Eyes on the Tracks: Train Driver Acceptance of Driver Condition Monitoring Systems

Exploring how to Promote Acceptance in the Design of an Alertness Feedback System based on Eye Measurements

Maurits Rietveld

Master Thesis Report, in partial fulfillment for the degree of
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May 7, 2024

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Eyes on the Tracks: Train Driver Acceptance of Driver Condition Monitoring Systems

Exploring how to Promote Acceptance in the Design of an Alertness Feedback System based on Eye-tracking and Blinking Measurements.

Master Thesis Report
in partial fulfillment for the degree of

Communication Design for Innovation
Faculty of Applied Sciences
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TUDelft

If a system doesn't work for people,

it doesn't work.

JOHN D. LEE

Preface

The difficulty of staying alert is recognizable for many: anyone wanting to focus on a tedious task knows the feeling of pushing your alertness to the limit, and trying to refocus. Could then a device help that can monitor your alertness, by giving some kind of feedback? These intricate interactions between humans and technology have fascinated me for some years now, making me follow a masters in Communication design for innovation, after my technical schooling in Aerospace Engineering. In this research, I was able to dive deeply into this fascination topic of train driver alertness, and acceptance of alertness technologies.

This master thesis was thus written as part of the master 'Communication Design for Innovation' at Delft University of Technology, while performed in close collaboration with the Dutch Railways. This thesis was performed during the period of September 2023 until April 2024.

During this thesis, I got much support from various people who I would like to thank. Special thanks to Caroline Wehrmann for her close mentoring, and Ellemieke van Doorn for the opportunity she gave me of doing this research as part as an internship at NS. Much thanks as well to all my colleagues at this team, in particular Joep von Berg for our interesting discussions on how to deal with these complex concepts of alertness. I am also very thankful for the train drivers who I had the opportunity to interview, as they openly shared their experiences of alertness, conveying their passion for their jobs. Finally, much thanks to all my good friends and family for supporting me throughout.

I hope you enjoy reading this document,

Maurits Rietveld
Delft, May 7, 2024

Summary

Train drivers are challenged to stay alert during train driving, for a big part due to the limited amount of tasks, and monotony of tasks. Driver condition monitoring(DCM) is a technology that involves measuring the driver's alertness state in real-time, in which the non-intrusive option of eye-based measurements is considered. Since DCM's are upcoming in car and truck industry, train operators are now also showing interest in this technology to improve alertness, having the intention to make train driving even safer. New technologies are often resisted in railway operator companies, shown by strikes and works council involvement that often occur when new train technologies are implemented. Hence, in designing a successful DCM feedback system, understanding early on how acceptance can be promoted in such DCM systems is crucial. Currently, it is unknown how drivers recognize and deal with alertness in the first place. Also for implementing DCM's in the future, it is unknown what is required for such DCM feedback designs for acceptance to be promoted. This research thus aims to investigate how acceptance of train drivers can be promoted in a DCM feedback system.

Exploring the problem, semi-structured interviews with four train drivers showed that drivers do deal with low alertness. They also gave reasons for using current technical systems, directing the focus to the usefulness of technology and whether it is easy to use.

Theoretical Approaches

Considering a DCM system that can measure eye-directions, blinking behavior and gaze fixations, theoretical insights propose that you can use these measurements to infer driver distraction, sleepiness and mind-wandering. In these theoretical concepts, some considerations are important, such as distraction being a normative judgment, context sensitive and prone to the hindsight bias. The three concepts of low alertness are in literature distinct concepts, yet they are highly related in practice.

Theoretical approaches towards acceptance of technologies are generally focused on influencing the intention to use a technology. Generally used is Technology Acceptance model for evaluating acceptance of various technologies, proposing that the perceived usefulness and perceived ease of use are important to model an intention to use, and actual use of, such DCM technology.

Method

A qualitative approach led to conducting focus groups with train drivers and office employees to investigate the sensitive topic of alertness. These focus groups opened up the opportunity to investigate how train drivers currently deal with alertness, and to understand why train drivers would accept a DCM feedback system. Tools were used to facilitate this conversation, such as first writing individually writing down answers before the group conversation, using a case example as discussion topic, and discussing pre-made design concepts. In total, four train drivers and four office employees participated. To analyze the results qualitatively, thematic analysis was performed by coding iteratively.

