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# D3.1

# Framework for operational design of experimental work in *i*-DREAMS

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

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# Disclaimer



# Copyright

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# Glossary and abbreviations

| **Word / Abbreviation** | **Description** |
|---|---|
| ACT-R | Adaptive Control of Thought-Rational |
| CAN bus | Controller Area Network |
| CPD | Conditional Probability Distributions |
| DBN | Dynamic Bayesian Networks |
| DCF | Driver Calibration Framework |
| DREAM | Driver Reliability and Error Analysis Methodology |
| ECU | Engine Control Unit |
| ECG | Electrocardiogram |
| EEG | Electroencephalogram |
| GDPR | General Data Protection Regulation |
| GCW | Gross Combined Weight |
| HDPV | Heavy Duty Passenger motor road Vehicle |
| HDV | Heavy Duty Vehicle |
| HGV | Heavy Goods Vehicle |
| HFF | Human Functional Failure |
| I-DVE | Integrated Driver-Vehicle-Environment |
| LCV | Light Commercial Vehicle |
| LGV | Light Goods Vehicle |
| OBD | On Board Diagnostics |

| | |
|---|---|
| OEM | Original Equipment Manufacturer |
| ORR | Office of Road and Rail |
| SPAD | Signal Passed At Danger |
| SSS-V | Sensation Seeking Scale |
| STZ | Safety Tolerance Zone |
| TCC | Transport Co-ordination Centre |
| TCI | Task-capability Interference |
| UNECE | United Nations Economic and Social Council |

# Executive Summary

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. Moreover, safety-oriented interventions will be developed to inform or warn the driver in real-time in an effective way as well as on an aggregated level after driving, through an app- and web-based gamified coaching platform (post-trip intervention).

There are two main purposes of this report. The first is outline the theoretical framework that relates to driver and context monitoring within the *i*-DREAMS platform, with a specific focus on the concept of the Safety Tolerance Zone (STZ). This will include an overview of the theories that describe the driving task and a detailed theoretical description of the *i*-DREAMS' Safety Tolerance Zone (STZ) concept. The second purpose is to define the *i*-DREAMS transport modes and to indicate areas of difference between them that will affect the development of the monitoring and communication tools that will be developed by the project. A survey of stakeholders is presented as part of this work.

Four relevant theory types were identified: Control Theory, Motivational Theories, Crash Models, Computational Models. Control Theories: Task Capacity Interface (Fuller, 2000) and Driver Calibration Framework (Horrey, Lesch, Mitsopoulos-Rubens, & Lee 2015), were considered highest priority. Both recognise the importance of stable and dynamic operator/vehicle factors, as well as drivers' personal appraisal of the situation. Motivational Theories: e.g. Risk Homeostasis Theory (Wilde, 1998) acknowledge that safety is not drivers' only motivation. Crash models: e.g. DREAM (Ljung Aust et al., 2012) demonstrate multiple phases lead to collisions. Computational Models: e.g. I-DVE (Glaser, Rakotonirainy, Gruyer & Nouveliere 2007) provide a bridge between theoretical and mathematical models.

The concept of the STZ is rooted in control theory. Driving is a control task that is conducted in an unstable environment, which is created by the driver's movement in relation to a defined track and moving and stationary objects. Control theory assumes that control actions made by drivers depend on perceptual processes. To control their goal-directed behaviour, drivers make decisions in a negative feedback loop to keep resulting discrepancies from this comparison within acceptable limits. One well known control theory, Fuller's Task Capability Interface Model (TCI) (2005, 2011), states that driving is safe (low risk of crash) when the task difficulty is matched to the driver's capability. The STZ is made up of three phases. The 'Normal Driving' phase is where the driver's coping capacity comfortably meets or exceeds the task demands. If the coping capacity deteriorates or the task complexity increases, and the driver is operating on the edge of their capacity the risk of a crash increases and the driver enters the 'Danger Phase', or second phase. The third phase is the 'Avoidable Crash Phase' where the task demands outweigh the coping capacity and a crash situation is unfolding but there is still time for to take action to avoid the crash. The phase of the STZ also influences the type of real-time intervention that is necessary. Within the 'Normal Driving' phase there is no need for an intervention. Once the 'Danger Phase' is entered a warning will be given but if the situation deteriorates further, then an instruction may be more effective. However, it must be considered that these warnings/instructions may be ignored if the driver does not recognise that there is an increased risk.

An important explanatory factor in driving behaviour that is included in the STZ concept is that the driver's risk perception guides their actions and there can be a mismatch between

this ‘subjective reality’ and the ‘objective reality’ i.e. the driver’s perception of risk and the actual likelihood of a crash. Subjective reality, however, is very difficult to measure in the real world. This presents two potential approaches for the *i*-DREAMS platform:

- To use objective ‘world view’ measures only to trigger an intervention but use post-trip intervention to influence driver risk perception and behaviour.
- To take into account driver recognition and interpretation of risk when triggering an intervention as well as the ‘objective world view’ above.

The *i*-DREAMS platform will be tested using four different transport modes: Buses, Cars, Trucks and Trains/Trams. Buses are heavy duty motor road vehicles conceived for the road transport of passengers, where “motor vehicle” implies a power-driven, with at least four wheels. Passenger cars are defined as vehicles belonging to category M: Motor vehicles having at least four wheels and for the carriage of passengers. Consideration will also be given as to whether ‘light goods vehicles’ usually described as vans are included in this category. The term ‘truck’, refers to a Heavy Goods Vehicle (i.e. goods vehicles of over 3.5 tons maximum permissible gross weight) operating in both logistic areas of long haul and short haul transport. A train is a form of rail transport and defined as a series of connected railway carriages or wagons moved by a locomotive or by integral motors. Trains generally run on railroad tracks and can convey freight or cargo, or passengers. A tram is defined as a passenger vehicle which runs on rails laid on public roads and is powered by electricity conveyed through overhead cables.

A survey of transport stakeholders was conducted to gain indicative information about important safety breaches, factors that are considered contributory to safety breaches and whether technology like the *i*-DREAMS platform would be useful. In total, the survey received 103 responses. Individuals were asked to complete the survey representing the views of the transport mode they felt they had the most experience in. Most responses were in relation to passenger cars (63), followed by bus/coach (25), trucks (10), trains (4) and trams (1). Overall, the survey results showed several similarities across the various transportation modes. Although there were very few responses for trains/trams, where there were differences in responses, they tended to be between the other three modes and the train/tram, indicating that the train/tram operation is different and the *i*-DREAMS platform is likely to need alterations for this mode. There were also differences between modes which were more likely to have passengers for example buses/coaches and trains/trams in terms of safety. In addition, the survey found:

- The importance of driver trust and driver engagement
- System could aid by providing timely warnings
- Rewards, positive reinforcement and evidence-based feedback will help with engagement
- Stakeholders would like technology to measure/monitor driver state in the future.

The next steps in the methodological developments are:

- To further develop and fine-tune the concept of the Safety Tolerance Zone
- To translate the concept of the Safety Tolerance Zone into a mathematical mode that can be used to create algorithms for the triggering of interventions
- To review the outputs of the work described above and select the variables and measurement tools that should be integrated into the monitoring module *i*-DREAMS platform
- To review the outputs of the work described above and select the most effective real-time and post trip intervention strategies to be integrated in the intervention module of the *i*-DREAMS platform. This will include the time of warnings or instructions provided.

# 1 Introduction

## 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. Moreover, 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. 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 on a total of 600 participants representing car drivers, bus drivers, truck drivers and train drivers.

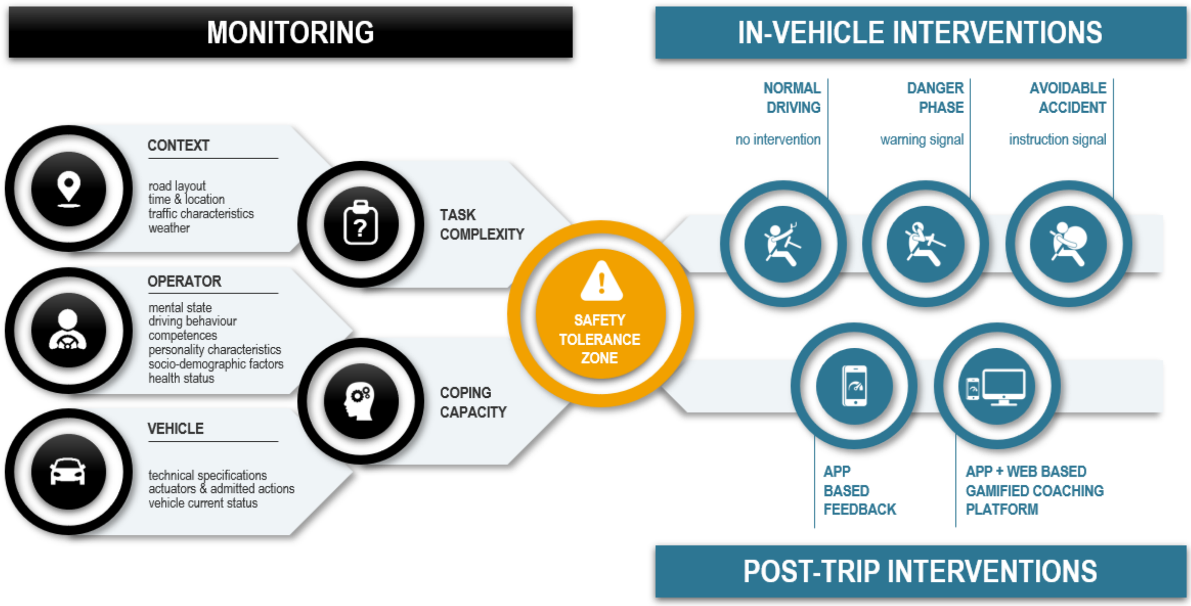



*Figure 1: Conceptual framework of the i-DREAMS platform.*

The key output of the project will be an integrated set of monitoring and communication tools for intervention and support, including in-vehicle assistance, feedback and notification tools; and a gamified platform for self-determined goal setting. Furthermore, a user-license Human Factors database with anonymized data from the simulator and field experiments will be developed.[1]

## 1.2 About this report

*i*-DREAMS is divided into five broad technical work areas: State of the art (monitoring and interventions), Methodological development, Technology development, Trials, and Analysis.

[1] Further general project information can be found on the website: https://idreamsproject.eu

This report is the first of the methodological work area of *i*-DREAMS. The methodological work area is concerned with the definition of a context-aware Safety Tolerance Zone and the development of a driver and environment assessment and monitoring system that will assist drivers in staying within this Safety Tolerance Zone (see Figure 1). The work will be informed by the state of the art (monitoring and interventions) work area and in particular:

- The state of the art for impact in terms of safety, and the measurement tools for variables that could be used within the monitoring platform.
- The state of the art for methodologies and tools to provide real time interventions and post trip interventions with the aim of increasing safe driver behaviour

It will also provide information to the technology development and trials work areas which will test and validate the system. Specifically, it will inform the assessment of the available technology for variable collection and how these can be integrated into the *i*-DREAMS platform.

There are two main purposes of this report. The first is outline the theoretical framework that relates to driver and context monitoring within the *i*-DREAMS platform, with a specific focus on the concept of the Safety Tolerance Zone (STZ). This will include an overview of the theories that describe the driving task and a detailed theoretical description of the *i*-DREAMS' Safety Tolerance Zone (STZ) concept. The second purpose is to define the *i*-DREAMS transport modes and to indicate areas of difference between them that will affect the development of the monitoring and communication tools that will be developed by the project. A survey of stakeholders is presented as part of this work.

Chapter 2 will provide an overview of driving theories including control theory, driving risk, crash models and computational models of driving behaviour. Chapter 3 sets out the theoretical background and the concept of the Safety Tolerance Zone and Chapter 4 discusses the driving theories with the Safety Tolerance Zone concept.

Chapter 5 reports the findings from a survey of transport stakeholders representative of the *i*-DREAMS modes. Chapter 6 introduces the *i*-DREAMS trial transport modes, including general definitions, and considerations to be taken into account in the development of the *i*-DREAMS platform. Finally, chapter 7 introduces some practical considerations and describes the next steps of the project.

# 2 An overview of driving theories

Many theories or theoretical models exist that aim to describe the driving task. The driving task is highly complex, and theories have to take into account drivers' actions and reactions to the road traffic system. This chapter is not exhaustive, instead it aims to give an overview of the type of theories that exist and some details about a selection of specific theories. It should be noted that a theoretical model is not the same as a mathematical model. Theoretical models are theories that usually have evolved over time to explain a phenomenon. Evidence for their validity can be given from individual studies but a theoretical model is rarely conclusively proved. Mathematical models on the other hand are usually data driven and developed using statistical and probability-based methodologies. In some cases, it is necessary to translate a theoretical model into a mathematical model. The chapter is divided into four sections: Theories relating to control theory; theories that describe the concept of risk within the road traffic system; crash causation models; and conceptual models that provide a bridge between theoretical and mathematical models.

Although the theoretical models briefly described below have been developed with road transport in mind, in many ways they are applicable to the driving task faced by train and tram drivers. Therefore, this section aims to summarise relevant theories and models of driving task in relation to all the transportation modes considered as part of the *i*-DREAMS project.

## 2.1 Describing the Driving Task: Control Theory

Driving theories based on control theory seek to describe the driving task within the context of behavior being governed by internal controls (thoughts, feelings, beliefs) and external controls (environmental or societal influences). Horrey et al. (2015) explains this further: Humans selectively attend to environmental cues to make judgements regarding the state of the world. Similarly, people conduct self-appraisals and often make inflated or erroneous estimates of their ability or performance. Moreover, subjective evaluations are not well-calibrated to objective measures. People have the propensity to view themselves more optimistically, irrespective of actual performance, abilities, or prospects (e.g., Alicke & Govorun, 2005). The result of such errors in calibration can be poor decisions or risky (driving) behavior. Biases or errors may result from incomplete gathering or improper processing of available information. In many cases, it concerns general estimates that can persist over time and in different situations. However, errors in estimates or judgments can also occur in real-time, meaning that calibration errors can occur in the processing and determination of the current state of the world. In relation to such calibration, self-regulation models such as the TCI model from Fuller (refer to Horrey et al., 2015 for further references) denote the need for accurate appraisals of momentary demands, in order to adjust behavior. According to such theories of demand regulation, safe performance hinges upon the ability to recognize the relation between driving task demands and personal capabilities. A well-calibrated driver will recognize when task demands exceed individual capabilities, taking necessary measures to restore the balance (e.g., by reducing speed). Poorly calibrated drivers may fail to take the necessary countermeasures, placing themselves at risk of a crash. Despite being useful, Horrey et al., (2015) acknowledge that these models describe a rather high-level view of the described constructs and lack an explicit description of underlying mechanisms and factors that can influence appraisals of the self and the situation.

### 2.1.1 Hierarchical Control Model

Michon (1985) argued that driver research should focus on the cognitive element of driver behaviour, not just the behaviour itself. He suggested that there is a distinct hierarchical cognitive control structure of human behaviour within the traffic system. Michon (1985) sets out what has been described as the Hierarchical Control Model (Panou et al., 2007). This divides the driving task into three related and (nested) hierarchical levels: Strategic, Manoeuvring, and Control:

**Strategic**: planning related aspects of driving task such as route planning and time restraints, before the drive is even initiated. This does not have a direct relationship with the driving task but it does set criteria for the other levels.

**Manoeuvring**: the interaction between drivers and the traffic system. This involves input from the environment as well as the application of existing knowledge of the driver; e.g., traffic rules within so called ‘controlled action patterns.

**Control**: the process of physically driving e.g., steering, applying the brakes, changing gear, etc. This tends to automatic behaviour or ‘automatic action patterns'.

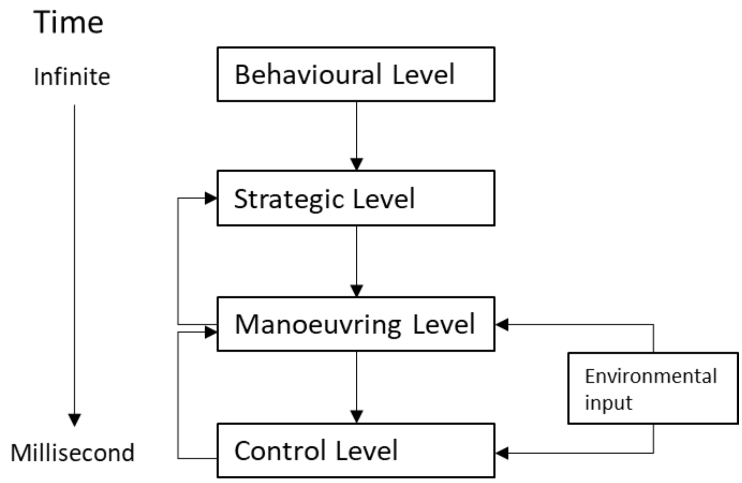



*Figure 2: Hierarchical structure of the driving task (based on Panou et al, 2007)*

A fourth ‘Behaviour’ level has been added above the strategic level. (Christ et al., 2000 cited in Panou et al., 2007). It incorporates the driver’s attitudes, age, gender and other personal factors that could affect driving behaviour/crash involvement.

In relation to trains and trams, this may still be applied. Although trains potentially do not have the manoeuvring aspect the same way as other forms of road transport (e.g. traffic systems), many trams share the road with multiple road users. Train drivers however still have environmental aspects and inputs to consider, such as changing speed limits, station stops, passengers embarking and disembarking, which could be applied to the manoeuvring level. The strategic, control and behaviour levels would also apply to all aspects of train and tram driving.

### 2.1.2 Task Capability Interface (TCI) model (Fuller, 2000, 2005, 2011)

Fuller’s (2011) Task Capability Interface (TCI) model aims to understand driver decision making, starting from the idea that perceptual processes and control actions come with limitations. The driver needs to continuously operate within these limitations, ensuring that driving task demands are in line with the driver’s capability (Figure 1). Once vehicle movement is initiated, the probability of a crash is one unless the driver continuously adjusts his/her driving behavior in order to avoid a collision. When task demand exceeds capability, for whatever reason, loss of control occurs and unless compensatory action by another road user is taken to prevent this outcome (e.g., by switching lane), a crash will occur (Fuller, 2000).

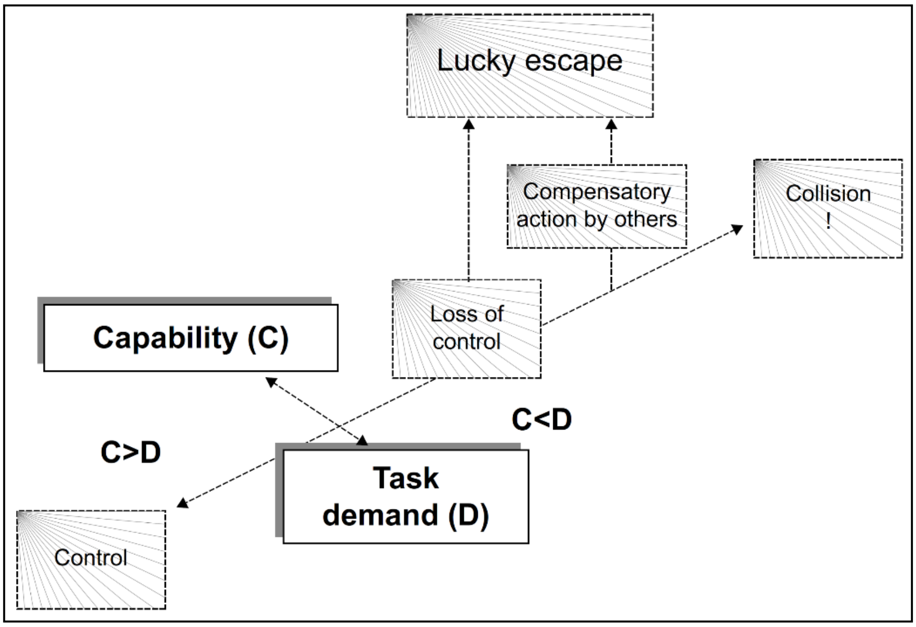



*Figure 3: Basis of the Task Capability Interface model as first described in Fuller (2000). The concept of limited capacity can be located at the interface between driver capability and driving tasks demand (Source: Fuller 2011).*

*Driving task difficulty, capability and demand.*

Driving task difficulty is related to the separation between task demand and available capability, with a greater capability in relation to task demand leading to a lower task difficulty, and the other way around. The distinction between demand and capability equals concepts like spare capacity or safety margin. Driving task demand is characterised by both information input as well as response output, related to determining the driving situation ahead and appropriate vehicle manoeuvring. Task demand can be influenced by numerous factors such as vehicle characteristics, route choice, roadway environment, and other road users. Driver capability originates from driver characteristics such as basic physiology, education and training, and experience. Capability provides drivers with strategies for the attainment of information and preadaptation to anticipated task demand changes. Importantly, driver capability is affected by driver state, for instance emotion or fatigue. Changes in task demand influence task difficulty directly in the case of a stable capability. With an increase in task demand, the margin of capacity that is available to deal with the additional task demand decreases. When this happens, the driver becomes more vulnerable to performance error consequences and to acute high demands.

*Task difficulty homeostasis*

Within the TCI model, the concept of task difficulty homeostasis hypothesis relates most to the underlying idea of control theory. This hypothesis refers to drivers' continuous real-time decision-making that is performed in order to keep the perceived driving task difficulty within certain boundaries. Most often, but not always, these decisions relate to the adjustment of driving speed. For instance, slowing down when task difficulty increases due to snowy driving circumstances. Another example of a driving parameter used to control perceived task difficulty relates to headway, which can be increased in difficult circumstances. Homeostasis does not only refer to real-time decision-making in case of increased task difficulty, the other way around is possible as well. For instance, when drivers increase their speed in case of a decrease in task difficulty.

Perceived task difficulty arises from the meeting point of (or balance between) perceived task demand and perceived capability. In case task demand is underestimated or capability is overestimated by the driver, the perceived level (or the subjective level) of task difficulty is less than is objectively the case. This perceptual process can also be referred to as calibration accuracy. Drivers that are not well-calibrated usually function with less spare capacity, more often driving towards the boundary where task demand meets capability. A mismatch in this calibration process, both in the underestimation of demand as well as the overestimation of capability, relates to novice drivers. For instance, they are not well calibrated to estimate the effects of distraction on their driving performance. Two additional comments can be made about the process of homeostasis. First, on some occasions, a lag between driver adjustments and task demand may occur, i.e. a response delay. Second, there is a difference between actual perceived demand and anticipated perceived demand. Indeed, one important component of driver capability refers to the anticipation of changes in task demand and accompanying adjustments in driving behaviour. Returning to the example of novice drivers, anticipatory adjustments to task demand change are poorer in less experienced drivers.

