome evaluation, while the RE-AIM framework can be utilized for individual process evaluation. Finally, after obtaining scores for each individual criterion, a summative evaluation score will provide the overall assessment of a safety intervention.

5.1 Next steps

The next steps include the **organisation of the back-office database** which will provide all the necessary data for evaluating interventions. Furthermore, during the on-road and simulator studies, the design of appropriate surveys will also assist in performing the questionnaire evaluations needed for the change objective assessment of the presented methodology. Furthermore, the back-office database will also assist in performing comparisons between countries and different transportation modes, which subsequently will enhance the intervention performance evaluation and the quality of the assessment results.

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Annex 1: Technology acceptance questionnaire

Technology acceptance questionnaire

Please think about the [in-vehicle information and prompts that were presented to you during driving] / [the intervention platform].

To which extent do you agree or disagree with the following statements (Strongly Disagree', 'Disagree', 'Slightly Disagree', 'Neutral', 'Slightly Agree', 'Agree' or 'Strongly Agree')

Construct / items	Real-time intervention	Post-trip intervention
Performance expectancy *		
The system is useful while driving.	x	
Using the system increases my driving performance.	x	x
If I use the system, I will reach my destination safely.	x	
Ease of use / effort expectancy		
My interaction with the system is clear and understandable. *		x
It was easy for me to become skillful at using the system. *		x
I find the system easy to use. *		x
Learning how to operate the system is easy for me. *		x
I think the *i*-DREAMS system is easy to use +	x	
I think the *i*-DREAMS system is easy to understand +	x	
I think the *i*-DREAMS system is annoying +	x	
Attitude towards using technology *		
Using the system is a good idea.	x	x
The system makes driving more interesting.	x	x
Interacting with the system is fun.		x
I like interacting with the system.		x
Social influence *		
I would be proud to show the system to people who are close to me.	x	x
People whose opinions are important to me would like the system too.	x	x
In general, people who I like would encourage me to use the system.	x	x
Facilitating conditions *		
While using the system I can maintain safe driving behavior.	x	
I have the knowledge necessary to use the system.		x
Self-efficacy * I could complete a task or activity using the system ...		
... if there was no one around to tell me what to do.		x

Construct / items	Real-time intervention	Post-trip intervention
... if I could call someone for help if I got stuck.		x
… if I had a lot of time.		x
… if I had just the built-in help facility for assistance.		x
Anxiety *		
I have concerns about using the system.	x	x
I think I could have an accident because of using the system.	x	
The system is somewhat frightening to me.	x	
I fear that I do not reach my destination because of the system.	x	
I am afraid that I do not understand the system.	x	x
I am confident that the system does not affect my driving in a negative way.	x	x
Perceived Safety *		
I believe that using the system information is dangerous.	x	
Using the system information requires increased attention.	x	
The system distracts me from driving.	x	
I feel save while using the system information.	x	
Using the system information decreases the accident risk.	x	x
I can use the system information without looking at it.	x	
Perceived Usefulness + I think using the *i*-DREAMS system ...		
... makes me a safer driver.	x	x
... makes it easier to drive.	x	x
... makes me more aware of my surroundings (other vehicles, lane position, etc.).	x	
... reduces distractions.	x	x
... improves my driving.	x	x
Trust +		
I trust the information I receive from the *i*-DREAMS system.	x	x
I think I can depend on the *i*-DREAMS system.	x	
I will feel more comfortable doing other things (e.g., adjusting the radio) with the *i*-DREAMS system.	x	
Behavioral Intention to Use +		
If I had a choice, I would continue to use the *i*-DREAMS system.	x	x
I would recommend the *i*-DREAMS system to other drivers.	x	x

* adapted from Osswald et al. (2012); + adapted from Ghazizadeh et al. (2012)