Current Alertness

For current alertness strategies, the results showed that drivers recognize sleepiness the most, while fatigue and mind-wandering (task-related tiredness) are perceived as similar to sleepiness. Distraction was also not

recognized, as they are occupied more with a 'distributing' and 'prioritizing' their attention. To deal with low alertness, train driver use both current technical systems (dead man's pedal, ATB) to assess their alertness and become more alert, as well as individual tools (e.g. self-motivation and changing the temperature).

Acceptance Factors

For acceptance, themes emerged of perceived usefulness & perceived ease of use of technology, feelings of competence & autonomy, and trust towards the organization. The themes one-on-one led to appropriate design requirements to promote acceptance for designers that design DCM feedback systems.

Perceived usefulness was a relevant factor, as train drivers made comments about the relevance of problems, whether the goal is appropriate (e.g. if the feedback goal is to inform, alarm or intervene), and whether it is of sufficient advantage (E.g DCM's were not always seen as sufficiently advantageous over the dead man's pedal). Hence, it is needed to take into account how drivers perceive technology as useful, requiring to consider what alertness problems train drivers recognize, to choose goals that are seen as appropriate, and to assess how drivers perceive the relative advantage of using such a technology compared to the current situation .

Additionally, it was found that it helps if results are demonstrable (e.g. be able to demonstrate amount of prevented SPAD's), the DCM feedback fits the tasks and responsibilities, and it should be perceived as sufficiently reliable and accurate.

Next, whether drivers perceive themselves to be competent and have control over their ability to drive safely were important factors. This was firstly shown from their feeling of responsibility and their needs to have the skills and opportunity to carry out this responsibility (e.g. a need to be in control of their alertness and prevent de-skilling of alertness strategies). This calls to consider the effect of DCM feedback on the driver's feeling of driving control and skills that are necessary to carry out their responsibilities. Also their attention capabilities are seen as important to appreciate (e.g. in being selected and trained to stay attentive and alert). This calls for creating a feedback design that promotes use of attention capabilities, instead of replacing them. A dislike towards over-trusting technologies was also mentioned (e.g. a dislike towards 'leaning' on ATB), showing that it is important to consider to what extend a feedback system replaces a task, or requires the driver to stay actively involved (suggesting informing the driver with feedback is beneficial over alerting the driver).

Finally, trust towards the organization showed to be important, as individual based measuring is distrusted on whether the organization keeps drivers individually accountable (e.g. during incident investigations or as performance metrics) showing that DCM data must be used with integrity (such as guarantying to only use data for the goal of safety). Hence, protecting data measured with DCM is seen as crucial for its acceptance. (e.g. by not storing DCM data at all)

Conclusion

In short, designing DCM feedback in a way that promotes acceptance is proposed to consider how drivers find a device useful, how their perceptions of autonomy and competence are influenced, and how to foster the trust towards the organization with respect to data use.

Contents

Nomenclature

ATB	Automatische treinbeïnvloeding / Automatic Train Control
ATO	Automatic Train Operations
CDI	Communication Design for Innovation
DAS	Driver Advisory System
DCM	Driver Condition Monitoring
DCMS	Driver Condition Monitoring System
ERTMS	European Rail Traffic Managment System
HFE	Human Factors Engineering
NS	Nederlandse Spoorwegen (Dutch Railways)
PCIM	Perceived Characteristics of Innovation Model
PU	Perceived Usefulness
SPAD	Signal passed at danger (STS-passage in Dutch)
STS-passage	Stoptonend sein passage (SPAD in English)
TAM	Technology Acceptance Model
TPB	Theory of Planned Behaviour

1 Introduction

Train driving is a highly safe form of travel, as seen in its low amount of incident rates, for example in the Netherlands (DutchRailways, 2024). This can be attributed to many things, most importantly by better traffic management, better traffic safety systems in the 1970's and 1990's, and safer solutions at road-railway crossings. As such, while train drivers are responsible for punctual and comfortable driving, their main responsibility is ensure safety during train driving.