*Individual differences in preferred task demand and difficulty*

Importantly, the boundaries of preferred task demand vary between individuals. The lower boundary is based on a minimum that aligns with both making acceptable progress and sufficient stimulus so that boredom, drowsiness and sleep are prevented. The upper boundary is based on variables such as perceived capability, motivation for effort investment, and journey goals. The latter can have a direct influence on speed choice, for instance, when the driver is running late and speeds up. This increase in speed raises task demand and causes the driver to operate within a situation of higher task difficulty than he/she would normally prefer. Meanwhile, task difficulty is experienced by drivers in a similar manner as they perceive risk. Indeed, this perception of risk may serve as a surrogate for task difficulty. In contrast, risk perception and statistical risk are not that similar and are even independent from each other at lower levels of perceived risk ratings and task difficulty.

Drivers vary in the levels of preferred task demand and difficulty they want to adopt based on their individual dispositions. Four different groups can be distinguished: low risk threshold (safer, typically older and more experienced), high risk threshold (positive towards high-risk behaviour and thrill-seeking, typically young, inexperienced and also poorly calibrated, and male), opportunistic (want to get ahead, no speeding for the sake of speeding and only when they believe it is safe, more likely to be male), and reactive drivers (not always concerned with making progress, generally avoids unsafe driving but strongly influenced by emotions, more likely to be female).

*Task difficulty allostasis and compliance*

Several variables can temporarily increase a driver's risk thresholds, for instance, anger and aggression, social influences, thrill seeking, etc.. The fact that factors can have an immediate influence of the task difficulty level that drivers are prepared to accept denotes that the concept of risk homeostasis requires an update. Specifically, homeostasis is probably not the most appropriate control concept. Whereas homeostasis relates to the maintenance of a set target conditions in face of external variation, allostasis relates to dynamic target conditions that vary according to the driver's needs and circumstances. Therefore, allostasis reflects driver's control process better than homeostasis. To illustrate, in an emergency, it is possible that you would accept more risks than usual in order to arrive at your destination in time (e.g. when you are trying to reach a relative in distress as quickly as possible).

One last relevant component is compliance, which relates to the decision output from the task difficulty allostasis. The output from this process can be a certain speed that is achievable in terms of task difficulty but is above the legal speed limit. Therefore, the TCI model needs to include the disposition of the driver to choose a speed within the legal limit above a speed based on preferred task difficulty. The disposition to comply with stated limits varies greatly between individuals. This variation is represented by both rather stable individual differences (e.g. focus on potentially positive or negative outcomes) and momentary influences. Many drivers do not necessarily aim to break rules but rather seek a preferred level of task difficulty by adjusting demand, for instance, by increasing speed when the set limit is perceived to be too low.

### 2.1.3 Driver Calibration Framework

The Driver Calibration Framework (DCF) (Horrey et al., 2015) builds further on earlier calibration models by including aspects of information processing and lens modeling. With information processing, the authors of the DCF refer to cognitive stages of the selection and processing of relevant information, and processes of decision-making (action selection) and execution. Meanwhile, attention is described as an important component, regulating the information flow. The lens modeling component describes how people make judgements concerning the state-of-the-world by using different information cues. The accuracy of the perception is then influenced by the manner in which people selectively weigh the available information, which can be referred to as their cue utilization strategy. Calibration errors may arise from incomplete processing or inappropriate use or weighing. Some cues may be overweighed while some are underweighted, and in some cases, this can even include a complete disregard of certain information. This potential incomplete use of information can also be linked to heuristics used in human judgement and decision-making theories; in case they are based on the intention of preserving resources.

The conceptual DCF is visualized in Figure 4. Two lens models are displayed that contain information cues ($X_1$, $X_2$, … $X_n$) that can be used to subjectively assess the objective state-of-the-world or the actual driving abilities. The bottom lens model displays the judgement of the state-of-the-world, which is embedded in a model of information processes including perception and cognition (right bottom). This estimate is based upon both top-down (e.g., information from long term memory) and bottom-up (e.g., salience) influences. In addition, perceived abilities can also influence driver's estimates of the state-of-the-world. For instance, by using a different weighing policy for cues reinforcing his or her beliefs. Calibration in this sense can be considered as the correspondence between the objective measurement of the state-of-the-world and the driver's subjective estimate. After this assessment, drivers will select and execute a response, influencing the current state-of-the-world, rendering feedback to the driver. These different information processing stages are subsequent to differing levels of attention, which is a limited resource. Attentional limitations can be caused by both global (e.g., age, experience) and situational (e.g., fatigue, multi-tasking, emotion) factors. This leads to varying attentional allocation strategies that can have a positive, in case of preserved resources and a sufficient judgement, or a negative outcome, in case of misleading or false judgement that withhold potential risk. The upper lens model displays information cues used to guide self-evaluations of abilities. This calibration of skill refers to the correspondence between the driver's actual abilities and their perceived abilities. Importantly, the estimations from the driver and the feedback that is generated after responses can also serve as information cues, guiding the perception of ability. Moreover, global factors (e.g., age, personality traits) interact with the perception of ability. The DCF thus entails calibration relating to momentary judgement of both the state-of-the-world and self-appraisal of capability. In sum, the DCF describes the information flow that ranges from selection, processing and integration, to response execution impacts both the state-of-the-world (entailing the necessity of cyclic information processing), and enduring self-appraisals. For instance, a global factor such as experience may impact the perception of own skills in young novice drivers since they did not encounter a sufficient number of situations that would lead to appropriate feedback, influencing how information is weighed and interpreted. Moreover, additional experience can free up attentional resources, supporting a momentary assessment of the state-of-the-world.

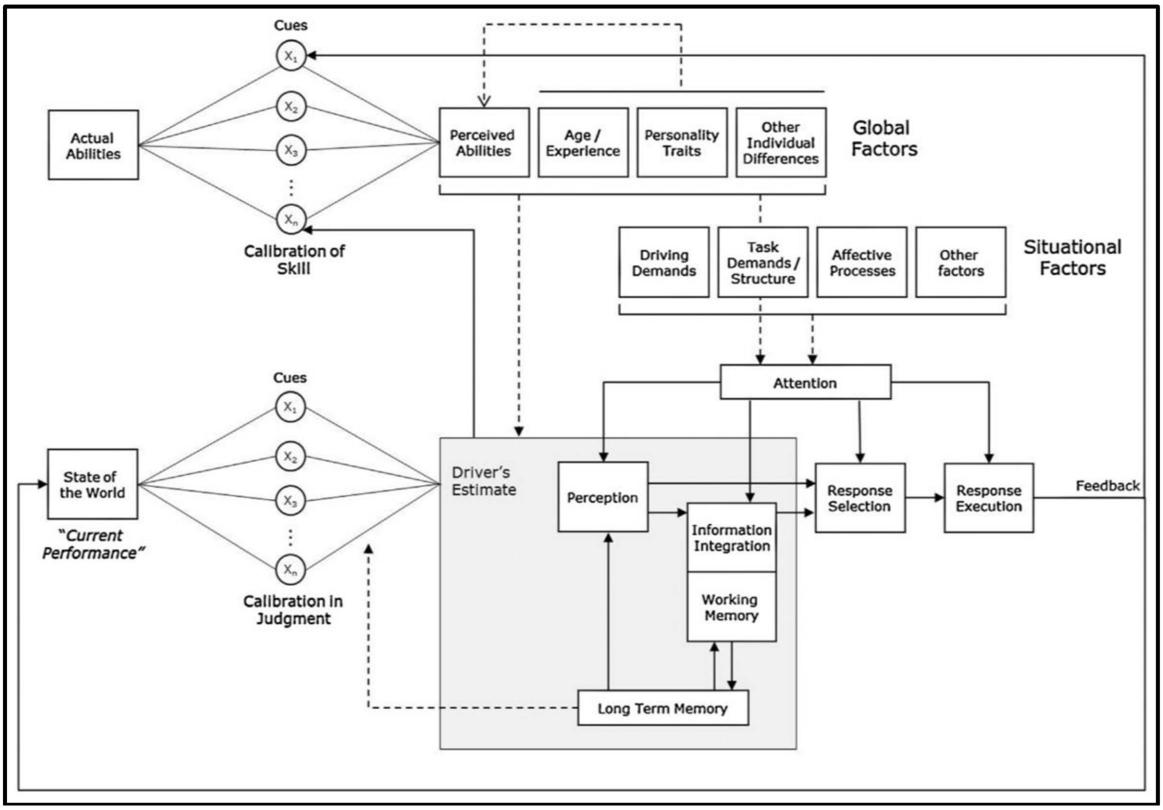


*Figure 4: Driver calibration framework. Source: Horrey et al. (2015)*

### 2.1.4 The relationships between mental workload, task demand, and driving performance

Pereira da Silva (2014) provides a commentary and discussion about what is known about the relationship between mental workload, task demand and driving performance.

Various definitions of mental workload are presented; according to one 'mental workload' can be considered the proportion of information processing capability used to perform a task. Defining factors are task specificities as well as individual characteristics (age, driving experience), motivation to perform the task, strategies applied on task performance, and the physical and emotional state. Neurophysiologic, perceptual and cognitive processes are also involved.

A linear association of task demand and mental workload is rejected, and an integrated system is described with the factors task demand, workload, performance and adaptive strategies: if one changes, all others are affected. Furthermore, the concept of 'mental effort' (Kahneman, 1973) is introduced, which can be described as the effort applied to information processing in order to maintain an adequate level of performance (when task demand increases). Then again, 'mental effort' can also refer to a compensatory effort when the driving performance begins to decrease due to e.g., fatigue or distraction. The performance can be maintained with additional mental effort up to a certain point. In addition, individual differences in motivation or adaptability for example, provide evidence against a linear relation of task demand and workload. Phenomena such as 'dissociation' are mentioned, where task demand increases while driver workload decreases (Parasuraman & Hancock, 2001, in Pereira da Silva, 2014). This could be especially relevant to train drivers, who can have long stretches of low workload in terms of train driving, but high task demand when monitoring signals and speed for example. Ultimately, the assessment of workload is related to the subjective task difficulty as experienced by the driver.

When it comes to determine how much workload is too much, the model of regions (A to C), proposed by Meister (1976, in Pereira da Silva, 2014) and extended to include a region D by de Waard (1996, in Pereira da Silva, 2014), presents useful insight. This is a variation of the Yerkes-Dodson Law (Yerkes and Dodson, 1908) that describes an empirical relationship between arousal and performance.

- Region A: task demand is low, workload is low, performance is high. If task demand increased the performance efficiency is not compromised.
- Region B: task demand increases, performance decreases, workload may increase as a result
- Region C: task demand as well as workload increase, drastic decrease of performance as a result
- Region D: task demand is so low (e.g. monotonous tasks) that task difficulty and workload increase

Region A is further subdivided into subregions A1, A2, A3. In the middle region A2 the operator is able to easily manage task demand. The red line for the point at which increased workload leads to decreased performance can be located between region A2 and A3. The operator can easily handle the task demand and performance remains stable even if there is an increase in task demand (region A2). In region A3 the operator can only maintain the performance level with temporary use of compensatory effort. In A1 the task demand is so low that increased effort may be needed to maintain performance.

Different methods to measure workload are described. In terms of road transport, lateral control is considered one of the most important driving performance measures. If the driver's attention level is low (e.g., due to fatigue or mobile phone use), the number of lateral position deviations increase. However, for all transportation modes, longitudinal control indicators are used to measure workload, in particular speed variation and time needed to correct speed. Physiological measures (e.g., heartbeat, electroencephalogram, eye-movements etc.) are sensitive to changes in workload levels and measurable before changes in driving performance occurs.

## 2.2 Motivational Theories

Some driving theories focus on the collision risk drivers pose and their perception of that risk within the wider traffic system. Such theories focus on behaviour in relation to perceived risk rather than the task demand versus driver capabilities that the previous section focused on.

Summala (1988) provides an overview of models that deal with the risk drivers pose in the road traffic system: A first theory was that the driver's skill determines crash risk – less skilled drivers are more likely to crash. This was criticised as the differences among drivers are not great enough to assess risk based on pure skill. Then in the 1930s and 1940s the idea that drivers adapt their behaviour to environmental changes was considered. By the 1960s and 1970s, the idea was that driving is a ‘self-paced task’ where the driver alters behaviour in response to task difficulty. One theory was that the driver adjusts their risk based on their feelings of anxiety that are triggered during the driving task (Taylor, 1964, In Summala, 1988). In this way driving models moved from skills based to motivation based and the concept of subjective risk was introduced.

### 2.2.1 Zero Risk Theory

This theory (Summala, 1988) looks at the motivational basis of driving behaviour and adaptation to the perceived risks on the road.

Driver behaviour is explained on the basis of the example of speed choice. The opportunity to satisfy various motives and the (mis-) perception of a deterministic environment that supposedly can be handled due to past experiences that are not associated with fear and risk, pushes the driver to higher speeds.

Two domains are central to explain behaviour with the *zero-risk theory*: (1) motivational processes and (2) adaptation to perceived risk on the road.

(1) Increased or high speed may satisfy different motives such as easy and (subjectively) fast transportation from A to B, reluctance to reduce a high level of speed, minimizing effort (e.g., effort to slow down and to adapt to speed of another driver), demonstration of skills (in front of peers), maintenance of habitual behaviour etc.

(2) Adaptation to perceived risk: The subjective risk is referring to an immediately experienced fear or uncertainty in a given situation (as opposed to risk estimation at a distance) that is related to fear or loss of control over the vehicle or of being on a collision course. Drivers typically tend to escape or avoid this experience, while slight uncertainty can (temporarily) be accepted. Novice drivers usually get rid of this prevalent uncertainty or fear with increased experience and increased automatization of driving. A sense of control and confidence is established, and mental models of driving and traffic become more complete. Then again, as the internal models become more deterministic, the stochastic element of traffic is increasingly neglected, discarding the basic fear response to specific traffic situations. The actual variation in driving environments is rejected. Thus, the perception of risk is distorted.

While some aspects of this theory are specific to road transport drivers, it can still be applied to train drivers from a motivational and adaptation to perceived risk point of view. Increased or high-speed driving of a train can be a result of minimising effort, or lack of attention, and train driver experience and confidence in their ability could impact adaptation to perceived risk.

Risk is controlled by the driver by maintaining a *safety margin*, which can be understood as spatial (e.g., *Is there enough space to pass a cyclist?*) or temporal distance to a hazard (e.g., ‘time to collision’). The safety margins are maintained based on simple heuristics derived from past driving experience.

### 2.2.2 Risk Homeostasis Theory

The premise behind Wilde’s Risk Homeostasis Theory (Wilde, 1998) is that humans do not seek to minimise risk – instead the aim to optimise it. The theory states that the amount of risk individuals are prepared to accept depends upon four factors: the expected benefits of risky behaviour, the expected costs of risky behaviour, the expected benefits of safe behaviour, and the expected cost of safe behaviour. Risk homeostasis theory states that at any one time perceived risk is compared with an individual's target or accepted level of risk, and behaviour will be adjusted to reduce discrepancies between the two states. The individuals action carries a certain level of probability that a crash will occur and the sum of all actions during a year explains the crash rate. The crash rate will then influence individual's perceived level of risk and therefore continue the cycle. For example, Wilde (1998) suggests that individuals choose higher travel speeds on stretches of road with low crash rates.

Fuller (2011) suggests that risk allostasis is a better way to describe drivers' optimising of risk. See section 2.1.2 above for detail.

## 2.3 Crash Causation Models

Driving theories also seek to explain when things go wrong in the driving task as well as periods of 'normal' driving. The section will describe two crash models that have been developed specifically with road transport in mind.

### 2.3.1 The DREAM model

The Driver Reliability and Error Analysis Methodology (DREAM) is a road traffic crash causation analysis tool (e.g., Ljung Aust et al., 2012). It is underpinned by a crash model that takes a system approach. The model states that within the road traffic system there are three interacting elements: human, technology, and organisation. This relates to the driver (human), the vehicle and traffic environment (technology) and overarching factors such as vehicle and roadway design or driver training (organisation). The model views driving as a control task that involves continuous adaptation to a changing environment in a way that promotes goal fulfilment (Fagerlind et al., 2008).

A crash is a result of breakdown in the driving system whereby the loss of control is caused by unsuccessful interactions between the human, technology and organisation. Before a crash becomes inevitable, blunt end failures can exist within the system. These are latent failures that cause the system to be less safe e.g., inattention, lack of experience but do not necessarily lead to a crash. In contrast, sharp end failure e.g., leaving lane unintentionally or travelling too fast for the roadway or conditions requires corrective action to be performed by the vehicle or driver to prevent a crash occurring. This is illustrated by Figure 5. See Talbot et al., (2013) for further detail.

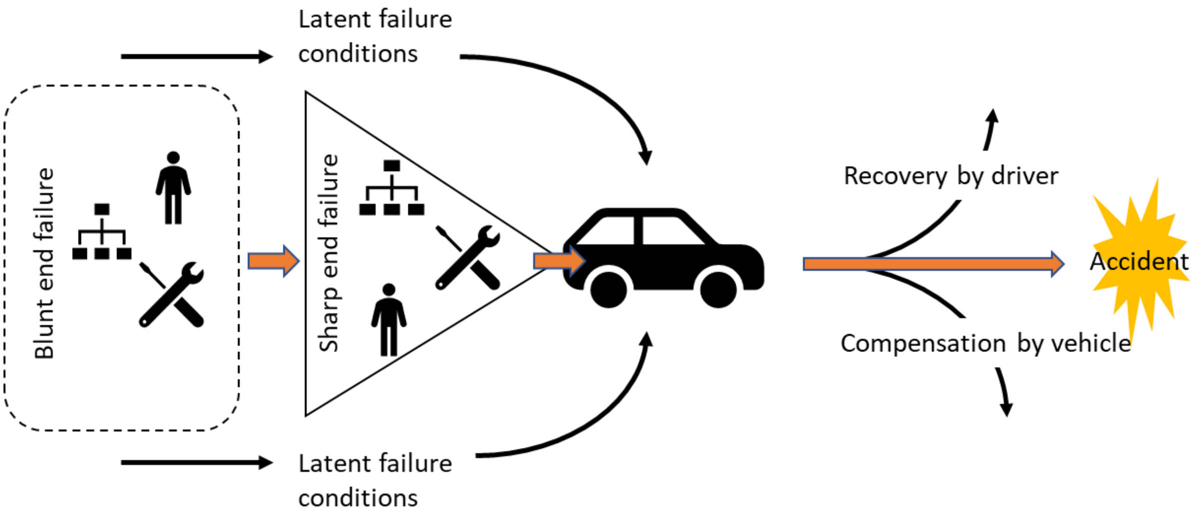



*Figure 5: DREAM crash model. Adapted from Hollnagel,1998, in Talbot et al., (2013).*

Although developed for road transport, systems-based models can be applied to other transport modes. In the context of rail, the specific blunt end and sharp end failures would change but the rail transport system is similarly made up of driver-technology-organisation.

### 2.3.2 Human Functional Failure

Human Functional Failure (HFF) (Van Elslande, 2008) is also a systems-based crash causation analysis methodology. It describes a crash scenario as a sequence of events (see Figure 6). The first is the *driving phase*. This phase is before a problem arises. The driver is driving 'normally' i.e. there are no unexpected demands and they are in control of speed and manoeuvres. This means that there is a balance between the demands and ability of the system components to respond to one another. The second is the *'rupture' phase*. This is when an event occurs that the driver did not expect, for example a manoeuvre of another road user or the road sharply bends, which leads the driver's workload to rise potentially beyond their ability. In relation to trains, this could also be due to an unexpected signal change or an alert that a Signal-Passed-At-Danger (SPAD) has occurred. This causes a 'conflict' (within the system) to occur. This in turn leads to the '*emergency phase*'. During this phase the driver may attempt to carry out an emergency action in order to avoid a crash. The demands on the driver are to solve a problem quickly within the limits of the system as a whole. If the driver is unsuccessful in solving this problem, they enter the *Impact phase*. The impact phase comprises the crash and its consequents and determines the severity of both material damage and injury.

| Driving phase | Rupture phase | Emergency phase | Impact phase |
|---|---|---|---|
| ↓ | ↓ | ↓ | ↓ |
| Behaviour on approaching the place | Meeting an unexpected event | Avoidance manoeuvres and dynamic demands | Nature of impact |

*Figure 6: Human Functional Failure crash phases (from Appelt et al., 2011)*

Van Elslande (2008) also describes a functional chain that describes the driving activity (Figure 7). There can be a 'failure' at any point of the chain that can lead to a crash occurring.

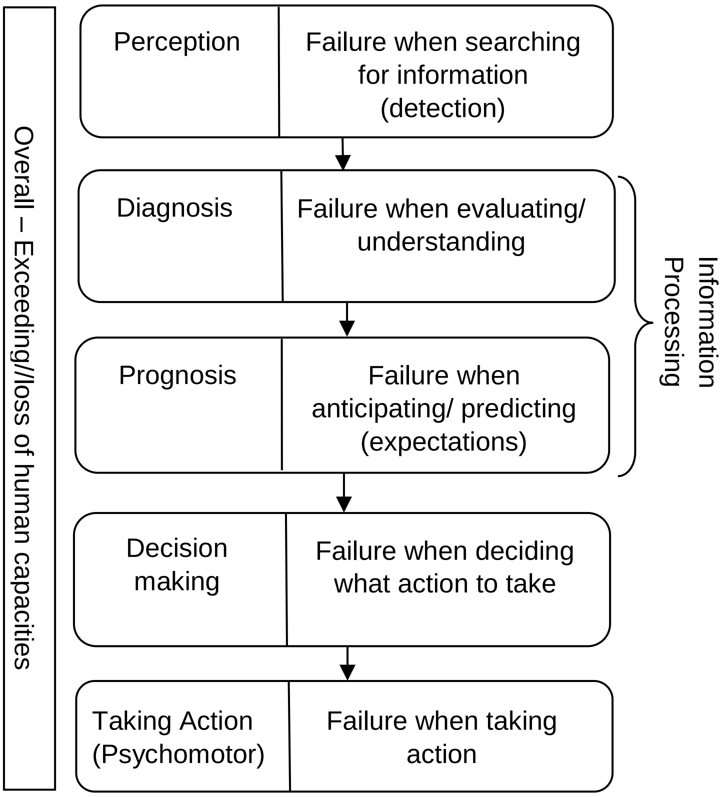



*Figure 7: Functional chain involved in driving activity (from Appelt et al., 2011)*

In order to react appropriately to the various situations encountered while driving, the driver first has to detect the relevant information in the environment. This is the perception stage of the driving task and requires the driver to physically see and attend to what they see. Failures here will disrupt the whole chain. The next stage in the driving task is for the driver to process the information they have perceived. This is the Diagnosis and Prognosis stages of the driving task and failures can occur at either stage. The driver has to work out the significance of what they perceive. Based on their diagnosis of the situation, the driver will make a judgement about what is going to happen next. The fourth stage is for the driver to decide what manoeuvre to perform based on their prognosis of the situation. The last stage of the driving task is to correctly execute the planned manoeuvre by correctly operating the controls of the vehicle.