These developments in train driving reduced the amount, and types of tasks the train driver needs to perform. Train drivers currently mainly control the speed and deal with traffic signals as one part of their tasks, while they also supervise technical systems and look out the window for objects and people on the tracks.

As humans have difficulty performing well when they have too little tasks to do (i.e. a low workload), (de Waard, 1996), and are generally bad at sustaining their attention for longer periods of time on monotonous tasks (Bainbridge, 1983), train drivers are challenged to maintain their alertness sufficiently, staying active and attentive. Given that it is already challenging to stay alert during train driving, new technologies can have impacts on their alertness and attention as well: automation or supportive technologies often reduce the workload even more, and involve more supervisory tasks. (Bainbridge, 1983) (Verstappen, Wilms, & Weide, 2017)

The topic of alertness is also often found hard to deal with by railway operators (such as the Dutch Railways). On one side, low alertness and distraction are found as concrete causes of railway incidents, such as driving through a red traffic light (called a 'Signal Passed at Danger (SPAD) or 'Stoptonend Sein Passage' (STS) in Dutch). On the other side, it is difficult to concretely investigate how alert train drivers are in their day to day job, and to understand to which extent drivers have to deal with low alertness. For example, the amount of smartphone use during train driving is fairly unknown, and it is hard to see its effects on lowered safety.

Driver condition monitoring as a potential solution

One technology that is upcoming in mobility, especially in truck and car driving, is 'driver condition monitoring' (DCM). This technology monitors the alertness of the driver by various means (such as eye-measurements or nervous system activity with EEGS), and can be used to give some sort of feedback to the driver if lowered alertness is detected, such as raising an alarm, a simple alert or provide information. DCM's consisting of an infrared-camera, measuring the eyes, are considered high potential for mobility and detecting lowered alertness in drivers, mostly as they are non-intrusive (measuring does not interfere with driving) are perceived as relatively accurate in detecting lowered alertness, compared to other techniques, such as EEG. (Kashevnik, Shchedrin, Kaiser, & Stocker, 2021).

Recently, railway operators have shown interest in such a device , as it is believed to potentially support drivers in staying alert in their low workload environment. For example, first experiments are conducted in the United Kingdom (Leach & Tailor, 2021) on the accuracy of such devices. The potential of Driver condition monitoring is believed to be in being supportive for train driver's alertness in the current situation, and potentially in the future to mitigate alertness effects of new technologies that lead to an even lower workload and more supervision type of tasks.

Implementing new technologies in train driving operation in The Netherlands.

However, it is at this point unknown to what extent driver condition monitoring is applicable to train driving. Firstly in its effectiveness to improve alertness: how can giving feedback on the alertness of drivers make them more alert?

Also whether train drivers accept such a DCM technology is an important issue. At railway operators in The Netherlands, such as The Dutch Railways ('Nederlandse Spoorwegen', 'NS'), the implementation of new train driving technologies is often accompanied by resistance: new technologies generally are critically received, having led to technologies not being implemented or not used by train drivers as intended. Also, changes in train driver's jobs have in the past led to involvement of the works council and personnel strikes, which means that train driver acceptance has a very visible and direct impact on society. This acceptance of technology could also be difficult to predict: in the past, new technologies in railway industry were often resisted unexpectedly with works council involvement and strikes at first, yet in some cases later on accepted. Especially sensitive are the topics of decreasing variety in the job, such as repetitive routes (generally called 'rondje rond de kerk') and individually measuring performance of driving (called 'meten op de man'). So, in the case that new technologies have potential to improve railway operations, either from safety, performance or well-being of workers, it is hence crucial to take into consideration how new technologies can be implemented such that chances of acceptance are highest. This can consist of making well-considered design choices and adopting useful strategies on how to introduce the technology. Taking into account how new technologies effect the train driver's job, and understand what choices lead to acceptance, is hence crucial. Especially in the design of such an individual-based technical system, that tries to deal with the sensitive topic of keeping drivers alert.

1.1. Problem Statement

Train driver alertness is an important topic for railway operators, being a relevant factor to address in making train driving even safer. With the emergence of driver condition monitoring in other mobility industries, it is not yet known how DCM's can give feedback on the train driver's alertness appropriately. Most importantly, new technologies are often resisted in Dutch Train driving industry, creating the need to understand what is important in such systems for train drivers to accept it.

1.2. Research Objectives & Research Questions

Hence, the objective is to explore how to design a feedback system for DCM's in a way that both improves safety by dealing with alertnss, and promotes acceptance of train drivers. The goal of this research is hence to find out how driver condition monitoring can be used by train drivers from an acceptance point of view. This led to the research question:

How can acceptance of train drivers be promoted in the design of an alertness feedback system based on

driver condition monitoring?

To design appropriate DCM feedback systems, it is on the one hand needed to understand the context of how train drivers deal with alertness, which leads to understanding how a DCM feedback system can help. On the other hand, it is needed to understand what is important for train drivers to accept DCM feedback systems.

Understanding how drivers deal with alertness
Firstly, understanding the intricate topic of alertness during train driving is important. As stated before, alertness is sometimes a factor during incidents, yet how train drivers deal with alertness is relatively unexplored. One big objective is a better understanding of train driver alertness in the current situation, both to find out if lowered alertness occurs, and to understand how they deal with lowered alertness. This context is crucial in knowing in what ways DCM's can fit and be of use to drivers. For this, research questions RQ1 & RQ3 were created: Does lowered alertness occur? & How do train drivers currently deal with alertness?

Investigating Acceptance of DCM
After this, it must be understood what is important for train drivers to accept a system that gives feedback with driver condition monitoring. To come up with a suitable approach, the context can first be investigated why train drivers accept current technologies: This led to RQ2: Why do train drivers accept current technology? Now looking specifically at DCM feedback systems, it can be investigated for what reasons train drivers would accept this system in their cabin. This gives rise to RQ4: What acceptance factors are important in the context of train driving with DCM technology?

Requirements for a DCM feedback design
The acceptance factors are then a basis to form design requirements to designers in railway companies on how to design feedback systems that use driver condition monitoring. This then led to RQ5: What is required from a DCM feedback system in order to promote train driver acceptance?

The research questions can be found in figure 1.1.

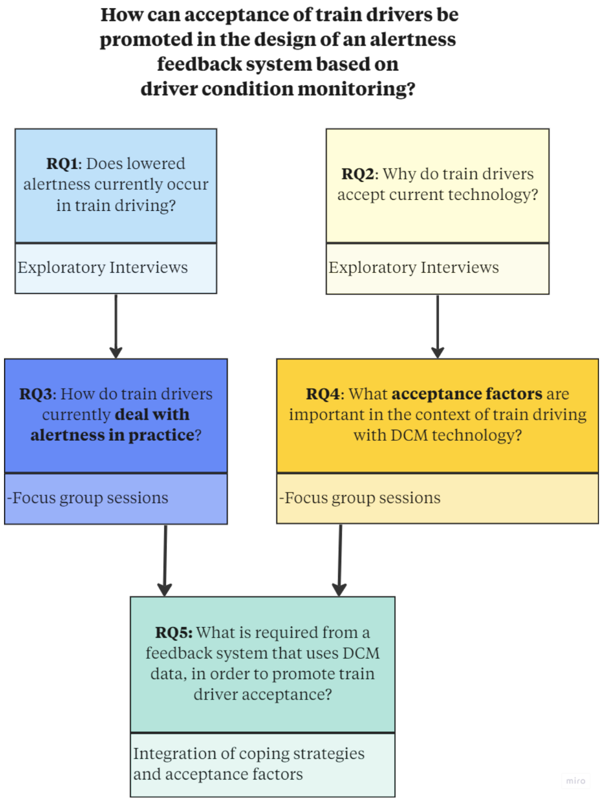


Figure 1.1: Research questions with corresponding methods that were used. The arrows show interdepencies between research questions

1.3. Research Process

Because of the exploratory nature of this research, and many perspective that must be integrated (from the train driver's job, alertness and acceptance), the design process requires an iterative approach by cycling through divergent thinking and convergent thinking. For this, the double diamond approach is useful, as it's used in complex design contexts. It consists of multiple 'diamonds' of divergent and convergent thinking. (LondonDesignCounsel, 2015) This process is guided by answering the mentioned research question and sub-questions. The design process is shown in figure 1.2. Within the report, it means the first two questions are answered at Exploratory Investigations, while the main bulk of the thesis focuses on RQ3 & RQ4. In Design requirements, RQ5 is answered.