## 2.4 Computational models of Driver behaviour

There are many different types of models that aim to describe driver behaviour.  Some are more statistical in nature e.g. gap acceptance models or seek to replicate the real world e.g. simulation models.  This chapter aims to give a theoretical overview of the models and concepts that seek to describe driver behaviour.  'Computational models' are used to describe models that halfway between a statistical or mathematical model and a theoretical mode. These can be seen as the concept behind a mathematical model or the bridge between theoretical and mathematical models. An example of three computational models that seek to describe driver behaviour in relation to the context of the driving task are described in this section. The focus of the descriptions are the concepts behind the model rather than describing the more technical aspects. This only provides a snapshot of such models and this section does not attempt to be exhaustive.  All the models mentioned here were developed with road transport in mind, and therefore may not be relevant to trains and trams. This is an important consideration to take forward. In terms of development of the *i*-DREAMS models, all the relevant transportation modes, including trains and trams, will be considered.

### 2.4.1 Integrated Driver-Vehicle-Environment model (I-DVE)

The I-DVE was proposed as a model for assessing crash risk, accounting for the complex interaction between the driver, the vehicle and the driving environment. Crash risk was modelled with two criteria: the probability that a collision will occur, and the crash severity associated with the event. The I-DVE was validated by means of simulation with empirical data such as time to collision, energy equivalent speed, injury severity, and driver profiles. Glaser et al., (2007) focus on frontal and rear-end collisions and present concepts and equations for the two scenarios accordingly.

Regarding the cognitive process of decision making, I-DVE takes three levels into consideration:

- Operational level: vehicle handling and specific manoeuvres on the basis of longitudinal control, lane keeping, and lane change manoeuvres
- Tactical level: choice of the most appropriate manoeuvre in terms of reducing crash risk
- Strategic level: related to higher level, general goals such as routing. Within the I-DVE three driver profiles are proposed to facilitate modelling which are described as risk-cost functions (relating the cost of choosing a certain driving behaviour to its risk estimation). The three profiles are:
    - The *careful driver* maintains a constant level of risk, independent of the costs.
    - The *disregarding driver* accepts increased risk with increasing costs.
    - The *hedonistic driver* accepts risky situations when the cost is low but is careful as the costs increase.

### 2.4.2 Example of an integrated driver model developed in the ACT-R cognitive architecture

used to represent various cognition processes in computational models. A cognitive architecture is a general framework for specifying computational behavioural models of human cognitive performance. They typically interact with a simulated environment that is almost identical to the environment used by human participants. An important feature is that cognitive architectures integrate both the abilities and the limitations of the human system (e.g., cognitive processes are serial and cannot run in parallel). Salvucci (2006) used the cognitive architecture, Adaptive Control of Thought-Rational (ACT-R) (Anderson et al. 2004, cited in Salvucci, 2006), to develop a computational model of the driving task. More precisely, the model focuses on vehicle control (operational level), monitoring (tactical level) and decision making (tactical level) on a multilane highway, accounting for steering profiles, lateral position profiles and gaze distribution (indicating distraction) during the driving tasks lane keeping and changing, as well as curve negotiation. The last-named driving tasks were validated based on key scenarios presented to participants in a driving simulator. Associated equations and assumptions as well as validation outcomes from the simulator are presented in the paper.

### 2.4.3 Understanding and modelling the human driver

Macadam (2003) takes a control system modelling approach to describe common crucial aspects of human driver modelling and identifies corresponding driver models that are used to predict the combined performance of the driver and the vehicle. The focus is on driver tasks at the operational level: lateral and longitudinal control tasks (path-following, obstacle avoidance, headway control).

Driver characteristics which must be considered for computational modelling are:

- Physical limitations:
  - Time delay in reacting to stimulus due to processing time and information transmission time. For example, the reaction time to visual stimuli under (near) ideal conditions is about 180ms. Information processing and response time varies for visual, auditory, kinaesthetic and tactile information
  - Ranking of sensory cues: Although it is agreed that visual information is dominant for driving, the ratio to other sensory information is dependent on the scenario (e.g., relative increase of importance of kinaesthetic cues during crosswind).
- Physical attributes: for example, anticipation (e.g., speed adjustment when entering a curve), internal cognitive representations of how the vehicle must be controlled, invention of new control strategies in unfamiliar situations.

Relevant factors that have been considered less frequently in models – but deserve more attention – are for example the consideration of individual differences in driver skills and experience. Studies of longitudinal, lateral, and combined control behaviour are reviewed Macadam (2003).

# 3 The theoretical concept of the Safety Tolerance Zone

The Safety Tolerance Zone (STZ) is a central component of the conceptual framework of *i*-DREAMS (Figure 8). The framework is composed of two modules – 'Monitoring' and 'Intervention'. The monitoring module will define what is measured in relation to the 'Context' of driving – that is the environment including infrastructure, the 'Operator' –including mental state while driving, personality and demographic characteristics and the 'Vehicle' - including technical specifications and the current state. This information will then be used to calculate the task complexity and the coping capacity. It is necessary to perform such calculations in real time during driving as well as after the journey has been completed. This will then inform the driving status in terms of the STZ. In turn, the status of the STZ will determine the type of real-time intervention that is provided. Post-trip interventions will use the data collected during a trip to provide information and advice to the driver with the aim of influencing behaviour for future trips.

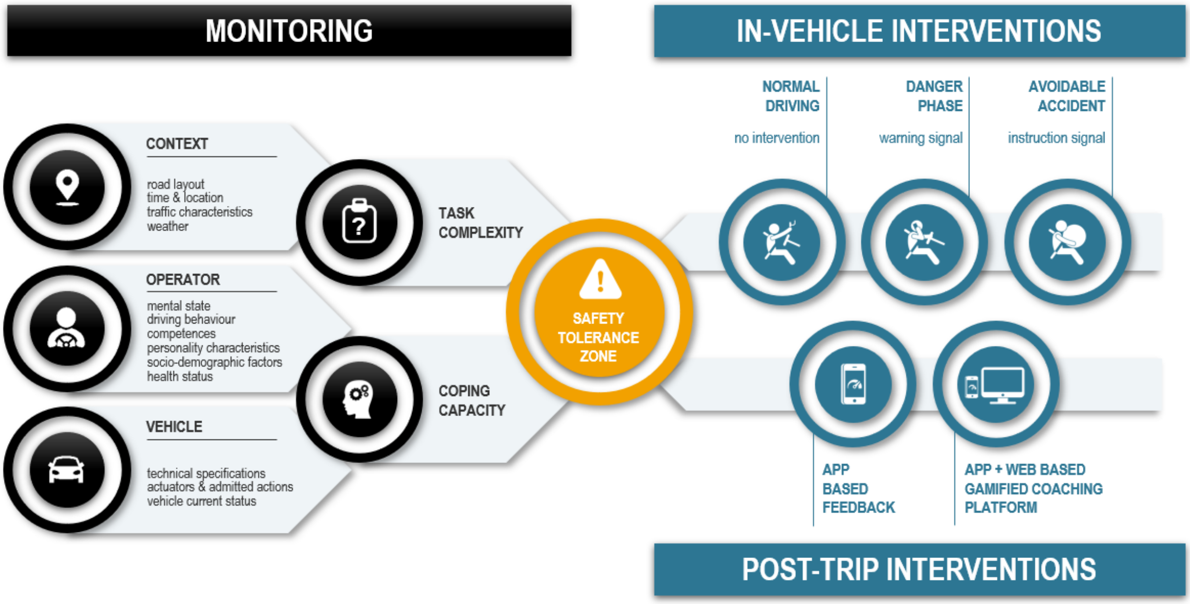



*Figure 8: Conceptual framework of the i-DREAMS platform.*

The following sections will elaborate the Safety Tolerance Zone and the concepts that underlie it.

## 3.1 Theoretical considerations

The STZ is an abstract entity, informed by established theory (see Chapter 2). The term 'Safety Tolerance Zone', although abstract in nature, refers to a real phenomenon, i.e. self-regulated control over transportation vehicles by (technology assisted) human operators in the context of crash avoidance.

The human operator does not however act in isolation. They are an integral part of the transport system which is made up of a complex interaction of operators, vehicles, infrastructure, other environmental factors and the rules and regulations that govern them. Multiple factors can contribute to a crash and relate to any part of the transport system and the interaction between the elements in that system. Therefore, crash avoidance methodologies need to consider both factors relating to the operator and the wider system.

According to Fuller (2005; 2011), safety within the driving task can be explained by a process whereby the operator's capability is matched with task demand. To expand, if the task demand is greater than driver capability then safety is decreased and the crash risk increased (see section 2.1.2 for a more detailed explanation). In this situation, to reduce this risk, the driver capability has to increase (e.g., driver stops performing a secondary task like texting or eating) or the task demand has to decrease (e.g., reduced speed, road/track curvature decreases).

However, the operator is not a passive actor in the system. Individuals tend to overestimate their own abilities (Alicke, 2005), including driving (Roy & Liersch, 2013). More specifically, vehicle operators are believed to compare perceived task demand and coping capacity to evaluate whether they are in balance or not. This judgement is referred to as perceived task difficulty or load. The operator's judgment about whether their capability is matched to driving task demands will influence their behavioural response. The operator has to recognise or perceive that risk is increasing and interpret that they need to act as well as perform successfully corrective action to have an influence themselves on crash risk (cf Van Elslande et al., 2008, and section 2.3.2). Fuller (2005; 2011) observed that human operators are inclined to change vehicle control if task difficulty is either too low (a situation typically experienced as boring) or too high (a situation typically experienced as threatening or dangerous). As a simple example, in a rural roadway environment that involves few other road users, drivers may increase their speed to increase task load and reduce boredom. Similarly, drivers that combine a secondary task with the primary driving task, e.g., eating or texting, may reduce their speed to reduce task load. Such task adjustments made by the operator are not always based on conscious decisions, rather, they are often made in an automatic manner in response to increased affective arousal that accompanies the imbalance between task demand and coping capacity. Although these operator adjustments appear to be negative, they can also refer to balance adjustments that are necessary to perform tasks efficiently and safely. This is also known as risk compensation.

It can therefore be asserted that the phenomenon referred to by the term 'Safety Tolerance Zone' has its roots in two different dimensions of reality. On the one hand, the STZ concept is rooted in the objectively observed state-of-the-world, of which the vehicle operator is an integral part. On the other hand, the STZ concept is always rooted in the vehicle operator's experience of the objective state-of-the-world as well – that is the driver will make driving decisions based on their motivations and their own recognition and interpretation of risk. Fuller (2011) describes this as risk allostasis where the driver has a target level of risk that they are comfortable with and they adapt their driving behaviour accordingly. This target level does not have to remain the same overtime, rather it will change depending on the driver's motivations and risk acceptance at that particular time.

Two key features make the STZ concept and the *i*-DREAMS platform unique. First an integrated approach is taken whereby monitoring the status of objective state-of-the-world will be based on a combination of measures monitoring the environmental context, driver and vehicle as a whole system, rather than limiting the focus on any one area in isolation. Second, the STZ theory takes into account how vehicle operators experience and react to this objective reality, although this might be difficult to operationalise within the *i*-DREAMS platform.

## 3.2 Safety Tolerance Zone: Formal working definition

As mentioned in the section above, the term STZ refers to the real-world phenomenon of (technology assisted) human operators self-regulating control over transportation vehicles in the context of crash avoidance. Of key importance to *i*-DREAMS is the point at which self-regulated control can be considered as '**safe**'. Though this safety concern is most prominent in situations where crash risk starts to develop or has further developed into a potentially imminent threat, one of the key-objectives of the *i*-DREAMS platform is to keep vehicle operators as much as possible in a state of ‘normal driving’, with the lowest possible risk of a crash scenario developing.

The formal working definition for the STZ is:

**“the time/distance available [for vehicle operators] to implement corrective actions safely [in the potential course towards a crash]”.**

In its full complexity, the STZ is a ‘multi-phased’ construct, consisting of three different subzones, i.e. normal driving, danger phase, avoidable crash phase. Metaphorically speaking, the STZ represents a kind of window in the time-space domain. This window is opened from the moment that vehicle operators initiate movement, since movement implies coverage of a certain amount of space and time.

The following section will explain how, considering the objective risk (of crash occurrence) and the operator’s recognition and interpretation of this determines, the STZ is conceptualized. Depending on how the objective state-of-the world evolves, the possibility of a crash scenario developing will vary from ‘no potential for a crash scenario to start developing’, to ‘potential for a crash scenario to start developing’, or to ‘a crash scenario already started to develop’.

The following section will describe the three phases of the STZ concept used in *i*-DREAMS. This has implications for both the risk monitoring and the intervention module of the *i*-DREAMS platform.

***Normal driving***

The label ‘normal driving’ refers to the phase of the STZ where, based on current conditions in the objective state-of-the world, there is no indication that a collision scenario is likely to unfold at that time. Under conditions of normal driving, no real-time interventions are required. From a conceptual point of view, this implies that, for as long as a moment-to-moment registration of the current state-of-the-world does not detect the potential for a crash course to start developing, the STZ is conceptually to be understood as time-space window where the human operator’s self-regulated vehicle control can be qualified as ‘normal driving’.

***Danger phase***

The label ‘danger phase’ refers to the phase of the STZ where, based on current conditions in the objective state-of-the-world, the potential is detected for the start of a collision scenario. Within the *i*-DREAMS system the ‘danger phase’ subzone can only be initiated if 1. a change is detected between the current-state-of-the-world (the objective view of driver capability verses task demand, as measured by the *i*-DREAMS platform) and the state-of-the-world immediately preceding it, and, 2. that detected change in the state-of-the-world now indicates conditions which suggest that a crash may develop. In case such a change in the objective state-of-the-word takes place, the STZ changes its conceptual status from ‘normal driving’ to ‘danger phase’. In more detail, the latter means that the human operator’s self-regulated vehicle control has become less safe in a sense that the potential for a crash course to start developing, has been initiated. This may have been as a result of decreased driver capability or external conditions creating greater task demand or some combination of driver related and external factors.

In response to a transition from ‘normal driving’ to ‘danger phase’, the real-time intervention component of the *i*-DREAMS platform would issue **a warning signal**. Irrespective of the sensory modality of this warning signal, it is the timing that will ultimately determine its functionality. There are two options for when a signal should be triggered:

1. Reactive: If the warning signal is issued following the moment where the conceptual status of the STZ has changed, the signal is intended to reinstate a state-of-the-world where conditions qualify as ‘normal driving’. This would be an illustration of how the warning signal serves a reactive functionality. If the warning were successful, the STZ would change its conceptual status back to ‘normal driving’ because either the warning signal induced the appropriate corrective actions on the side of the vehicle operator, or because conditions outside the vehicle operator changed in such a way that the potential for a crash course to start developing, disappeared.
2. Proactive: An alternative approach would be to issue the warning signal prior to the moment when the conceptual status of the STZ changes from ‘normal driving’ into ‘danger phase’. In that case, the warning signal would serve a proactive function, not aimed at the reinstatement of the current state-of-the world from danger phase conditions back into normal driving conditions, but as a prompt for the continuation of the normal driving conditions. Such a proactive functionality however, would pose several additional challenges in terms of operationalization and technical implementation because it requires the monitoring module of *i*-DREAMS platform to predict the potential of such a future change of state and to do so continuously and in real-time.

If the warning signal is not able to induce the required corrective action, and the conditions outside the vehicle operator control do not change the potential for a crash course continues to develop. The conceptual status of the STZ would then further evolve into ‘avoidable crash phase’.

***Avoidable crash phase***

The label ‘avoidable crash phase’ refers to that particular subzone of the STZ where, based on current conditions in the objective state-of-the-world, a collision scenario is actually starting to develop, but the vehicle operator still has the potential to intervene and avoid a crash. If such a change in the objective state-of-the-world takes place, the STZ changes its conceptual status from ‘danger phase’ to ‘avoidable crash phase’. More specifically, this means that the human operator’s self-regulated vehicle control has become even less safe in the sense that the potential for a crash to happen has been initiated. Again, this may be influenced by external events within the road traffic system or a deterioration in the operators’ capability or a combination.

In response to a transition from ‘danger phase’ to ‘avoidable crash phase’, the real-time intervention component of the *i*-DREAMS platform would issue an instruction signal. As was the case for a warning signal, it is the timing and nature of the instruction signal that will ultimately determine its functionality; i.e., reactive vs. proactive. Also, in the case of a proactive instruction signal, additional challenges in terms of operationalization and technical implementation arise. It requires the monitoring module of *i*-DREAMS platform to predict the potential of such a future change of state and to do so continuously and in real-time under even stricter (i.e. shorter) time-space constraints (since an actual crash event has become a realistic option).

If the instruction signal is unable to induce the required corrective actions from the vehicle operator, and conditions outside the vehicle operator control do not improve the potential for a crash course to further develop, the conceptual status of the STZ might further evolve into ‘unavoidable crash phase’. The latter, however, falls outside the scope of the *i*-DREAMS platform.

In summary, the conceptual status of the STZ dynamically changes depending on how the objective state-of-the-world evolves, and the status of the vehicle operator included therein. Changes in the objective state-of-the-world are not only caused by the movements controlled by the vehicle operator, but by other phenomena outside of the vehicle operator’s control as well (e.g., movements controlled by other human operators, physical conditions of the road environment or the vehicle being operated, climatological circumstances, etc.).

## 3.3 Imbedding the STZ concept in the *i*-DREAMS platform: From theory to practice

The theoretical basis of the concept of the Safety Tolerance Zone has some practical implications for its integration within the *i*-DREAMS platform. The first step is to consider how to measure the objective world view and to use such measurements to provide information on the status of the STZ. Figure 1: Conceptual framework of the i-DREAMS platform.Figure 1 provides an illustration of the decision-making process that will evaluate the phase of the STZ and trigger the appropriate intervention.

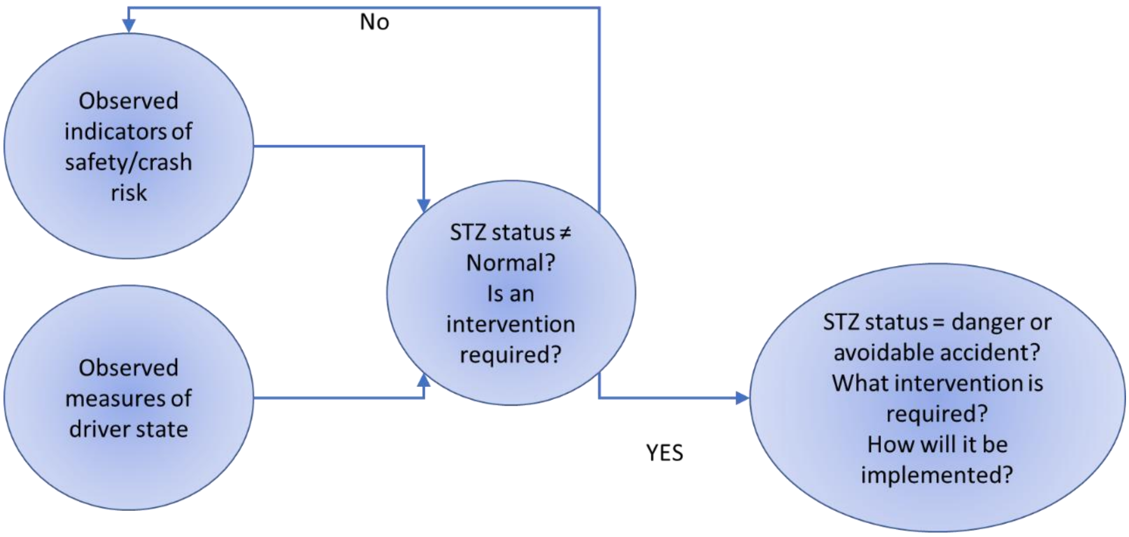



*Figure 9: Example of STZ decision-making process for real-time triggering of interventions*

The premise of Figure 9, is that it is necessary to capture indicators of safety/crash risk and driver state to determine the STZ status at any point in time. Multiple context, operator and vehicle variables will be necessary for this. Some of these could be referred to as surrogate safety indicators which are discussed below.

### 3.3.1 Surrogate safety indicators

It is proposed that a change in the conceptual status, in terms of crash risk, of the STZ will be triggered by the exceedance of a certain threshold values in surrogate safety indicators. Such exceedances indicate that a critical point in the time-space domain has been reached where the objective state-of-the-world has changed from ‘normal driving’ to ‘danger phase’ or to ‘avoidable crash phase’. In the context of crash avoidance (which is the key-objective of the *i*-DREAMS project), commonly used surrogate safety indicators are typically situated in the time-space domain (e.g., time to collision, headway distance, lane position, etc.), or indicators of driver behavioural response to the environment (e.g., longitudinal & lateral g-forces as a result of steering or braking manoeuvres). Therefore, these are considered as suitable candidate-indicators to be drawn from the objective dimension of reality to detect changes in the conceptual status of the STZ. Changes to safety indicators take place continuously, i.e. as an uninterrupted sequence of discrete time-space units. The extent of those time-space units varies depending on how the state-of-the-world evolves. This implies that sometimes the conceptual status of the STZ is rather ephemeral while in other cases, it is more stable.

Surrogate safety indicators will also be necessary to make judgements about driver capability. For example fatigue cannot be measured directly, instead an indirect measure has to be taken for example heartrate or blink duration.