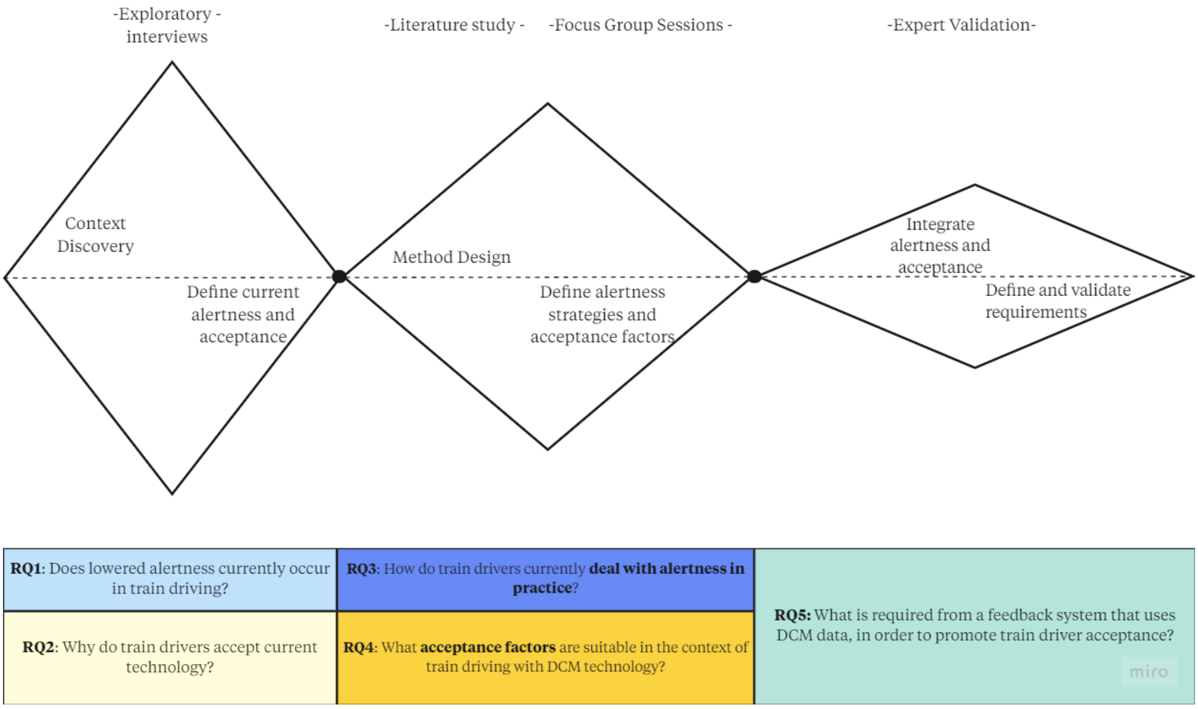


Figure 1.2: 'Triple Diamond' design process based on the 'Double diamond' design model. (LondonDesignCounsel, 2015) The emphasis in this model is on diverging and converging design processes to deal with complex problems (which are hard-to define and unpredictable). The phases separate the process of discovering the context, investigating alertness strategies and acceptance factors, and finally forming design requirements.

1.4. Inter-disciplinary Approach

This thesis is part of the MSc in Communication Design for Innovation (CDI) at Delft University of Technology (TUD). It is a social scientific master that studies the people involved in innovation processes. The research was conducted in the context of new technologies for train drivers, accompanied by much contact with the human factors experts at human-machine interaction (HMI) team at NS. It is hence useful to describe both scientific disciplines of CDI and HMI, and show what choices have been made to combine these scientific fields.