### 3.3.2 Considering the operator's impact on the Safety Tolerance Zone

As previously discussed, the operators' perception of risk and their interpretation of that risk influences their behaviour and therefore can also influence the STZ status and the likelihood of the STZ changing from 'normal driving' to 'danger phase' or 'avoidable crash'. If the monitoring module of the *i*-DREAMS platform can capture information about the operator's evaluation of a situation, as well as the objective world view, it would be useful for two reasons. First, it could allow the timing of warnings and instruction signals to be tailored to the individual. For example, if warnings or instruction signals are issued too often or too soon from the perspective of the vehicle operator, then they are more likely to be ignored. If individual differences could be considered by the *i*-DREAMS platform then the effectiveness (i.e. acceptability) of warning and instruction signals issued will increase. The second reason is that it could facilitate the process of developing proactive warnings and interventions. If something about the operators' perceived risk of the situation is known, then it could be used to predict behaviour and whether the status of the STZ is likely to change imminently. For example, if the monitoring module can infer that the vehicle operator has not recognised an increase in crash risk, even though objective levels of task complexity and coping capacity indicate otherwise, then this could indicate an imminent change in the way they currently control the vehicle (e.g., starting to shorten their safety margins), and thus to transition soon from the status of 'normal driving' to 'danger phase' or even to 'avoidable crash' phase. It should be noted that the shortening of safety margins could also be caused by a lack of action; e.g., due to reduced alertness or attention or by a deliberate act.

However, it should be recognised that a proactive warning given to an individual who is actively increasing his/her workload e.g., by increasing speed, may be unwanted and therefore be more likely to be ignored. In addition, the primary aim of the *i*-DREAMS platform is to improve safety, so any altering of the timing of warnings would have to be done within a margin that was acceptable from a safety perspective. In this latter case it may be more appropriate to address behaviour and warning acceptability via post-trip interventions.

In order to realise this in practice there is a need to overcome the challenge of identifying an accurate measure of operator experience without directly asking the driver.

### 3.3.3 Indicators of operator perception

Fuller (2005) as well as other researchers working on the application of Control Theories on driving behaviour (e.g. Horrey et al., 2015) propose that the operator's assessment of the (in)balance between task demand and coping capacity is expressed in the form of affective arousal. If perceived task difficulty is too high or low compared to what is personally considered as an acceptable level, this will be expressed as an affective arousal state. A situation typically experienced as boring will result in low levels of affective arousal while a situation typically experienced as threatening or dangerous will result in high levels of affective arousal.

Real-time direct observation of affective arousal is possible by means of sensors monitoring physiological indicators (e.g., galvanic skin conductance, heart rate, heart rate variability, P-300 event related potential (an EEG-measure), muscle tension, eye blinking, respiration rhythm) or endocrinological measures (e.g.,, secretion levels for epinephrine, norepinephrine, cortisol and blood-glucose concentration). Therefore, via registration of such measures, the *i*-DREAMS monitoring module could capture this affective arousal state. It is possible that this could be used as an indicator for the vehicle operator's assessment of task demand and coping capacity.

To incorporate such a measure in the *i*-DREAMS platform the predictive nature of arousal would have to be examined in detail and it would need to be established under what conditions arousal is an effective predictor of behaviour.

Another indicator that the operator's evaluation of the situation is insensitive to an objective evaluation would be if expected behaviour responses were not recorded. If the objective measures suggested that the STZ state had changed from normal to danger phase, but the operator did not take action or took an action that made the situation worse, then it could be concluded that the driver evaluation was misaligned with the objective measures. For example, if a vehicle was recorded as travelling too close the vehicle in front and the operator did not brake then the operator evaluation of the system could be said to be misaligned. This could be a result of a lapse e.g., reduced alertness, or due to a deliberate choice to maintain current or reduce safety margins. A combination of measures from the context, operator and vehicle would be needed to make such inferences.

A further predictor of operator behaviour is their risk-taking tendencies. Risk taking or sensation seeking can be seen as a trait; i.e., relatively stable overtime (Goldenbeld & van Schagen, 2016). It can be assessed via a standardised questionnaire (e.g., Sensation-Seeking Scale - SSS-V, Zuckerman, 2007) and then produce some type of correction factor that could be incorporated in the decision-making process of the *i*-DREAMS platform. The premise being that individuals who are more likely to take risks are likely to drive with smaller safety margins (Brackstone & McDonald, 2007; Jonah, 1997) and more likely to interpret a warning or instruction intervention as premature.

Driver behaviour measures could also be used to identify aspects of driving style; e.g., the timing and force of braking/acceleration. An option would be to seek to profile drivers based on the relevant objective measurements and to assess whether this could be used as a predictor for behaviour.

It will be necessary for the *i*-DREAMS project to explore the validity of such indicators and the feasibility of incorporating them in the *i*-DREAMS platform.

## 3.4 Summary

The Safety Tolerance Zone (STZ) is a theoretical concept that provides guidance for the algorithm development that determines the functioning of the *i*-DREAMS platform. Simply described it is the zone where the demands of the driving task (task complexity) are balanced with the ability of the driver to cope with them (coping capacity). The STZ is made up of three phases. The 'Normal Driving' phase is where the drivers coping capacity comfortably meets or exceeds the task demands. If the coping capacity deteriorates or the task complexity increases, and the driver is operating on the edge of his/her capacity the risk of a crash increases and the driver enters the 'Danger Phase'. The third phase is the 'Avoidable Crash Phase' where the task demands outweigh the coping capacity and a crash situation unfolds, but there is still time for the driver to take action to avoid the crash. The point at which the driver enters an 'unavoidable crash' phase is outside of the STZ as at this point it is not possible to assist the driver to avoid the crash.

The underlying construct behind the STZ is the self-regulated control that the human operator has of vehicles within the context of crash avoidance. Embedded in this is the idea that there are two ways of interpreting the driving status within the STZ. The first is the objective observation of the context, operator and vehicle that allows an objective judgement about whether the demand of the driving task is being matched by the capability of the operator (driver). The second is the operator's own interpretation (conscious or unconscious) about whether their capability matches the task demand which will influence their behaviour. Operators may not take corrective action if they do not recognise and interpret the risk of a crash increasing at the same time as an objective measurement suggests that action is necessary.

The phase of the STZ also influences the type of real-time intervention that is necessary. Within the 'Normal Driving' phase there is no need for an intervention. Once the 'Danger Phase' is entered a warning will be given but if the situation deteriorates further, then an instruction will be used. However, it must be considered that these warnings/instructions may be ignored if the driver does not recognise that there is an increased risk. This presents a range of potential approaches for the *i*-DREAMS platform:

- To use objective 'world view' measures only to trigger an intervention but use post-trip intervention to influence driver risk perception and behaviour.
- To take into account driver recognition and interpretation of risk when triggering an intervention
- A combination of the above

# 4 STZ and existing driving theories

The *i*-DREAMS framework and the Safety Tolerance Zone concept was not generated in isolation. The main influencing theories were Fuller's Task Capacity Interface (TCI) model (Fuller, 2000) and Horrey's Driver Calibration Framework (DCF) (Horrey et al., 2015) – both of which can be categorised as control theories. This chapter will first elaborate how the TCI and the DCF underpins the Safety Tolerance Zone and then more briefly discuss how the STZ relates to the other theory categories (Driving Risk, Crash Models, Computational models) that were discussed in Chapter 2.

## 4.1 STZ and Control Theories

The *i*-DREAMS project hinges upon the TCI Model (Fuller, 2005; 2011). Central in this model is the aspect of calibration, which stands for the idea that road users self-regulate their behavior in function of personal estimations of the (im)balance between imposed task demand and available capability or coping capacity, resulting into a certain level of task difficulty. Both task demand and available coping capacity are multi-dimensional concepts dependent upon a multitude of (endogenous and exogenous) variables. The personally estimated critical safety tolerance zone (i.e. the time/distance available to implement corrective actions safely) often does not correspond to objective safety margins. Also, what is acceptable as a safety tolerance zone, can be subjective with differences not only between individuals but also within the same individual (across different situations and time). These phenomena together mayundermine the effectiveness of self-regulative actions, resulting in an increased crash risk. According to experts, the time window used for interpretation is important for a deeper understanding of frameworks such as the TCI Model. As Horrey et al. (2015) explain, on the one hand, there is the situational perspective, considering the mechanisms contained by DCF to be operating constantly and in real-time while driving. On the other hand, the global perspective, considers these mechanisms to be operating within a larger time frame, namely, across the multitude of individual trips which together constitute a person's driving history. Furthermore, the global perspective relates the mechanisms contained by the DCF to factors that are more global and stable across time, such as age, experience, personality traits (e.g., sensation seeking, impulsivity), etc.

Both the TCI model and the DCF fit within the Safety Tolerance Zone (STZ) for two important reasons. First, the STZ phases relate to the balance of task demand and driver capability and that the operator may not display the least risky action or behavior while driving either because of a conscious or unconscious attempt to maintain a given level of risk (as perceived by the operator). Second, the STZ distinguishes between real-time factors influencing the calibration of demand and capability and more stable long-term factors. Objective coping capacity is dependent upon operator-related factors (i.e. mental state, lane position, safety-related attitudes & opinions, safety-related competences, personality, lifestyle, socio-demographic background, health status) and vehicle-related factors (i.e. technical specifications, technical status, actuators and admitted actions). Since some operator-related factors (e.g., mental state, lane position) and vehicle-related factors (e.g., technical status, actuators and admitted actions) can vary on a moment-to-moment basis, we need sensors able to register in real-time. For those operator-related factors (e.g., safety-related attitudes & competences, personality, lifestyle, socio-demographic background, health status) and vehicle-related factors (e.g., technical specifications) that are more stable over time, other assessment techniques (e.g., questionnaire surveys) are suitable.

The operator-related and vehicle-related characteristics that can vary on a moment-to-moment basis can be considered as 'proximal determinants' of objective coping capacity, or factors inducing moment-to-moment variations in the objective coping capacity. The operator- and vehicle-related factors that are more stable over time can be considered as 'distal determinants' of objective coping capacity, or factors inducing an effect on objective coping capacity that is more stable across time and that might be mediated by the proximal determinants. Typically, car assistance systems do not really consider such stable factors.

The other theories elaborated in the control theory section of Chapter 2, provide further insights. For example Michon's (1985) Hierarchical Control Model points out that driver behaviour has a number of cognitive influences, some of which apply to the journey as a whole (strategic e.g., purpose and route choice), and some relate to a particular event (manoeuvring – how the driver interacts with other environmental factors), and some to a particular action (control e.g., breaking). For *i*-DREAMS this provides a good indication of the kind of variables that should be considered when collecting Context, Operator and Vehicle data and that the data collection rate should be influenced by its position in the hierarchy; e.g., strategic data can be collected with a lower frequency than control related data. In addition, Pereira da Silva's (2014) work broadly complements the idea that there are different phases of a Safety Tolerance Zone. It points out that a low task demand may cause the workload to increase and therefore the overall task difficulty to increase, similar to the idea of driver calibration as described in Fuller (2011).

## 4.2 STZ and Motivational Theories

Driving risk theories relate to the idea of the subjective world view within the STZ. Both the Zero Risk Theory (Summala, 1988) and Risk Homeostasis Theory (Wilde, 1998) suggest that for drivers' safety concerns are not the only aspect and may not be the most important aspect that they take into account when deciding the appropriate safety margin when driving. For Summala, driving behaviour is influenced by motivation (e.g., want to get somewhere quickly), and adaption to perceived risk (i.e. effort to get rid of any negative feelings e.g., fear of loss of control), but the latter may be diminished in an experienced driver who has learned, for example, that they will not crash if they travel faster because of successful past journeys. For Wilde, drivers optimise risk by doing a cost-benefit calculation on their risky and safe behaviour options. What these theories suggest is both that subjective world view is an important aspect in driver behaviour and that a driver may be happy to drive within an objectively measured danger or avoidable crash phase of the safety tolerance zone. The dilemma this poses is that from a safety perspective, the situation is more risky and therefore an intervention is appropriate but that intervention may be unwelcomed and/or ignored by the driver.

## 4.3 STZ and Crash Causation Models

The crash causation methodologies described in Chapter 2 suggest that there is a timeline that leads up to a crash where the risk of a collision occurring increases. The idea that there are latent factors, e.g., levels of fatigue, that can exist within a system could be helpful in relation to the STZ. These factors may not directly lead to a crash, but they increase the risk in the system. Both methodologies also suggest that a critical event can occur that causes a situation in which action has to be taken to avoid a collision (Sharp End failure for DREAM and Rupture phase for HFF). The STZ phases do not directly align with either model but as the *i*-DREAMS system is designed to be preventative it could be seen as seeking to measure the transition between the HFF phases (Driving, rupture, emergency).The challenge is to pinpoint when the level of risk warrants an intervention and to provide that intervention in time to avoid a crash. In this sense, the *i*-DREAMS system will need to be predictive in nature.

## 4.4 STZ and Computational models

Computational models may themselves be based on other driving theories (control, risk etc). However, their importance to *i*-DREAMS is in how they can perhaps point the way to translate the theory of the STZ to a mathematical model that can reliably predict behaviour. Section 2.4 only provides a snapshot of such models and does not go into the mathematical detail – that will be the focus of work for the next stage in the *i*-DREAMS project. Instead the models give some indications of the things that could be considered in the next steps. For example, the I-DVE model takes the three components ‘driver’ (three profiles, speed, time headway), ‘environment’ (other vehicles, road type) and ‘vehicle’ (mass) into account which map onto the *i*-DREAMS operator, context, vehicle variables, respectively. The practical applications of this ACT-R driver model are twofold. It can serve systems that aim at recognizing and inferring driver’s intentions based on their action and it can facilitate the prediction of driver behaviour in a given situation. Hence, the relevance for realising the *i*-DREAMS platform can be argued. Also, the use of a cognitive architecture as a basic principle during the phase of mathematical modelling is not absolutely essential. Finally, Macadam (2003) provides a useful overview of factors which should be considered when modelling driver behaviour and discusses example applications. However, the publication is fairly old and updated information should be considered before it is applied in *i*-DREAMS.

# 5 Stakeholder survey

The Safety Tolerance Zone was not conceptualised with a particular transport mode in mind however the theory upon which it is based has a focus on road transport. The *i*-DREAMS platform will be trialled with four main transport modes, three of which are road based (Buses, Passenger Cars, Trucks) and the fourth 'Trains' are rail based and therefore operate in a very different environment. The possibly of including trams as trial vehicles is also being considered as these provide a halfway between the conditions of the road and rail. The next two chapters in this report aim to focus on the different transport modes and try and identify how the *i*-DREAMS platform can be applied and any mode related consideration. This chapter reports on a stakeholder survey that was conducted as part of the *i*-DREAMS stakeholder consultation activities and Chapter 6 defines the four modes, considers the mode specific aspects and provides more technical information relating to the implementation of the *i*-DREAMS platform.

## 5.1 Introduction

The stakeholder survey aimed to explore opinion of the main issues leading to incidents and crashes in certain transport modes, and how the *i*-DREAMS platform may best address these problems. Stakeholders from various transport modes (passenger cars, buses/coaches, trucks, trains and trams) were asked to provide information on the main crash types, the factors involved in causing these crashes, and how technology could help to reduce crashes and crash risk. The survey also aimed to gather opinion on barriers to successful implementation of the proposed *i*-DREAMS system, provide information on experience of technology both currently used within the various stakeholder operations, and what they would like to see implemented in the future.

The survey consisted of a series of questions, the majority of which had a list of pre-defined answer options. The questions and possible answers were developed by researchers at Loughborough University with experience in human factors, transport safety and driver state issues, and received approval by Loughborough University Ethics Committee. The survey included questions relevant to all transport modes (car, bus/coach, truck, train/tram). The final version of the survey was entered into Online Surveys for electronic distribution and completion (see Annex 1 for a copy of the survey). The survey was forwarded to relevant contacts by partners within the *i*-DREAMS project, was sent to two established mailing lists of transport professionals and was advertised through social media and on the *i*-DREAMS website. The link to the survey was live from 4$^{th}$ September 2019 to 2$^{nd}$ October 2019. For a more detailed description of the method, see D9.1 (Giorgiutti et. al., 2019).

## 5.2 Results

In total, the survey received 103 responses. This is a small sample size and therefore the results are not statistically significant and limited in their conclusions and implications. However, this was an opportunistic sample, and provides important information relating to stakeholder opinion.

In terms of the background of the stakeholders, the majority of respondents were academic or commercial researchers (37), and operators (20), with a small proportion of policy makers (8). 14 respondents selected 'other' as their field of work, including:

- Consultants (5)
- a Lawyer
- a University Lecturer

- a Data Analyst
- a Project Manager in public transport
- a Government Agent
- a Distributor
- a Purchaser
- a Regulator
- a Mobility and Road Safety Expert
- an Agent in an NGO for Transport Sustainability

Individuals were asked to complete the survey representing the views of the transport mode they felt they had the most experience in. Most responses were in relation to passenger cars (63), followed by bus/coach (25), trucks (10), trains (4) and trams (1). Considering this, the cross-mode comparison will focus on passenger cars, buses/coaches, and trucks, the results for trains and tram will be combined and summarised at the end of this chapter.

Although the survey received a reasonable response rate, when the questions are broken down and filtered, the results can decrease to smaller numbers, which is important to bear in mind. However, the responses provide valuable information relating to stakeholder opinions of crashes cause and prevention, and current and desired technology use.

The results will focus on comparisons across the different transport modes and the implications of the results for the *i*-DREAMS system. More general results per mode can be found in D9.1.

### 5.2.1 Collisions

Stakeholders were asked to select the types of collision which were the most important for their particular transport mode. Interestingly, this was different across the three modes, which can be seen in Table 1.

*Table 1: The most important type of collision per mode.*

| **Question** | **Cars (n=63)** | **Buses/coaches (n=25)** | **Trucks (n=10)** |
|---|---|---|---|
| **What type of collisions are most important?** | Collision with vulnerable road users (n=54) | Head on collision (n=14) | Rear end collision (n=7) |

*N.B. Answers to 'What type of collisions are most important (e.g., in most need of addressing) for your transportation mode?' – Q6*

Survey responders selected that the most important type of collision was collision with vulnerable road users for passenger cars, head on collisions for buses/coaches and rear end collisions for trucks. Reviewing the qualitative comments indicates that rear end collisions in trucks can be associated with incidents while manoeuvring backwards, for example while docking for loading/unloading purposes. The comments also mentioned that road crashes with trucks occur more rarely than with other motor vehicles. Head on collisions and collisions with other road users as selected by passenger car and bus/coach stakeholders have a severe risk of injury, whereas rear end collisions may have a higher frequency, but a lower risk of injury.

It is important to note that the question asked the experts to select the type of collision 'most important' in your transportation mode, with the definition of 'most important' being defined by the responder. Therefore, the collisions may be the ones that occur the most frequently, or they could be the ones that would be the most severe in terms of safety or risk.

### 5.2.2 Safety breaches and contributing issues

To aid in the development of the *i*-DREAMS system, stakeholders were asked to select the first, second and third most important safety breaches for their mode and highlight the main contributing issues, the results of which can be seen in Table 2.

*Table 2: The most important safety breaches per mode with contributing issues.*

| | **Cars (n=63)** | **Buses/coaches (n=25)** | **Trucks (n=10)** |
|---|---|---|---|
| **Most important safety breach** | Loss of control (n=19) | Loss of control (n=5)<br>Sudden braking (n=5) | Close following another vehicle (n=4) |
| ***Contributing issues*** | *Excessive speed* | *Loss of control = fatigue/sleepiness*<br><br>*Sudden braking = inattention /distraction* | *Inattention / distraction*<br>*Stress (time pressure)* |
| **Second most important safety breach** | Loss of control (n=9)<br><br>Close following another vehicle (n=9) | Loss of control (n=6) | Missed traffic signal, unintended lane departure, loss of control, close following another vehicle, failure to give way, junction overshoot, passing too close, illegal manoeuvre, avoiding objects on road, other (n=1) |
| ***Contributing issues*** | *Loss of control = excessive speed, lack of experience*<br><br>*Close following = stress (time pressure)* | *Inattention/ distraction*<br>*Adverse weather* | *Combined – inattention / distraction* |
| **Third most important safety breach** | Unintended lane departures (n=10) | Passenger behaviour (n=4) | Sudden braking (n=2) |
| ***Contributing issues*** | *Inattention/ distraction* | *Insufficient speed, work underload, inattention/ distraction, substance impairment, lack of experience, road geometry, traffic volume* | *Excessive speed, work overload, inattention/ distraction* |

*N.B.* Answers to 'Apart from collisions, please select what you think are the three most important safety breaches/incidents for your transportation mode?' – Q7, and 'Which issues contribute to the most important safety breach/ incident identified in question 7'? – Q8

The results suggest that there were some similarities across the different transportation modes in terms of the first, second and third most important safety breaches. The pre-defined response of Loss of control was selected as the most important safety breach by passenger cars and buses/coaches and was also the second most important safety breach for these transportation modes, alongside close following another vehicle for passenger cars.

Close following another vehicle was the most important safety mode for trucks. Sudden braking was also selected by buses/coaches and trucks as important safety breaches, which may be in relation to their size and stopping distance. Bus/coach stakeholders also selected passenger behaviour as an important safety breach, highlighting some of the differences between the modes in terms of safety, trucks (and in some instances passenger cars) not having to consider passenger safety.

In terms of contributing issues to the prioritised safety breaches, inattention/distraction was mentioned by all three modes for various safety breaches. Excessive speed was selected as contributing issues to loss of control for passenger cars sudden braking. Interesting both passenger cars and trucks mentioned stress (time pressure) as a contributing issue to the safety breach of close following another vehicle. Bus/coach stakeholders mentioned fatigue/sleepiness as a contributing issue loss of control. The results highlight that factors related to both driver state and driver performance contribute to important safety breaches.

In order to explore whether there were specific safety breaches that stood out as the most important to each mode, a composite variable was created from the responses for the questions relating to the first, second, and third most important safety breaches. For each selected option, the number of responses to the first most important safety breach were multiplied by three, the number of responses to the second most important safety breach were multiplied by two, and the number of responses to the third most important safety breach were multiplied by one. These figures were then complied to provide a ‘weighted response’ for each pre-defined safety breach option. For example, 8 respondents had selected ‘Failure to give way’ as the most important safety breach, 5 as the second most important and 7 respondents selected it as the third most important. The weighted response was therefore 41 (8x3+5x2+7x1). This was conducted for each safety breach per mode. Figure 10, Figure 11 and Figure 12 show the weighted results. Loss of control is the highest scoring safety breach for passenger cars and buses/coaches. Close following another vehicle is the second highest scoring safety breach for trucks, the second safety breach for passenger cars, and the third highest scoring safety breach for buses/coaches.

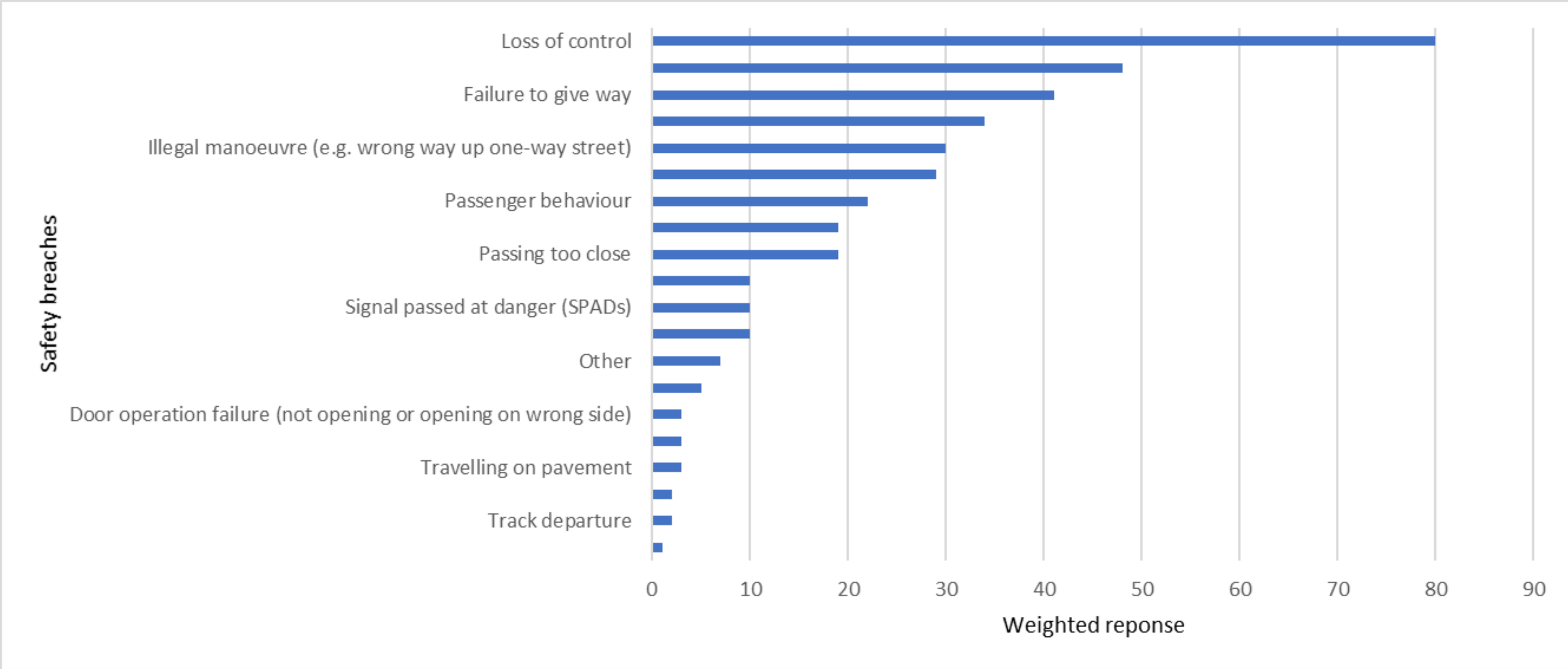



*Figure 10: Weighted results of the most important safety breach for passenger cars*

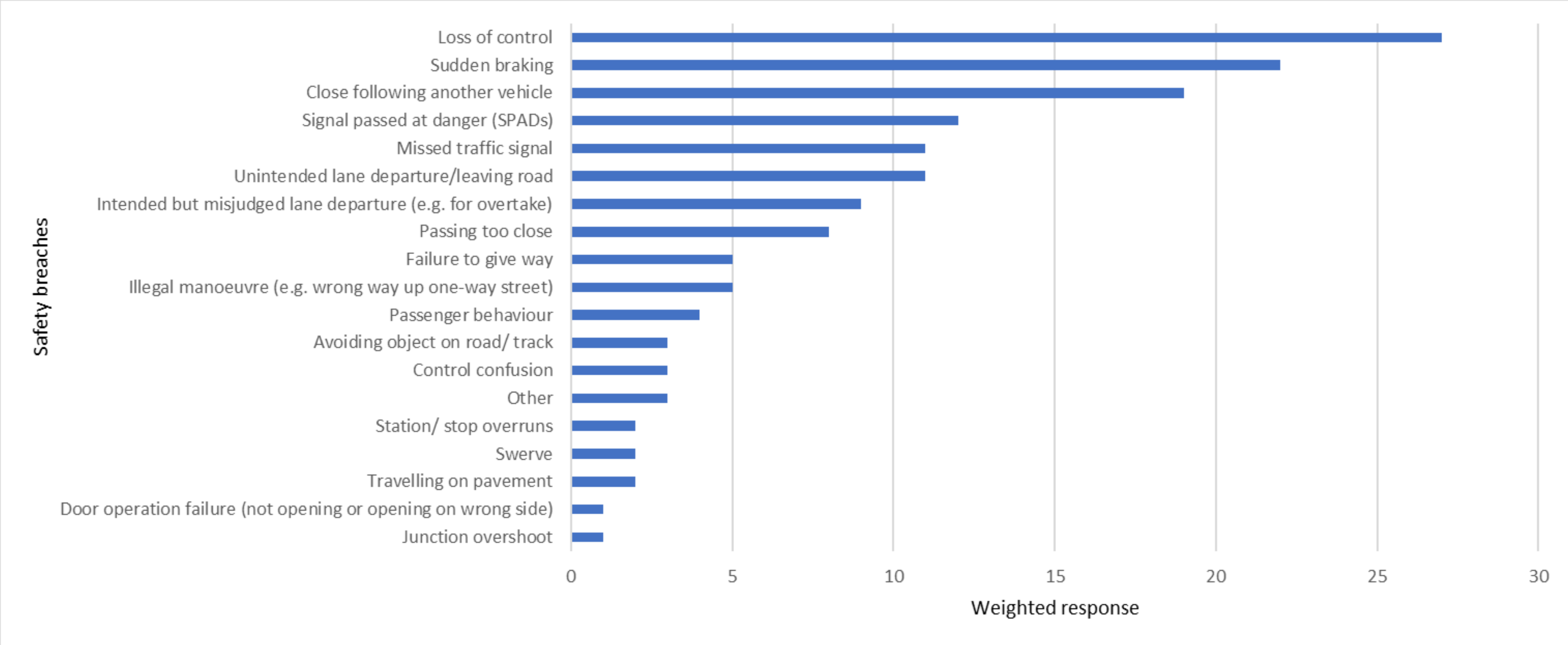



*Figure 11: Weighted results of the most important safety breach for buses/coaches*

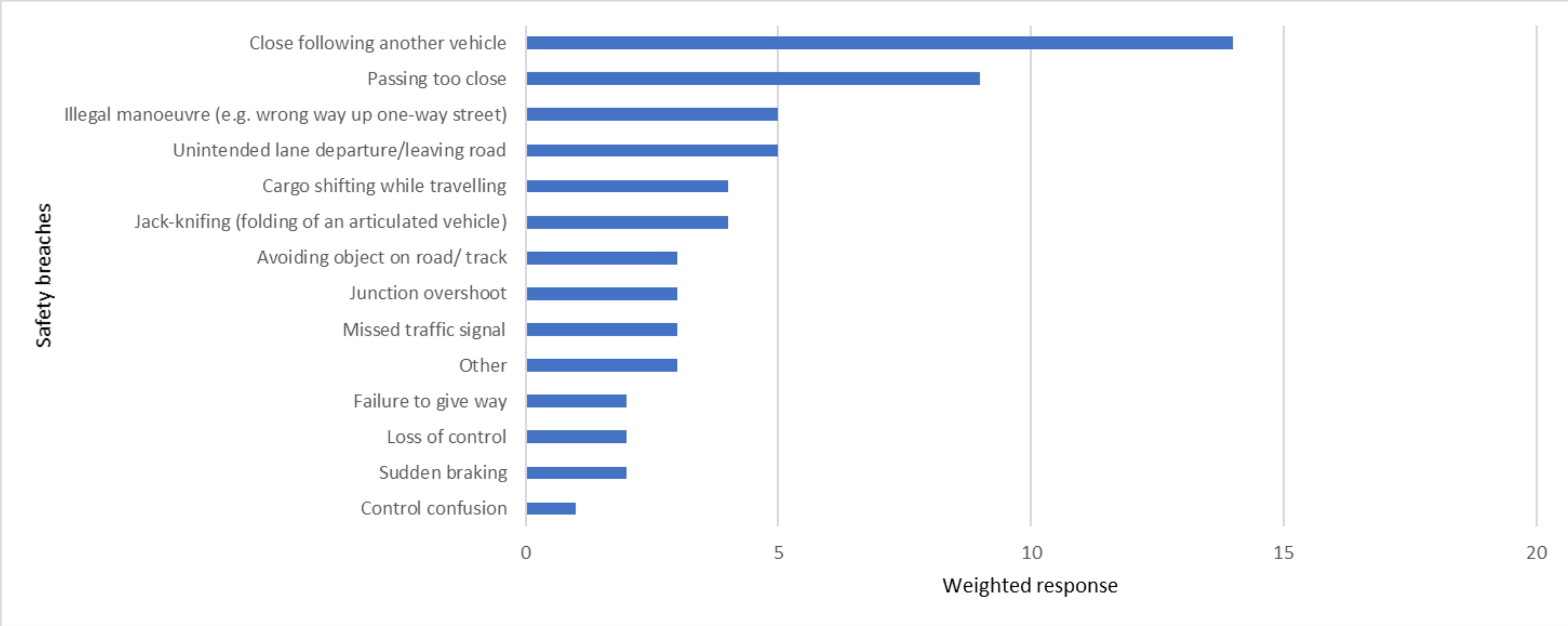



*Figure 12: Weighted results of the most important safety breach for passenger trucks.*

Stakeholders were also asked to suggest how they thought the *i*-DREAMS system could aid in the previously prioritised safety breaches. Overall, the suggestions were common throughout the three modes. Providing timely warnings was the most popular option for how the *i*-DREAMS system could aid with various safety breaches. Responses for all modes also stated manipulation of distractions (e.g., lowering the volume of music or provide auditory warnings), manipulation of vehicle motion, suggesting driver tips for a safer/more comfortable drive, and providing information on environmental and road geometry conditions.

### 5.2.3 Barriers and constraints for real time assistance

Stakeholders were asked to select what they believed would be the barriers and constraints for implementing real time assistance in relation to the *i*-DREAMS system. The options most frequently selected for each mode can be seen in Table 3. Survey respondents were able to select as many options as they felt were relevant to the question.

*Table 3: The main three barriers and constraints to real time assistance per mode.*

| **Question** | **Cars (n=63)** | **Buses/coaches (n=25)** | **Trucks (n=10)** |
|---|---|---|---|
| **Barriers and constraints for real time assistance** | Driver trust (n=36) | Driver engagement (n=17) | Driver engagement (n=6) |
| | Driver engagement (n=26) | Driver trust (n=12) | Driver trust (n=5) |
| | Personal refusal (n=24) | Driver distraction concerns (n=10) | Expense, equipment failure (n=4) |

*N.B. Answers to 'What are the largest barriers and constraints you see for driver assistance in real time?' – Q12*

Interestingly, the results are similar across the different modes. The results suggest that driver trust and driver engagement are the main two barriers across the three modes. For cars and buses, the third barrier/constraint is also driver related with personal refusal for passenger cars and driver distraction concerns for bus/coach. This is different for trucks, where expense and equipment failure are the third selected barrier/constraint. This suggests the importance of drivers in terms of engaging with the system in order for it to work, and that in most cases stakeholders felt that in terms of barriers, it could be drivers themselves rather than logistical or technical issues. Driver trust and driver engagement are important factors to be considered in terms of implementing a system which provides real time assistance. However, 'driver trust' could be interpreted in one of two ways. It could refer to the trust drivers have in the *i*-DREAMS system itself, or it may refer to drivers trust in how the data and results would be used in a professional sense, for example in terms of driver monitoring or crash investigation. These issues would also need to be taken into consideration.

### 5.2.4 Current and desired use of driver assistance technologies

One aim of the survey was to gather information on what technologies are currently being used to assist drivers in the various transport modes and their importance, and which technologies stakeholders may like to or not like to use (Q13). The results for each mode can be seen in Table 4.

Two aspects of question 13 were for stakeholders to select the technology they are currently using which they think is important, and the technology which they are not currently using but would like to use. Figure 13, Figure 14 and Figure 15 show a summary of the most frequently selected options for each of the sub questions per mode.

*Table 4: The main options for current important technology use and desired technology per mode.*

| **Question** | **Cars (n=63)** | **Buses/coaches (n=25)** | **Trucks (n=10)** |
|---|---|---|---|
| **What technology are you using and find important?** | Reversing camera/detector (n=41) | Dynamic stability control (18) | Dynamic stability control (n=9) |
| | Automatic emergency braking (n=38) | Reversing camera/detector (n=17) | Automatic emergency braking (n=8) |
| | Insufficient headway and lane deviation monitoring (n=37) | Speed violation waring and speed limiter (n=15) | Lane deviation monitoring, speed limiter (n=7) |
| **What technology would you like to use?** | Attention/distraction monitoring (n=41) | Attention/distraction monitoring (n=20) | Blind spot monitoring (n=7) |
| | Fatigue monitoring (n=39) | Fatigue monitoring (n=19) | Missed signal, fatigue, attention/ distraction monitoring, and pedestrian detection (n=6) |
| | Missed signal monitoring (n=30) | Blind spot monitoring (n=15) | |

*N.B. Answers to 'What technologies are currently being used to assist drivers in your transportation mode?' – Q13*

In terms of currently used technology which is important, there were some similar responses across the modes. Reversing cameras/detectors was one of the main three technologies selected by passenger cars and buses/coaches. Dynamic stability control was the first choice for buses/coaches and trucks, and these modes also both mentioned a speed limiter. Automatic emergency braking was the second choice technology for cars and trucks, and these modes also both mentioned lane deviation monitoring. The three most popular options for each mode also related to indicators that help with driving performance, for example lane position, speed, braking, reversing, rather than say state monitoring.

In relation to desirable technologies or technology that stakeholders are not currently using but would like to use, attention/distraction monitoring and fatigue monitoring were mentioned by all of the three modes and were the first and second choice for passenger cars and buses/coaches. This suggests a desire by stakeholders to be able to monitor aspects of driver state and corresponds to the contributing issues to the important safety breaches, as inattention/distraction was mentioned by all three modes. Other performance indicators were also selected, with blind spot monitoring being the most popular choice for trucks and the third most selected choice for buses/coaches, as well as missed signal monitoring the third most desirable technology for cars, and joint second for trucks. Pedestrian detection was also the joint second option for trucks. Overall, the results were similar across the three modes, and again corresponded to the contributing issues the stakeholders selected for the important safety breaches.

Stakeholders were also asked to record what additional technologies and future technology capabilities could contribute to safety within the specific transportation modes (Q14).

Increased automation was mentioned across all three transport modes. Fatigue/ distraction/vigilance monitoring was mentioned for passenger cars and trucks, which is in line with the results of Q13 and the technology stakeholders would like to use in the future. Alcolocks, platooning, driver feedback, infrastructure and warnings of other road users and road layout were also mentioned for passenger cars and buses/coaches. Stakeholders for trucks mentioned implementing manoeuvre sensors to avoid collisions while parking, which links to rear end collision being the most important type of collision for that mode. Similarly, buses/coaches mentioned front facing anti-collision sensors, which links to the most important type of collision for this mode as head on collisions. Stakeholders for passenger cars also mentioned implementing incentivisation for safer driving, which would be linked to engagement with post-trip interventions.

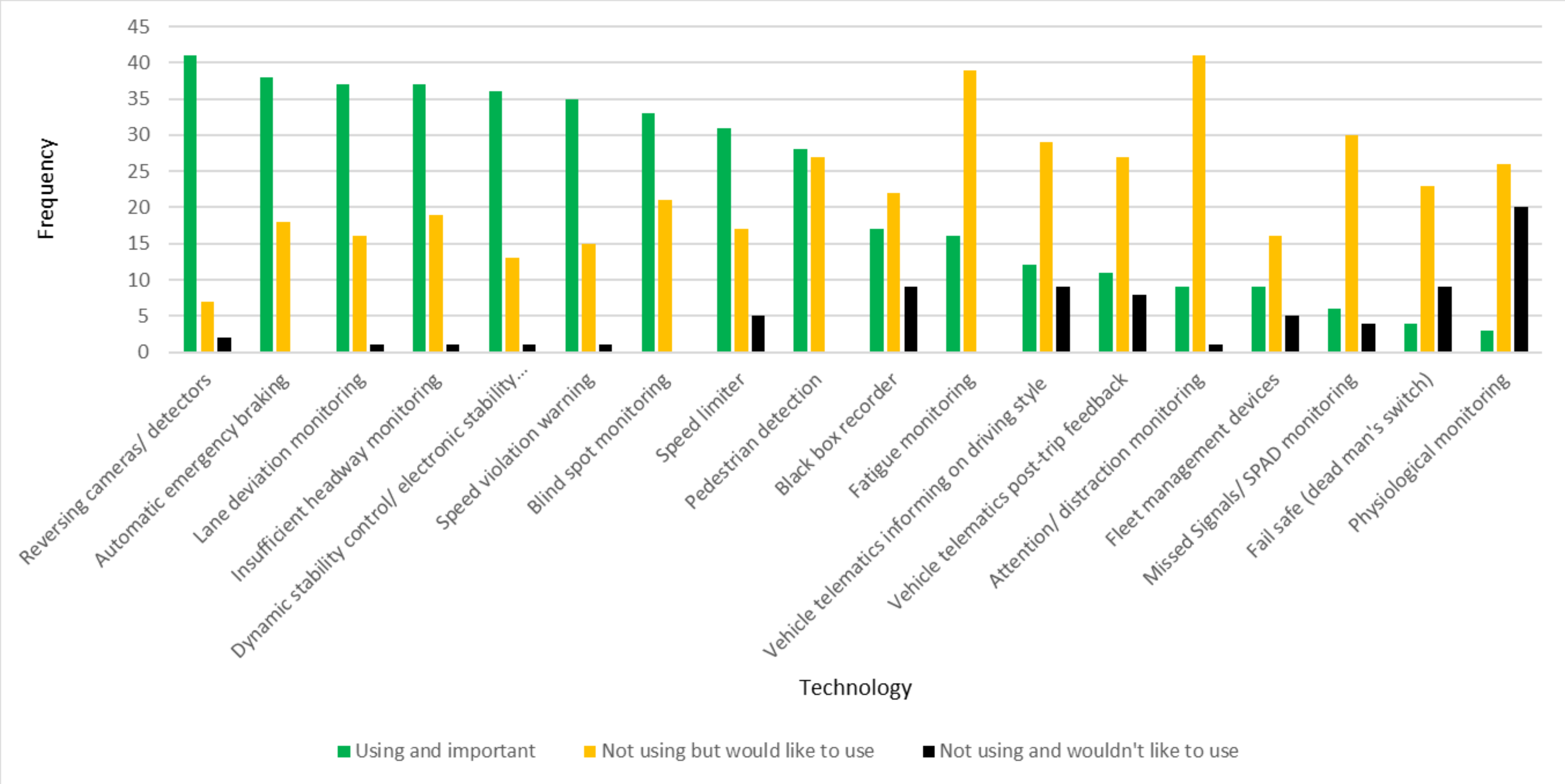



*Figure 13:* Technologies used to assist drivers for passenger cars

*N.B. Answers to 'What technologies are currently being used to assist drivers in your transportation mode?' – Q13*

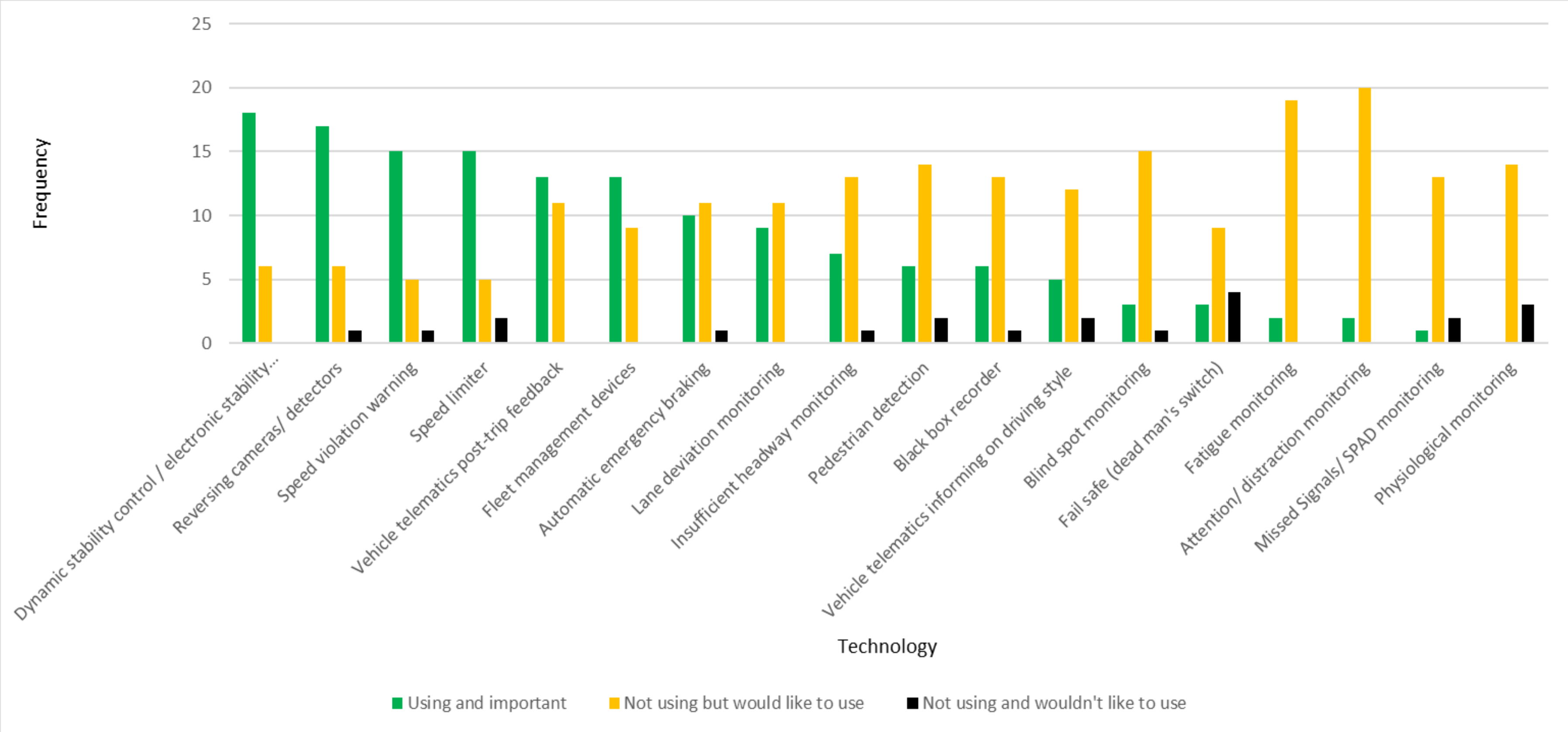



*Figure 14:* Technologies used to assist drivers for buses/coaches

*N.B. Answers to 'What technologies are currently being used to assist drivers in your transportation mode?' – Q13*

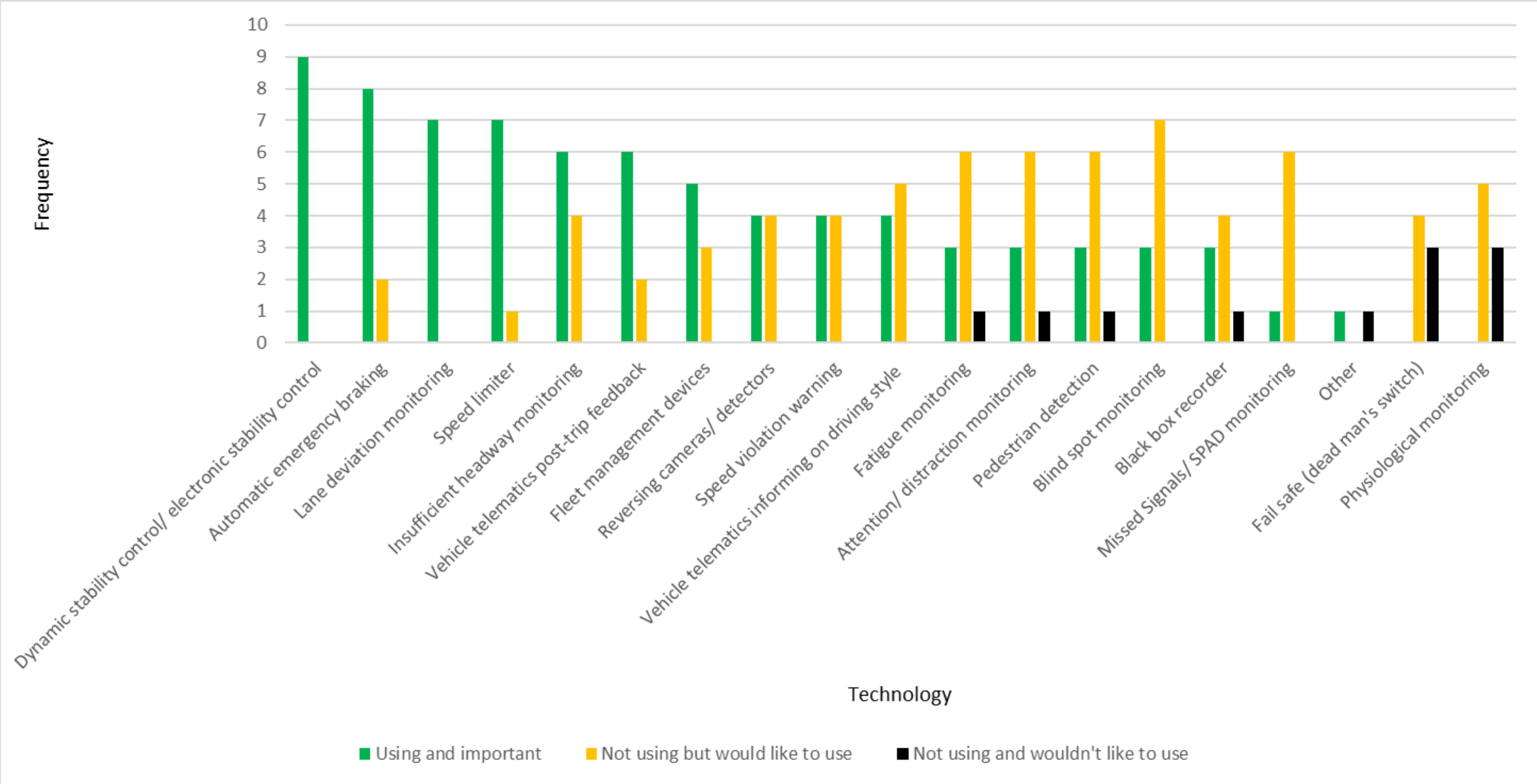



*Figure 15:* Technologies used to assist drivers for trucks

*N.B. Answers to 'What technologies are currently being used to assist drivers in your transportation mode?' – Q13*

### 5.2.5 Engagement with post-trip interventions

Stakeholders were asked to select what they thought would incentivise people to engage with post-trip interventions. The three most selected options per mode are displayed in Table 5: The main three options to incentivise engagement with post-trip interventions per mode.

*Table 5: The main three options to incentivise engagement with post-trip interventions per mode*

| Question | Cars (n=63) | Buses/coaches (n=25) | Trucks (n=10) |
|---|---|---|---|
| **What would incentivise people to engage with post-trip interventions?** | Rewards (n=44) | Rewards (n=19) | Rewards (n=8) |
| | Positive reinforcement (n=34) | Evidence based suggestions/feedback (n=15) | Positive reinforcement (n= 7) |
| | Evidence based suggestions/feedback (n=30) | Positive reinforcement (n=13) | Evidence based suggestions/feedback (n=4) |

*N.B. Answers to 'What do you think would incentivise people to engage with post-trip interventions in your mode?' – Q15. Note. Rewards e.g., monetary or performance incentives; positive reinforcement e.g., encouragement of good habits.*

Comparable to the barriers/constraints to real time assistance results, Table 5: The main three options to incentivise engagement with post-trip interventions per mode indicates that the stakeholders across the three modes selected similar options for what would incentivise people to engage with post-trip interventions. Rewards was the main choice for all the modes, with positive reinforcement and evidence based suggestions/feedback as the other two main options for all modes. This, along with the results from Q12 barriers and constraints, suggests that in terms of real time assistance and post-trip interventions, the implementation and associated issues could be similar for passenger cars, buses/coaches and trucks.

The qualitative comments also suggest similar results in terms of engagement with post trip interventions. When asked for personal experience of platforms monitoring driver behaviour and providing gamified feedback, either while driving or as a post trip intervention (Q16), stakeholders for passenger cars and buses mentioned systems and apps that could compare driver performance and encouraged competition to be safer between drivers. It was stated that drivers appeared to respond well to these apps and systems, however that it was important that they were implemented with an established safety culture, and that gamification would work better post-trip rather than while driving.

### 5.2.6 Summary of findings for Train and Tram

As the responses for train and tram were so few (n=4, n=1 respectively), they have been combined and will be descriptively summarised here.

In terms of collisions, rear end collisions were selected as the most important for these modes. However, this was explained in the comments that while head on collisions would be a greater risk, on railways trains run one behind each other and therefore rear end collisions are likely to be the greater risk if safety systems fail.

The safety breaches selected by trains/trams as the most important were different to passenger cars, buses/coaches and trucks, and were quite specific to train/tram operations.

The most important safety breach was SPADs, followed by station overruns and door operation failure. However, in terms of the contributing issues, inattention/distraction was the most popular issue, in line with results from the previous three modes. Work underload and overload, missed checks, missed communication and stress (time pressure) were also mentioned as contributing factors. In relation to how the *i*-DREAMS system could aid with the prioritised safety breaches, provide timely warnings was the most popular selection, which coincided with the other modes responses. Similar responses were also provided for the other suggestions, with manipulate distractions, manipulate vehicle motion, and suggesting driver tips for a safer/more comfortable drive also being chosen.

In terms of barriers and constraints for real-time driver assistance, similar to the other three modes, trains/trams stakeholders indicated that driver engagement would be the first barrier, followed by union involvement and finally expense. This again suggests the need for engagement before implementation. Again, similar to passenger cars, buses/coaches and trucks, the main incentives would be positive reinforcement, evidence based suggestions/feedback, and rewards and gamification. The qualitative comments also supported the notion of implementing or using the system within an established safety culture.

The results indicated that the most important technology that is currently being used within trains/trams is the failsafe (dead man's switch), followed by SPAD monitoring, automatic emergency braking, speed violation warnings and black box recording. Although there are some differences here compared to the other three modes, the most important technologies currently being used are again related to driver performance and driver monitoring. In relation to desired technology or technology that stakeholders would like to use, the responses for train/tram were again focuses on aspects of driver state, similar to the other three modes, with fatigue and attention/distraction monitoring being mentioned. This also coincides with the contributing issues to the important safety breaches that were identified. Vehicle telematics post trip feedback was also selected for trains/trams, which the previous modes did not highlight as the most desirable.

## 5.3 Implications for *i*-DREAMS

The results presented in this section provide valuable information relating to stakeholder opinion of crashes cause and prevention, and current and desired technology use. It is important to bear in mind that although the survey was completed by a range of stakeholders across the transportation industry for four separate modes, the response rate was small, with 103 responses in total. Therefore, the results are indicative and not statistically significant, which needs to be considered when discussing the conclusions and implications. However, the results of the survey are important and can be used to inform the design of the *i*-DREAMS system.

Overall, the results showed several similarities across the various transportation modes. Although there were very few responses for trains/trams, where there were differences in responses, they tended to be between the other three modes and the train/tram, indicating that potentially the train/tram operation is different. There were also differences between modes which were more likely to have passengers for example buses/coaches and trains/trams in terms of safety.

In general, the most important collisions selected for each mode were different, and this was also reflected in the additional technologies' stakeholders would like to see, which were in some cases linked to the individual modes most important collisions. In relation to the most important safety modes, loss of control, close following another vehicle, and sudden braking were mentioned across all the modes. Regardless of the safety breach, inattention/

distraction was considered to be an important contributing factor for all the modes. This corresponds with results indicating that additional or desirable future technologies should focus on measuring and monitoring driver states, such as attention/distraction and fatigue. There was also a consensus relating to how the *i*-DREAMS system could aid in terms of safety breaches, with provide timely warnings as the most popular suggestion.

In terms of barriers and constraints to real time assistance and incentives for post-trip engagement, there was generally a consensus amongst the stakeholders. The results suggested the importance of engaging drivers as part of the implementation process and using the system in an established safety culture. It was indicated that rewards, positive reinforcement and evidence-based suggestions and feedback would help to incentivise people to engage with post trip feedback. In terms of currently used important technology, the results tended to focus on driver performance indicators, whereas the future technologies focused more on measuring/monitoring aspects of driver state.

# 6 The *i*-DREAMS' trial modes

The *i*-DREAMS platform will be tested using four different transport modes: Buses, Cars, Trucks and Trains (plus potentially trams). This chapter will describe the modes and the features that are relevant to the *i*-DREAMS platform in terms of Context, Operator, and Vehicle. The challenges that are associated with each mode will also be indicated.

## 6.1 Buses

### 6.1.1 Generic Definition

Buses comprise a wide range of vehicles conceived for the road transport of passengers, and, eventually, their luggage. The word bus is broadly employed as a synonym of heavy-duty passengers' motor road vehicle (HDPV), where "motor vehicle" implies a vehicle driven by its own means and having at least four wheels.

From a formal standpoint, buses belong to category M, i.e. motor vehicles with at least four wheels designed and constructed for the carriage of passengers. These differ from *cars* by their ability to carry more than 8 passengers. The EU directive 2007/46/EC defines buses as vehicles with the ability to carry more than 8 passengers, in addition to the driver, and distinguishes two categories as function of its gross weight, M2 and M3, whereas the latter comprises all vehicles exceeding a gross mass (maximum laden) of 5000 kilograms.

Complementary to the main EU framework classification, motor vehicles of category M2 or M3 can be further classified (Directive 2001/85/EC) regarding further vehicle characteristics and specifications. Classes I, II and III define road vehicles of category M2 or M3 with a capacity exceeding 22 passengers in addition to the driver. Class I vehicles possess areas for standing passengers, to allow frequent passenger movement. On its turn, Class II comprises vehicles constructed principally for the carriage of seated passengers but allowing standing passengers in the gangway and/or in an area which does not exceed the space provided for two double seats. Finally, Class III vehicles are constructed exclusively for the carriage of seated passengers. For category M2 or M3 vehicles with a capacity up to 22 passengers, these fall into Class A if they are designed to carry standing passengers or Class B otherwise.

This classes can be further classified according to its physical structure (chassis and bodywork), to accommodate, floor height, number of decks and articulation.

- *Articulated vehicle* comprises the group of vehicles which consists of two (typical articulated bus) or more (e.g., BRT) rigid sections which articulate relative to one another. Each section intercommunicates so that passengers can move freely between them.
- *Double-deck vehicle* describes a vehicle where the spaces provided for passengers are arranged, at least in one part, in two superimposed levels. The upper deck only allows for seated passengers; hence all standing passengers must travel in the lower deck.
- Low-floor buses are vehicles of Class I, II or A in which at least 35 % of the area available for standing passengers is without steps and includes access to at least one service door.

From the commercial point of view, it is usual to further distinguish low-floor and low-entry buses. The latter typically respect the strict the definition (Directive 2001/85/EC) of low-floor buses providing a step-free area adjacent to at least one of the service doors, although it is not uncommon for this area to connect at least the two first doors, whereas low-floor buses are entirely free from steps and provide a flat surface across the whole standing area.

The different heavy-duty road vehicles for the transport of passengers (HDPV) can be categorised and grouped using numerous criteria (weight, size, floor, passenger capacity, etc; some more meaningful than others). Regardless, its operational profile and transport conditions provide a generally good criterion to identify and evaluate the different types of HDPV, and manufacturers and operators tend to make a clear distinction between “buses” and “coaches”. In such regard, for most, if not all, HDPV one could define Urban and Suburban (City), where most passengers travel in the standing position, and Interurban (Regional Intercity) “buses”, in which passengers travel mostly seated but standing is allowed, and long distance Intercity (Express Intercity) or Tourism “coaches”, where only seated passengers are allowed. The former is mainly associated with short journeys, within city limits or between large cities and its peripheral residential suburban/satellite cities/towns, and industrial clusters, i.e. Class I, II and A, whereas the latter operates long distance passengers transport typically linking two or more large population centres or for tourism purposes, i.e. Class B and III. Additionally, category M2 vehicles are commonly regarded as micro and minibuses, whereas M3 vehicles comprise midi, standard, 3-axle vehicles, articulated and double deck vehicles.

Contrary to trucks, for “buses”, a clear and objective definition of short and long distance (haul) or a distinction between suburban and interurban or between interurban and intercity is hard to establish, as these are culturally and geographically dependent conceptions, resulting from the organic growth of populated settlements.

In summary, buses are heavy duty motor road vehicles conceived for the road transport of passengers, where “motor vehicle” implies a power-driven, with at least four wheels. From a formal standpoint, buses belong to category M, i.e. motor vehicles with at least four wheels designed and constructed for the carriage of passengers and differ from *cars* by their ability to carry more than 8 passengers, in addition to the driver. On formal ground, depending on their gross weight, buses fit into two categories, M2 and M3, whereas the latter comprises all vehicles with a maximum laden mass exceeding 5 tonnes.

### 6.1.2 Description of potential *i*-DREAMS trial vehicles

*Table 6: A description of buses in the context of an i-DREAMS trial vehicle*

| Trial Option type | Vehicle | Context | Operator |
|---|---|---|---|
| Urban | Local/urban bus | Small towns (small presence) Moderately complex mixed traffic environment (easier access to the buses to perform changes to installation) | Professional driver<br>Frequently reasonably inexperienced drivers<br>Shift worker, but almost exclusively daytime activity<br>Few short and repetitive routes, provides for plenty of interaction with regular passengers and related distractions<br>Have to pass a medical examination to gain and retain licence.<br>Have extensive training programs and mandatory technical and legal training (Driver licence, mechanical aptitude) |
| | Urban bus | Dorm suburban areas, neighbouring Lisbon (indirect presence) Moderately complex mixed traffic environment | Professional driver<br>Shift worker, mostly daytime activity<br>Typically, experienced driver<br>Drivers tend to work on restricted sets of routes<br>Have to pass a medical examination to gain and retain licence.<br>Have extensive training programs and mandatory technical and legal training (Driver licence, CAM (mechanical aptitude)) |

| | | | |
|---|---|---|---|
| Mixed, mostly intercity and regional | Long distance/Express (large presence) | Mostly highway, high speed journeys<br>Large interaction with slower speed (truck) vehicles<br>Many overtaking operations<br>Tedious, extensive journeys | Professional driver<br>Experienced driver (many years of experience)<br>Shift worker<br>Daytime activity is prevalent but there are many early morning and late afternoon shifts that comprise large “night” (absent daylight) driving periods. There is also some night activity, typically long or international routes (in such cases drivers typically work pairs and drive alternated periods, so rest conditions are less than optimal). Have to pass a medical examination to gain and retain licence.<br>Have extensive training programs and mandatory technical and legal training (Driver licence, CAM (mechanical aptitude)) |
| | Tourism / “wet-rental” (large presence) | Mix between the above environments (probably interesting if we have very limited pilot) | Professional driver, typically top drivers<br>Experienced (many years of experience)<br><br>Shift worker, but tend to have a weekly or monthly work program<br>It is usual for multiple day tours, which means that drivers sleep away from home. For high-end tourism drivers will share the hotel with tourists 4* and 5* hotels, for lower end tourism they will sleep in alternative accommodation (but more comfortable than in a truck |

| | | | |
|---|---|---|---|
| | | | sleep cabin) Have to pass a medical examination to gain and retain licence.<br>Have extensive training programs and mandatory technical and legal training (Driver licence, CAM (mechanical aptitudes) TCC (special permit for children transport))<br>Mostly daytime activity, although some intercity connections and city tours can take place at night-time. |
| Mixed, mostly urban | Specialty transport [e.g.,: school bus, sightseeing, airport shuttle, factories]<br>(large presence) | Most vehicles and drivers are typically assigned also to other tasks. This type of service is commonly “squeezed” in larger/regular driving tasks to optimize driver’s working time. As such, there will be data from plenty of drivers but a reduced amount of data from each subject.<br>The one that are exclusively dedicated to this type of work tend to run much fewer mileage and therefore will provide few data. | Professional driver<br>Semi-Professional driver (sometime mechanics and former drivers perform this type of operations)<br>It is frequent for less experienced drivers and “seldom-driving” human resources to perform these driving routines on a regular basis and more seldom by experienced drivers<br>Mostly daytime activity, but there is also a significant amount of early morning and late afternoon/evening driving periods (school bus and factories)<br>Have to pass a medical examination to gain and retain licence.<br>Have extensive training programs and mandatory technical and legal training (Driver licence, CAM (mechanical aptitudes) TCC (special permit for children transport)) |

### 6.1.3 Considerations for trials

- Different vehicles (make, model and age) provide different type/amount of data (from Engine Control Units (ECU), tacho., etc.). There also might be concerns relating to GDPR.
- Drivers from local/urban bus services run by Barraqueiro Transportes are geographically dispersed and may have some difficulty accessing a centralized simulator.
- In the cases of indirect presence (service not explored directly by Barraqueiro Transportes but other companies within the group) it may be more complex to install a large number of devices / obtain the necessary authorizations. Also access to the drivers will also be harder.
- Drivers can sabotage and/or damage equipment (it has been observed in past experiences).

### 6.1.4 Considerations for the *i*-DREAMS System when fitted to Buses

Considering previous recommendations from local authorities, it is advisable that all non-native functions be integrated seamlessly within the driver's working station. However, integration may require a lengthy and expensive homologation procedure, particularly if done for a heterogeneous fleet. Furthermore, professional bus drivers tend to downplay alarms and warning from 3rd party sources and give more credence to OEM systems.

It is also important to evaluate insurance and OEM warranty issues that may arise if vehicle system malfunction takes place. For instance, Mercedes frequently advises its clients not to install 3rd party telematics or remote diagnosis systems not using the FMS connector, as it may void the vehicle warranty and limit in-motion systems functionality.

Heterogeneous fleets and systems usually make available distinct sets of data/variables and communication protocols and baud rates (e.g., SAE J1850 PWM/VPW, ISO 9141-2, ISO 14230PWP2000, ISO 15765 CAN).

Concerning data interfaces, on-board systems ordinarily connect either into the On Board Diagnostics (OBD-II/EOBD (physical connector - SAE J1962, data protocol - SAE J19379, HDV data protocol - SAE J1939), FMS interface or scan signals directly from the CAN-bus. The latter can be done by 'shunting' the wires or through induction, but in both cases warranty and reliability may arise. Using the OBD-II connectors can also give origin to some integration issues with some makes and models, which upon detecting a device connected to its on-board diagnosis bus, limits the in-motion diagnosis and dashboard functionalities.

On the other hand, FMS is a more recent standard interface designed specifically to access data from commercial goods and passenger vehicles for telematics. The original protocol was agreed on and conceived by a group of OEMs, namely Daimler AG, MAN AG, Scania, Volvo, DAF Trucks and IVECO, to facilitate 3rd party deployment of telematics solutions by providing data in accordance to SAE J1939 at a higher layer. The aim of this development is to provide 3rd parties an application layer that accesses the vehicle real-time data, thus avoiding the use of the on-board diagnosis connector and CAN-bus intercept connections. However, unlike the mandatory character of OBD-II, FMS interface is optional and thus is unavailable in many heavy-duty vehicles, especially older ones. Thereby it could be wiser to resort to a more universal/mandatory interface or risking to losing, partially, the universality/massification potential of the project outcome.

The use of different physical interfaces may lead to additional difficulties and costs regarding *i*-DREAMS' hardware development and integration, especially considering the broad modal scope of the project.

From the GDPR, ethics and Union perspective some disputes could be triggered. However, as long as the project complies with best practice recommendations and legal regulations, it is not expected that these seriously constrain the hardware deployment or the project's normal development.

## 6.2 Passenger Cars

### 6.2.1 Generic Definition

According to the EU commission guidelines (Council of the European Union & European Parliament, 2007) and the UNECE categorization (United Nations Economic and Social Council, 2005), passenger cars are defined as vehicles belonging to category M: "*Motor vehicles having at least four wheels and for the carriage of passengers"*. More specifically, and looking into more detail at the M vehicle category, passenger cars are all the vehicles included in the M1 sub-category as shown in Table 7:

*Table 7: Vehicle category description for passenger cars*

| • Category | • Vehicle Description |
|---|---|
| • M1 | • Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat, and having a maximum mass ("technically permissible maximum laden mass") not exceeding 3.5 tons |

Categories M2 and M3 describe buses and coaches and therefore are not included in the passenger car mode.

If Lights Good Vehicles (LGVs) or Light Commercial Vehicles (LCVs) are to be also taken into consideration within the generic passenger car mode, vehicles belonging to category N1 would also need to be considered. According to the EU Directive 2007/46/EC of 5 September 2007, LCV/LGVs are defined as "Vehicles designed and constructed for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes". Further specifications for N1 vehicles are given in the table below in Table 8:

*Table 8: Vehicle category descriptions for passenger cars, weight classes*

| Vehicles Category N1—Weight Classes | | |
|---|---|---|
| Class | Reference Mass, RW | |
| | Euro 1-2 | Euro 3+ |
| I | RW ≤ 1250 kg | RW ≤ 1305 kg |
| II | 1250 kg < RW ≤ 1700 kg | 1305 kg < RW ≤ 1760 kg |

| **Vehicles Category N1—Weight Classes** | | |
|---|---|---|
| **Class** | **Reference Mass, RW** | |
| | **Euro 1-2** | **Euro 3+** |
| III | 1700 kg < RW | 1760 kg < RW |

### 6.2.2 Description of *i*-DREAMS trial vehicles: Passenger Cars

*Table 9: A description of passenger cars in the context of an i-DREAMS trial vehicle*

| Vehicle | Context | Operator |
|---|---|---|
| Typical cars and Light Good Vehicles (LGVs) | Urban/sub-urban/ rural and built-in environments. Mixed traffic, Highways, Urban expressways, Intersections, Shared spaces within the area of operations | Private drivers |

### 6.2.3 Considerations for trials

- Technology level within vehicles (e.g braking, lane assistance)
- Damage inflicted by drivers/passengers (insurance & liability considerations
- Inclusion of LGVs/mini-buses?
- Data collection among countries – prevalence of new/old cars in one country affecting the amount of data collected from their CAN

### 6.2.4 Considerations for the *i*-DREAMS System when fitted to passenger cars

There needs to be a standardisation of vehicle models and types included in the trial studies among the different trial partners. For example, the consideration of LGVs or of vehicles manufactured after a specific year should be explicitly defined before the experiments begin. This will lead to better consistency among the data collected and the obtained results. Furthermore, liability, insurance and GDPR agreements need to be taken into account before fitting the equipment on the participants' vehicles. A challenge that might arise is the "common ground" between specifications of vehicles (e.g., in Germany, Greece and the UK), as well as the difference between insurance or liability plans.  In addition, wearable heart-rate monitors will be considered in cars as the steering wheel-based solution may require alterations to the upholstery of the car which would not be met favourably by car drivers.

## 6.3 Trucks

### 6.3.1 Generic Definition

As a starting point, we will refer to 'TRUCKS' as a mode in the *i*-DREAMS project by means of the label 'Heavy Goods Vehicle' (HGV).

To describe what the label HVG refers to more precisely, we adopt the formal definition as proposed by the European Road Safety Observatory in its official report on Traffic Safety Basic Facts 2018 – HGVs and Buses (ESRO, 2018: p. 2):

> "*Heavy Goods Vehicles (HGVs) are defined as goods vehicles of over 3,5 tons maximum permissible gross weight."*

In complement to this formal definition, a more detailed conceptualization for 'HGV' can be developed taking into account the following two specific aspects:

- the logistic area within which an HGV is being operated
- the vehicle combination type (for more detailed information, see the NFV-report by Aurell & Wadman, 2007).

As for 'logistic area', typically, the following two options can be found both in the academic literature as within the transport & logistics sector itself:

> **Long haul**, which can be defined as transport of goods *"farther than 200-300 kilometres from the driver's home terminal. Drivers operate a truck with a sleeper unit and in many instances, are gone for days at a time – and depending on the company, it can be two or three weeks."* (definition retrieved from http://www.csttdrivertraining.com/industry_info/long-haul-trucking/)

> **Short haul**, which can be defined as transport of goods *"operating within 200-300 kilometres of the driver's home terminal. Drivers operate a day cab unit and for the most part, are home every night. […] The majority of work connected with short haul work is driving a straight truck owing to the fact that these are more*

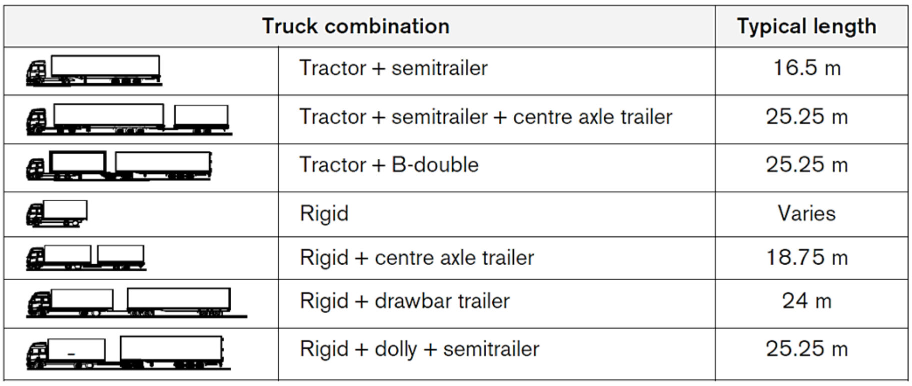
> *manoeuvrable in the tight spaces found in many cities. […] Operating a tractor-trailer unit or a straight truck, local work often consists of many pick-up and drop offs." (*definition retrieved from [http://www.csttdrivertraining.com/industry_info/long-haul-trucking/](http://www.csttdrivertraining.com/industry_info/long-haul-trucking/))

As for 'vehicle combination type, Aurell & Wadman (2007) base their overview of vehicle combinations for international traffic on Directive 96/53 EC. More in detail, they distinguish four 'regular' vehicle combinations. According to EU standards, these all have a GCW of 40t and a maximum permitted truck combination length of 18.5m for rigid tractors with trailers. The combinations mentioned are:

- Rigid truck
- Tractor and semitrailer (three different combinations are possible)
- Truck and centre-axle trailer
- Truck and full trailer

The European Accident Research & Safety Report 2013 released by Volvo Trucks further specifies that according to the European modular system, other so-called 'long' vehicle combinations are allowed in Europe. These long combinations have a maximum length of 25.25m and a maximum weight of 60 t. The report mentions the following seven truck vehicle combinations (Volvo Trucks 2013, p. 24 – see Figure 16 below for more details):

- Rigid truck
- Tractor and semitrailer
- Rigid truck and centre axle trailer
- Rigid truck and drawbar trailer
- Tractor and semitrailer + centre axle trailer
- Tractor and B-double
- Rigid truck and dolly + semitrailer



| Truck combination | | Typical length |
|---|---|---|
| | Tractor + semitrailer | 16.5 m |
| | Tractor + semitrailer + centre axle trailer | 25.25 m |
| | Tractor + B-double | 25.25 m |
| | Rigid | Varies |
| | Rigid + centre axle trailer | 18.75 m |
| | Rigid + drawbar trailer | 24 m |
| | Rigid + dolly + semitrailer | 25.25 m |

*Figure 16: Truck vehicle combinations in European countries and their respective lengths (source: Volvo, 2013)*

The Volvo report highlights that the most common truck combination in Europe is a tractor with one semitrailer with a typical total vehicle length of 16.5m (Volvo Trucks 2013, p. 25).

The same Volvo report further mentions that:

> "… there is generally no indication that long vehicle combinations are less safe than regular vehicle combinations, even though the dynamics of longer combinations are more complex." (Volvo Trucks 2013, p. 25).

> "… in most respects, the general pattern of accidents is similar for long vehicle combinations and regular vehicle combinations, albeit that there are some differences in accident distribution mostly attributable the different transport applications and traffic environments in which these combinations usually operate." (Volvo Trucks 2013, p. 25).

In summary, the term 'truck', refers to a Heavy Goods Vehicle (i.e. goods vehicles of over 3,5 tons maximum permissible gross weight) operating in both logistic areas of long haul and short haul transport under the more specific vehicle combination of a tractor with one semitrailer, a total vehicle length of 16.5m, and a maximum weight of 40t.

### 6.3.2 Description of *i*-DREAMS trial vehicles: Trucks

*Table 10: A description of trucks in the context of an i-DREAMS trial vehicle*

| Trial Option type | Vehicle | Context | Operator |
|---|---|---|---|
| Long haul | Drivers operate a truck with a sleeper unit – usually a tractor-trailer (articulated) style. | Transport farther than 200-300 kilometres from the driver's home terminal | Freight transport drivers.<br>Have to pass a medical examination to gain and retain licence.<br>Long haul drivers can be away from home for days at a time – and depending on the company, this can be a period of two or three weeks. |
| Short haul | The majority of work connected with short haul work is driving a straight (rigid) truck owing to the fact that these are more manoeuvrable in the tight spaces found in many cities. | Transport operating within 200-300 kilometres of the driver's home terminal.<br>Local work often consists of many pick-ups and drop offs. | Freight transport drivers.<br>Short haul drivers operate a day cab unit and for the most part, are home every night. |

### 6.3.3 Considerations for trials

- Different vehicles provide different type/amount of data (from ECU, tacho., etc.). It is not known beforehand which data variables will be available through the OBD-II connector.
- The physical access to the data connector (FMS or OBD-II) is different per model / type of vehicle, and existing on-board equipment for fleet management purposes may be present already on the data access port (Y-splitter cables needed in this case).
- Installation of equipment will have to be carried out by a certified installer and after normal working hours or during weekends since heavy vehicles are on the road during normal daytime hours
- Drivers from different transport companies are geographically dispersed and may have time- and/or location restrictions accessing a centralized simulator
- Drivers' could accidently or deliberately damage the equipment

### 6.3.4 Considerations for the *i*-DREAMS System when fitted to trucks

It is important to evaluate insurance and OEM warranty issues that may arise if vehicle system malfunction takes place. For instance, Mercedes frequently advises its clients not to install 3rd party telematics or remote diagnosis systems not using the FMS connector, as it may void the vehicle warranty in-motion systems functionality. However, recent legislation by the EU (REGULATION (EU) 2018/858 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending Regulations (EC) No 715/2007 and (EC) No 595/2009 and repealing Directive 2007/46/EC) seems to imply that the installation of OBD logging devices while a vehicle is in motion should not create problems. Article 61 of "CHAPTER XIV ACCESS TO VEHICLE OBD INFORMATION AND VEHICLE REPAIR AND MAINTENANCE INFORMATION" stipulates that '*Manufacturers shall provide to independent operators unrestricted, standardised and non-discriminatory access to vehicle OBD information, diagnostic and other equipment, tools including the complete references, and available downloads, of the applicable software and vehicle repair and maintenance information'*. In addition, paragraph 2.9 of Annex X of the same document states that '*For the purpose of vehicle OBD, diagnostics, repair and maintenance, the direct vehicle data stream shall be made available through the serial data port on the standardised data link connector specified in paragraph 6.5.1.4 of Appendix 1 of Annex 11 to UN Regulation No 83 and paragraph 4.7.3 of Annex 9B to UN Regulation No 49. When the vehicle is in motion, the data shall only be made available for read-only functions*'. This seems to imply that installation of an OBD-logger through the serial data port on the vehicle, when installed correctly by a certified person, to read data from the OBD-II port while the vehicle is in motion should not imply a warranty issue for the user, as this is against the statements included in the above legislation.

Heterogeneous fleets and systems usually make available distinct sets of data/variables and communication protocols and baud rates (SAE J1850 PWM/VPW, ISO 9141-2, ISO 14230PWP2000, ISO 15765 CAN), although most of them can be interpreted by the EM327 command protocol, which provides an interface between the lower-level protocols and a higher-level software layer.

Concerning data interfaces, on-board systems commonly connect into the OBD-II/EOBD (physical connector - SAE J1962, data protocol - SAE J19379, HDV data protocol - SAE J1939) or FMS interfaces or scan signals directly from the CAN-bus. The latter can be done by 'shunting' the wires or through induction, but in both cases warranty and reliability can become a problem. Using the OBD-II connectors can also give origin to some integration issues in some models, which upon detecting a device connected to its on-board diagnosis bus, limits the in-motion diagnosis and dashboard functionalities.

FMS is a more recent standard interface to access data from commercial goods and passenger vehicles. The original protocol was agreed and conceived by a group of OEMs, namely Daimler AG, MAN AG, Scania, Volvo, DAF Trucks and IVECO, to facilitate 3rd party deployment of telematics solutions by providing data in accordance to SAE J1939. The aim of this development is to provide 3rd parties to a software interface layer that accesses the vehicle, thus avoiding the use of the on-board diagnosis connector and CAN-bus connections. However, unlike the mandatory character of OBD-II, FMS interface is optional and thus is unavailable in most heavy-duty vehicles and thus the use of different physical interfaces may lead to additional difficulties regarding *i*-DREAMS' hardware development and integration, especially considering the broad modal scope of the project.

From the GDPR, ethics and Union perspective some disputes could be triggered. However as long as the project complies with legal recommendations and regulations, it is not expected that these seriously constrain the project's normal development.

## 6.4 Rail (Trains and Trams)

### 6.4.1 Generic Definition

For the purpose of this deliverable, trains and trams will be considered together as a transportation mode due to their similarities to each other and differences from the other modes (passenger cars/buses/trucks). However, in this section they will be defined separately. Information from the UK Office for Road and Rail (ORR) has been used within this section (https://orr.gov.uk/).

**Trains and Railways**

A train is a form of rail transport and defined as "a series of connected railway carriages or wagons moved by a locomotive or by integral motors"[2]. Trains generally run on railroad tracks and can convey freight or cargo, or passengers.

A train may be made up of either a single, or multiple, locomotive unit(s) to provide power to a number of unpowered vehicles. Alternatively, it may consist of several vehicles in a fixed formation with integrated power, therefore not needing a locomotive. Rail vehicles are commonly referred to as 'rolling stock'. Electric or diesel are commonly used to power trains. Diesel powered units do not require specialist infrastructure, however electric trains require electrified tracks or overhead lines to provide power.

A railway is a fixed guidance system which dictates the direction the train travels in. Railways and their construction are subject to strict regulation. A track may be 'licenced' for passenger trains, freight, or both.

**Trams and Tramways**

A tram is defined as a passenger vehicle which runs on rails laid on public roads and is powered by electricity conveyed through overhead cables[3]. Trams are usually lighter and shorter than trains, and generally operate at lower speeds, with more stop/start functions.

[2] https://www.lexico.com/en/definition/train
[3] https://www.lexico.com/en/definition/tram

They also have the additional hazard of usually operating in an environment with multiple road users, including other motorists, cyclists, and pedestrians.

The lines and networks which are operated by trams are called tramways. Tramways fall under the category of 'light rail', defined as "an urban rail transportation system that uses electric-powered rail cars along exclusive rights-of-way at ground level, on aerial structures, in tunnels, or occasionally in streets"[4](ORR 2019 – website). Light railways are governed by a less rigorous set of regulations than trains, with no specific safety legislation, however, some highway legislation applies.

[4] https://orr.gov.uk/about-orr/who-we-work-with/railway-networks/light-rail-and-tramways

### 6.4.2 Description of *i*-DREAMS trial vehicles: Rail

*Table 11: A description of trains and trams in the context of i-DREAMS trial vehicles*

| Trial Option type | Vehicle | Context | Operator |
|---|---|---|---|
| Trains | New fleet: Bombardier (UK) and Stadler (Swiss)<br><br>Diesel trains? Or mixed | Passenger trains within the areas between London and East Anglia.<br>Operates on rails in both urban and rural area, segregated from other modes (except at crossings);<br>The number of stops varies between routes. | Professional drivers, working for an operator. They will be trained to operate the specific train type and specific routes/lines.<br>Shift workers<br>Drivers are required to pass occupational and medical fitness examinations and medical fitness examinations have to take place every three year in the UK. |
| Trams | Powered by electricity | In areas of mixed traffic in south London. Part of the route is urban, and part is suburban.<br>Operate on rails, operating in dedicated areas and shared areas with other traffic. Multi-stop routes. | Professional drivers, working for an operator.<br>Shift workers |

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### 6.4.3 Considerations for trials

- On-rail trials are subject to safety case and union approval.
- For trains it is likely that trials will only be able to take place in a simulator. Train managers are more likely to take part.
- For trams 'on rail' trials are more likely.
- A driver monitoring system (Guardian) is already fitted to the trams.

### 6.4.4 Considerations for the *i*-DREAMS System when fitted to trains and trams

The most significant difference between road transport and trains/trams is that trains and trams run on rails. This means that the lateral movement of the vehicle is restricted by the infrastructure and not influenced by driver behaviour. This makes any measure of lateral position and lane keeping irrelevant. In the case of trains, headway measures would also be unhelpful as railway systems are designed so that a train should not encounter another train on the same line. What is more important for trains is knowing the status of signals and whether a 'signal passed at danger' (SPAD) incident has occurred. For trams, headway may be more relevant as other vehicles can cross the path of a tram and they interact with vulnerable road users such as pedestrian and cyclists.

The technology currently available in the project partnership to calculate heartrate (ECG) relies on a steering wheel design, therefore for trains and trams an alternative measure for ECG e.g., a wearable technology would need to be considered. Another difference related to technology is that an OBD devise is proposed to be used for road transport to measure data from the engine. If such data is necessary for trains/trams, then other options will need to be explored as access to the engine via an OBD will not be possible.

## 6.5 Cross-mode driver considerations

The focus of the previous mode specific sections has been on the vehicle itself and in relation to the fitting of technical equipment. Consideration also has to be given to the drivers (operators) of these vehicles. For the bus, truck and rail modes, the drivers will be professional and are likely to be employed or at least work on behalf of a company. Particularly for the bus and rail vehicles, multiple drivers are likely to drive the same vehicle and it will be necessary to identify these. This may be easier in the case of trains where most testing will be carried out within a simulator with the researchers present. For car drivers, if a wearable heart rate monitor is considered the best solution, then data may be lost if the individual forgets to wear e.g. the wrist band. Consideration will need to be give as to how the driver can be reminded of this to reduce data loss.

# 7 Practical considerations and next steps

There are two main purposes of this report. The first is outline the theoretical framework that relates to driver monitoring. This will include an overview of the theories that describe the driving task and a detailed theoretical description of the *i*-DREAMS' Safety Tolerance Zone (STZ) concept. The second purpose is to define the *i*-DREAMS transport modes and to indicate areas of difference between them that will affect the development of the monitoring and communication tools that will be developed by the project.

This report had two main objectives. The first was to outline the theoretical framework that relates to driver and context monitoring within the *i*-DREAMS platform, with a specific focus on the concept of the Safety Tolerance Zone (STZ). The second was to define the *i*-DREAMS transport modes and to indicate areas of difference between them that will affect the development of the monitoring and communication tools that will be developed by the project.

The concept of the STZ is rooted in control theory. Driving is a control task that is conducted in an unstable environment, which is created by the driver's movement in relation to a defined track and moving and stationary objects. Control theory assumes that control actions made by drivers depend on perceptual processes. To control their goal-directed behaviour, drivers make decisions in a negative feedback loop to keep resulting discrepancies from this comparison within acceptable limits. One well known control theory, Fuller's Task Capability Interface Model (TCI) (2005, 2011), states that driving is safe (low risk of crash) when the task difficulty is matched to the driver's capability. The STZ describes three conditions relating to this 'Normal Driving' where crash risk is low. 'Danger phase' where risk increases but a crash is not inevitable and 'Avoidable crash phase' where a crash will occur unless action is taken by the driver or the external situation changes. An important explanatory factor in driving behaviour is that the driver's risk perception guides their actions and there can be a mismatch between this 'subjective reality' and the 'objective reality' i.e. the actual likelihood of a crash. Subjective reality, however, is very difficult to measure in the real world.

The *i*-DREAMS trial modes encompass a range of vehicle types. There is a clear difference between road based (Bus, Truck, Car) and those that are rail based (Train, Tram). Buses and Trucks are the most similar and the major difference for cars is that the drivers are private individuals rather than professionals who may be employed by a company. The survey results also give indicative information that there are differences between the modes in terms of important safety breaches.

The next phases of the *i*-DREAMS project will need to focus on the translation of the concept of the Safety Tolerance Zone into the *i*-DREAMS platform. This will involve the selection of appropriate measuring equipment and technology, the creation of a mathematical model, algorithm development, and the evaluation of the most effective real time and post trip interventions. It is also important to take into account the differences between the *i*-DREAMS trial modes, to find a solution which is complimentary to all. The following sections will discuss these aspects further.

## 7.1 *i*-DREAMS platform

The *i*-DREAMS platform is still under development and as such will not be fully defined here. Neither is it the purpose of this document to give detailed lists of recorded variables. However, this section will give an overview of the types of variables that are being considered and some of the technologies/measurements that will be included in the *i*-DREAMS system. As previously discussed, the STZ calculations will make judgements about task demand versus driver capability. To do this Context, Operator and Vehicle variables such as those listed in Figure 17 will be considered. In the main, these will be used to calculate the objective world view. However, if the driver perceived view of task demand verses capability is to be considered, then indicators of arousal, risk taking, and driver behaviour/vehicle control need to be included.

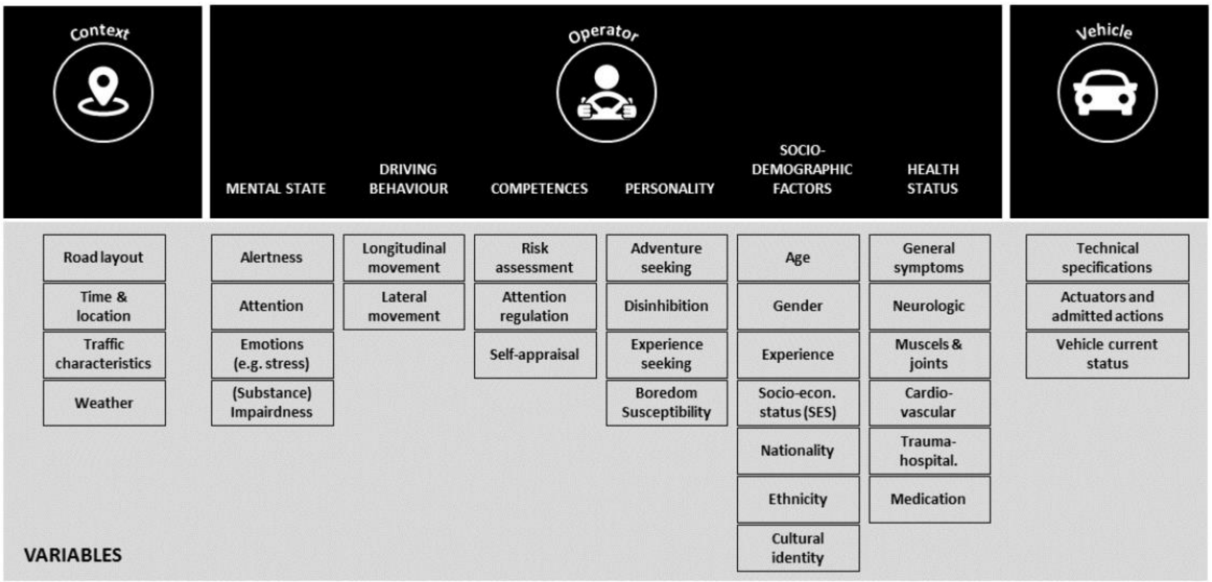


*Figure 17: Context, Operator and Vehicle variables considered by i-DREAMS*

An overview of some of the technology that will be used in the *i*-DREAMS platform is given in Figure 18. This should be viewed as a starting point and additional technology will be added if other functionality is required.

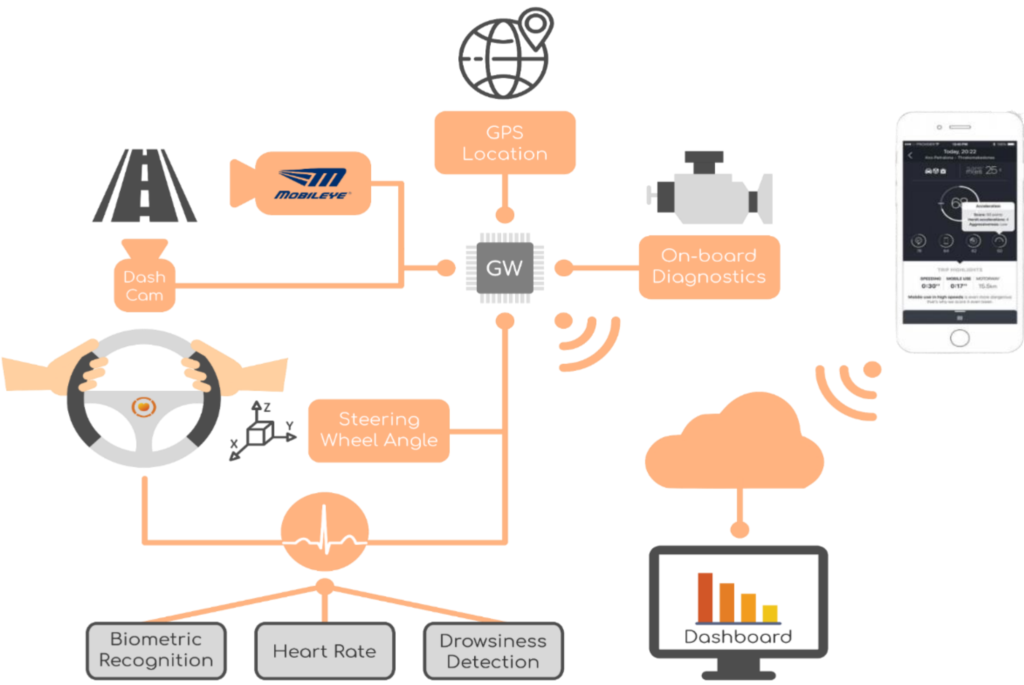


*Figure 18: The i-DREAMS framework technology overview*

Although the basic set of technology will be used in all the road transport modes (Buses, Cars, Trucks), it will need to be adapted for rail vehicles. The steering wheel-based measure of heart rate (CardioWheel) will be replaced by a wearable heart rate (ECG) monitor. It is also likely that a wearable heat rate monitor is more appropriate for the car mode as fitting the CardioWheel can effect the upholstery on a steering wheel, something that private drivers are less likely to accept. The MobilEye unit measures headway and lane departure, neither of which are relevant for trains although headway could be useful in the case of trams.

In relation to the concept of the STZ, the technology described in Figure 18 will measure the context, vehicle and operator measures that will be used to calculate driver capability and task demand in order to calculate which phase of the STZ the driver is operating within. The CardioWheel or wearable will measure the operator state, the on-board diagnostics will provide information on the vehicle and the MobilEye, dash cam and GPS location provides data on the context. Composite measures will also be used to infer aspects of driver behaviour. This is being examined in more detail elsewhere in the project (see below for further detail). It should also be noted that this is the starting point of the i-DREAM platform and the technology will be further defined or others added depending upon the recommendations from the ‘state of the art’ work.

## 7.2 Mode related considerations

The type of mode has implications for the translation of the concept of the Safety Tolerance Zone into the *i*-DREAMS platform that will be installed on vehicles. Chapter 5 highlights some of the considerations that need to be taken into account per *i*-DREAMS trial mode. However, the thresholds that demarcate the phases of the STZ are likely to differ between modes. For example, trucks may require an earlier warning than cars if differences in stopping distance are to be taken into account. In addition most modes are could have multiple users driving the same vehicle. The *i*-DREAMS system would therefore need to be able to identify which driver is also a trial participant.

The survey results discussed in chapter **Error! Reference source not found.** highlight that here are important safety critical events that apply to all the *i*-DREAMS modes (loss of control, close following, sudden braking) but that the collisions that were thought to be most important to prevent were different. Inattention and distraction were considered to be an important contributor to crashes for all transport modes and there was a consensus that timely warnings could assist with the prevention of critical events. In addition, the survey found:

- The importance of driver trust and driver engagement
- System could aid by providing timely warnings
- Rewards, positive reinforcement and evidence-based feedback will help with engagement
- Stakeholders would like technology to measure/monitor driver state in the future.

In conclusion, it is unlikely that a ‘one size fits all’ approach will be appropriate when designing the *i*-DREAMS platform. Instead, the monitoring and intervention modules and the decision-making processes to determine the status of the STZ will have to be optimised for each transport mode considered.

## 7.3 Development of a mathematical model

One of the next steps in the development of the *i*-DREAMS platform is to translate the theoretical concept of the Safety Tolerance Zone into a mathematical model. As previously stated in Chapter 3, there are two options:

- To use objective 'world view' measures only to trigger an intervention but use post-trip intervention to influence driver risk perception and behaviour.
- To take into account driver recognition and interpretation of risk when triggering an intervention as well as the 'objective world view' above.

The first step will be to focus on intervention triggers based on objective world view measures. Then the feasibility of adding measures that seek to infer, in real time, driver risk perception or allow for individual differences in behavioural responses to risk will be explored.

As the STZ concept refers both to the objective world view (i.e. the "global" and "undeniable" true state of the traffic environment) and the operator's interpretation and reaction to this (i.e. the understanding and perception of the objective reality from the side of the operator), the mathematical model conceptualizing the STZ should be such, that:

- Either or both the objective world view and the operator's view and the relationship between them can be described explicitly (although the starting point will be the objective world view)
- it can be tractable in real-time applications, and
- it can provide probabilistic or discrete thresholds for the initiation of the interventions.

As the data obtained by the *i*-DREAMS monitoring module would be sequential and temporal, models overviewed should be appropriate to accommodate such data. Murphy (2002) introduced the use of Dynamic Bayesian Networks (DBNs), as a tool to make probabilistic decisions in real-time from time-series observations. DBNs are an extension of Bayesian networks that are graphical representations of joint probability distributions of random variables used to handle temporal sequential data (e.g., Koller & Friedman, 2009). DBN representation of the probabilistic state-space is straightforward and requires the specification of the first time slice, the structure between two time slices, and the form of the Conditional Probability Distributions (CPDs). A crucial part in defining a DBN is the declaration of hidden (i.e., latent) and observed variables.

In order to "sketch" the outline of the DBN model for *i*-DREAMS, four variables layers, where each layer includes one or more random variables, could be considered: objective risk, "perceived" risk, context/operator/vehicle characteristics and sensor measurements. An exact mathematical description of the model as well as the methodology to infer the probabilities of interest, will be the crucial next steps to be followed.

## 7.4 Conclusion and Next Steps

This report sets out the theoretical basis of the concept of the Safety Tolerance Zone and explores the mode specific consideration that will need to be taken into account in the development of the *i*-DREAMS platform.

Work in other areas of the project are reviewing:

- The state of the art for impact in terms of safety, and the measurement tools for variables that could be used within the monitoring platform. (reporting Feb 2020)
- The state of the art for methodologies and tools to provide real time interventions and post trip interventions with the aim of increasing safe driver behaviour (reporting Feb 2020)

- The available technology for variable collection and how these can be integrated into the *i*-DREAMS platform. (Ongoing)

The next steps in the methodological developments are:

- To further develop and fine-tune the concept of the Safety Tolerance Zone
- To translate the concept of the Safety Tolerance Zone into a mathematical mode that can be used to create algorithms for the triggering of interventions
- To review the outputs of the work described above and select the variables and measurement tools that should be integrated into the monitoring module *i*-DREAMS platform
- To review the outputs of the work described above and select the most effective real-time and post trip intervention strategies to be integrated in the intervention module of the *i*-DREAMS platform. This will include the time of warnings or instructions provided.

**In all of the above, mode specific considerations as discussed in Chapter 5 and 6 will need to be considered.**

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# Annex 1: On-line Survey

## Page 1: Participant Information

You are invited to complete this survey exploring the needs of various transport modes with regards to driver monitoring and interventions. This is part of the i-Dreams Horizon 2020 project (www.idreamsproject.eu) which investigates advanced technology's ability to maintain a safety tolerance zone (safe driving performance) in multiple modes of transport. Your knowledge and expertise are vital for the development of this research to ensure technology being developed will address the most important problems.

We are asking a range of stakeholders to complete this survey which will inform the project's future plans.

This survey will take you approximately 15 minutes to complete. You can withdraw at any time by closing your browser.

If you have any issues or further questions please contact Dr. Graham Hancox g.hancox@lboro.ac.uk or Rachel Talbot r.k.talbot@lboro.ac.uk.

**Data Protection Privacy Notice**

The data collected in this survey will be held anonymously and securely by according to Loughborough University's data retention and handling policies. Personal data will be kept for the duration of the project only. The anonymised results will be kept by the research team for 5 years. The results will contribute to project deliverables and publishable research outputs. Once the data have been anonymised it may not be possible to withdraw your individual contributions from the research.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 814761.

## Page 2: Consent Form

Please take the time to read through this consent form. Contact Dr. Graham Hancox g.hancox@lboro.ac.uk or Rachel Talbot r.k.talbot@lboro.ac.uk if you have any questions.

If you do not agree with any of the given statements and do not wish to proceed, please close your browser and your details will be withdrawn from the study.

**Please read the following statements carefully:**

- I am over the age of 18.
- The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethics Approvals (Human Participants) Sub-Committee.
- I have read and understood the information sheet and this consent form.
- I have been provided with contact information where I can ask questions about my participation.

Use of Information

- I understand that all the information I provide will be processed in accordance with data protection legislation on the public task basis and will be treated in strict confidence.
- I understand that information I provide will be used for research outputs such as reports and publications. I agree that information I provide can be quoted anonymously in research outputs.

1. Based on the above information, I give my informed consent to participate in this study. * *Required*

◉ Yes

## Page 3: Demographic Information and Experience

**2.** In which country are you working? Please select one from the drop down box below. * *Required*

Please select ▼

**3.** Which of these best defines your field of work (please select only one): * *Required*

- ○ Academic researcher
- ○ Campaign group
- ○ Commercial researcher
- ○ Education/ training
- ○ Emergency service representative
- ○ Insurance
- ○ Manufacturer
- ○ Operator
- ○ Policy maker
- ○ Regional/ local authority
- ○ Sector representative
- ○ Other

**4.** Approximately how long have you been working in this field?

- ○ 0 - 5 years
- ○ 6 - 10 years
- ○ 11+ years

**5.** Which of these transport modes do you consider yourself to be predominantly experienced in working in (please choose only one): * *Required*

- ○ Bus/ Coach
- ○ Passenger car
- ○ Trains
- ○ Trams
- ○ Trucks

Note: Please answer all the following questions **only in relation to your chosen transport mode.**

If you feel you can answer for another transport mode please re-start the survey once you have finished this one and select the second transport mode.

## Page 4: i-Dreams Concept and Most Prevalent Collisions

The i-DREAMS project is developing a system that can monitor driver state (e.g. attention/alertness), the driving context (e.g. speed limits, weather) and driver behaviour (e.g. lane positioning, headway) in order to assist drivers. Real time warnings and alerts will be given when safety falls below a critical threshold with the aim of keeping drivers within a 'safety tolerance zone'. The safety tolerance zone is a continuum that includes normal or safe driving, a 'danger phase' where this risk of a collision is increased and an 'avoidable accident phase' where action needs to be taken to avoid a collision. If the i-DREAMS system detects that the driver has entered the danger phase a warning will be given and if it detects the transition into the 'avoidable accident phase' an instruction to take action will be given. The driver will also be provided with information following their trip (post trip intervention) to advise about when they were safe and unsafe.

The answers to the following questions for your chosen transport mode will help us in developing this system further.

Reminder: Please answer all the following questions **only in relation to your chosen transport mode.**

6. What type of collisions are most important (e.g. in most need of addressing) for your transportation mode? (select all that apply) * *Required*

- ☐ Rear end collision
- ☐ Head on collision
- ☐ Collision with vulnerable road users (pedestrian/cyclist/motorcyclist)
- ☐ Single vehicle collision
- ☐ Side collision (T bone)
- ☐ Junction/Intersection collision
- ☐ Collision with a stationary object
- ☐ Collision with an animal
- ☐ Don't know
- ☐ None
- ☐ Other

*b.* If you have any further comments, please use the textbox below.

## Page 5: Safety Breaches/ Incidents

This part of the survey uses a table of questions, view as separate questions instead?

7. Apart from collisions, please select what you think are the three most important safety breaches/incidents for your transportation mode.

| | Please select one safety breach/incident per option |
|---|---|
| Most important | Please select ▼ |
| Second most important | Please select ▼ |
| Third most important | Please select ▼ |

a. If you have any further comments, please use the textbox below.

The following 3 questions relate to the contributing factors for the safety breaches/incidents that you selected.

8. Which issues contribute to the **most important** safety breach/ incident identified in question 7? *
*Required*

Please select between 1 and 5 answers.

- ☐ Excessive speed
- ☐ Insufficient speed
- ☐ Missed communication
- ☐ Work overload (too much going on)
- ☐ Work underload (not enough going on)
- ☐ Missed checks
- ☐ Fatigue/sleepiness
- ☐ Inattention/distraction
- ☐ Substance impairment (e.g. drugs or alcohol)
- ☐ Lack of experience
- ☐ Stress (time pressure)
- ☐ Adverse weather
- ☐ Road geometry/infrastructure
- ☐ Impairment from a disability
- ☐ Traffic volume
- ☐ Missed observation
- ☐ Unfamiliar vehicle/controls
- ☐ Other
- ☐ Not applicable

*b.* If you have any further comments, please use the textbox below.

**9.** Which issues contribute to the **second most important** safety breach/ incident identified in question 7? *
*Required*

Please select between 1 and 5 answers.

- ☐ Excessive speed
- ☐ Insufficient speed
- ☐ Missed communication
- ☐ Work overload (too much going on)
- ☐ Work underload (not enough going on)
- ☐ Missed checks
- ☐ Fatigue/sleepiness
- ☐ Inattention/distraction
- ☐ Substance impairment (e.g. drugs or alcohol)
- ☐ Lack of experience
- ☐ Stress (time pressure)
- ☐ Adverse weather
- ☐ Road geometry/infrastructure
- ☐ Impairment from a disability
- ☐ Traffic volume
- ☐ Other
- ☐ Not applicable

*b.* If you have any further comments, please use the textbox below.

**10.** Which issues contribute to the **third most important** safety breach/ incident identified in question 7? *
*Required*

Please select between 1 and 5 answers.

- ☐ Excessive speed
- ☐ Insufficient speed
- ☐ Missed communication
- ☐ Work overload (too much going on)
- ☐ Work underload (not enough going on)
- ☐ Missed checks
- ☐ Fatigue/sleepiness
- ☐ Inattention/distraction
- ☐ Substance impairment (e.g. drugs or alcohol)
- ☐ Lack of experience
- ☐ Stress (time pressure)
- ☐ Adverse weather
- ☐ Road geometry/infrastructure
- ☐ Impairment from a disability
- ☐ Traffic volume
- ☐ Other
- ☐ Not applicable

*b.* If you have any further comments, please use the textbox below.

## Page 6: i-Dreams Concept Development/ Considerations

**Reminder:** The i-DREAMS project is developing a system that can monitor driver state (e.g. attention/alertness), the driving context (e.g. speed limits, weather) and driver behaviour (e.g. lane positioning, headway) in order to assist drivers. Real time warnings and alerts will be given when safety falls below a critical threshold with the aim of keeping drivers within a 'safety tolerance zone'. The safety tolerance zone is a continuum that includes normal or safe driving, a 'danger phase' where this risk of a collision is increased and an 'avoidable accident phase' where action needs to be taken to avoid a collision. If the i-DREAMS system detects that the driver has entered the danger phase a warning will be given and if it detects the transition into the 'avoidable accident phase' an instruction to take action will be given. The driver will also be provided with information following their trip (post trip intervention) to advise about when they were safe and unsafe.

This part of the survey uses a table of questions, view as separate questions instead?

11. How do you think the i-Dreams system could aid in preventing the safety breaches/incidents prioritised previously? Please select the top three options.

| | |
|---|---|
| One | Please select ▼ |
| Two | Please select ▼ |
| Three | Please select ▼ |

a. If you have any further comments, please use the textbox below.

**12.** What are the largest barriers and constraints you see for driver assistance in real time? *
*Required*

Please select between 1 and 5 answers.

- ☐ Working practices
- ☐ Union involvement
- ☐ Driver trust
- ☐ Driver engagement
- ☐ Expense
- ☐ Infrastructure reliability
- ☐ Different practices between automotive/truck/train operators
- ☐ Different policies among countries/authorities
- ☐ Data protection issues
- ☐ Personal refusal
- ☐ Installation time
- ☐ Technology distrust
- ☐ Equipment failure
- ☐ Legal contingencies
- ☐ Driver distraction concerns
- ☐ None
- ☐ Other

*b.* If you have any further comments, please use the textbox below.

## Page 7: Technologies Currently Available and in Use

This part of the survey uses a table of questions, view as separate questions instead?

**13.** What technologies are currently being used to assist drivers in your transportation mode? (Note: consider "important" in terms of safety, crash avoidance or mitigation).

| | ✱ Required | | | | | |
|---|---|---|---|---|---|---|
| | Not applicable | Using and important | Using not important | Not using but would like to use | Not using and would not like to use | Name or examples of technology being used if applicable |
| Lane deviation monitoring | ○ | ○ | ○ | ○ | ○ | |
| Missed signals/SPADs monitoring | ○ | ○ | ○ | ○ | ○ | |
| Fatigue monitoring | ○ | ○ | ○ | ○ | ○ | |
| Attention/distraction monitoring | ○ | ○ | ○ | ○ | ○ | |
| Insufficient headway warning (too close to vehicle in front) | ○ | ○ | ○ | ○ | ○ | |
| Pedestrian detection | ○ | ○ | ○ | ○ | ○ | |
| Automatic emergency braking | ○ | ○ | ○ | ○ | ○ | |
| Blind spot monitoring | ○ | ○ | ○ | ○ | ○ | |
| Reversing cameras/detectors | ○ | ○ | ○ | ○ | ○ | |
| Speed violation warning | ○ | ○ | ○ | ○ | ○ | |
| Fail safe (dead man's switch) | ○ | ○ | ○ | ○ | ○ | |
| Speed limiter | ○ | ○ | ○ | ○ | ○ | |
| Dynamic stability control/electronic stability control | ○ | ○ | ○ | ○ | ○ | |
| Physiological monitor (e.g. heart rate) | ○ | ○ | ○ | ○ | ○ | |
| Black box recorder | ○ | ○ | ○ | ○ | ○ | |
| Vehicle telematics informing on driving style (in real time) | ○ | ○ | ○ | ○ | ○ | |
| Vehicle telematics (post-trip feedback) | ○ | ○ | ○ | ○ | ○ | |
| Fleet management devices | ○ | ○ | ○ | ○ | ○ | |
| Other | ○ | ○ | ○ | ○ | ○ | |

a. If you have any further comments, please use the textbox below.

14. What additional technologies and future technology capabilities do you think could contribute to safety within your transportation mode?

## Page 8: Post-Trip Intervention

Post-trip interventions inform the driver of their performance and ways they could modify their behaviour after the journey has taken place.

**15.** What do you think would incentivise people to engage with post-trip interventions in your mode? *
*Required*

Please select between 1 and 5 answers.

- ☐ Rewards (e.g. monetary or performance incentives)
- ☐ Positive reinforcement (e.g. encouraging of good habits)
- ☐ Detailed explanations of the event/the drive
- ☐ Evidence based suggestions and feedback
- ☐ Personaliseable app (e.g.setting of personal goals)
- ☐ Gamification (e.g. compete with co-workers)
- ☐ Beta testing of new technologies
- ☐ Simulator training
- ☐ None
- ☐ Other

*b.* If you have any further comments, please use the textbox below.

**16.** Do you have any personal experience of platforms monitoring driver behaviour and providing gamified feedback (either while driving or as a post trip intervention)? If so, please provide information relating to the system and any strengths and weaknesses you may have encountered.

## Page 9: i-Dreams Future Participation

17. If you would like to be part of the i-Dreams User Expert Group to help inform our future research please give your email address here:

Note: We will only contact you in relation to i-Dreams and the email address will only be stored for the duration of the project (2019 to 2022).

iDREAMS

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