1.4.1. Communication Design for Innovation (CDI)

CDI investigates social topics within the context of innovation. It aims to investigate **how people deal with innovation throughout the innovation process**, and uses a **social-scientific** approach. Hence, social theoretical approaches, such as behavior, motivation and communication theories might be used to analyze how people deal with innovations. As innovation processes are unclear on which theoretical approach to is, one focus is to **closely iterate theory and practice**: applying theory to analyze the problem, and using practical insights by using these theories in practice. In this way, deduction and induction are alternated more closely than many regular scientific approaches. This quick alternation is needed in **complex problems** as problem definitions and appropriate theories are not clear from the start. To study people in these innovation contexts, **social-scientific methods** are used, such as interviews, surveys, focus groups, also using social design methods such as co-design and design thinking.

1.4.2. Human Machine Interaction (HMI)

Human machine interaction is a field that researches the **interaction between machines** (such as vehicles, machinery, control-rooms) **and the human operators** that control these machines (such as drivers, control-room operators, pilots). More generally, it is often seen as part of **human-factors engineering**, which is a field that 'aims to make technology work for people', 'most broadly, human factors engineering aims to improve human interaction with systems by enhancing safety, performance and satisfaction' (Lee, Wickens, Liu, & Boyle, 2017). Human factors is becoming more and more a field on its own, yet it can also be seen as a combination of various fields, such as psychology, engineering and design.

Hence, the emphasis of human factors and HMI concerns how people interact with technology, and the **effects on safety, performance, and (user) satisfaction.** It often adopts a **human-centered** approach, investigating how humans interact with technologies.

1.4.3. Combining Communication Design with Human Factors Engineering

Hence, CDI and HMI overlap considerably on the points of a focus on how people deal with new technologies, use of social scientific theories and methods. On the other hand, they vary on their emphasis: CDI is focused on people in innovation contexts, while HFE is focused on designing technology that fits end-users in the interaction with technology. This thesis is part of the MSc of Communication Design for Innovation (CDI), and hence mainly adopts approaches of CDI. However, the case contexts requires some approaches more applicable in human factors research, such as human-centered research over co-design. The following choices of the inter-disciplinary approach were made:

- **Extensive Context Exploration from CDI**
  The problem can be considered complex by its challenge to define the problem and to predict what changes of the designs have on the outcome of acceptance and alertness improvements. This complexity makes it important to extensively analyze the case context of train driver alertness and DCM technology.
- **Iteration of theoretical approaches from CDI**
  This complexity also creates the challenge of finding appropriate theoretical models, making iteration on theoretical approaches an inherent part of the research process. By researching both communication theory and acceptance theory, the research might provide new perspectives into acceptance.
- **Human-Centered Approach from HMI**
  The context is in a professional environment, in which users (train drivers) are professionally trained on specific aspects and are hence experts in train driving. For this, it might be appropriate to use human-centered design processes to gain input from these train drivers. Co-design practices might be less appropriate because of the difference in expertise and professional role between designers (knowledge on alertness and interaction between human and machine) and the train driver (which are experts in experiencing alertness and using technologies). More discussion on the approaches of human-centered research and co-design can be found in the Discussion chapter (Section 11.3.2).

1.5. Structure of the Report

The report starts by exploring the context: how do train drivers perform their job, and why is DCM considered as a solution? To get a better grip on the problem of low alertness and technology acceptance, it is researched in 'Exploratory Investigations' whether low alertness occurs in the cabin, and for what reasons drivers accept current technologies.

With these insights in mind, the main research starts to answer the main questions of how train drivers deal with alertness, and for what reasons drivers would accept DCM feedback systems. This is done by two chapters on a theoretical framework: both a theoretical framework of alertness, and of acceptance are proposed. These theoretical perspectives give a lens to look at current driver alertness and acceptance of a potential DCM feedback system. One methods chapter follows, showing how train drivers were involved to answer the questions of current alertness and DCM acceptance. The results are then set-out in separate chapters, one each for alertness and acceptance.

From these results, design requirements are proposed to design a feedback system that promotes acceptance.

Then, the conclusion answers all research questions, explaining how train driver acceptance can be promoted in DCM feedback systems. Finally, the discussion chapter reflects on the use of the theories, methods and transferability of results to other mobility domains. It also gives suggestions for future research directions and suggests potential DCM feedback design considerations.

2
Context: Train driving and DCM Technology

The job of train driver comprises of many aspects that are related to alertness: driver tasks, responsibilities, training, and technologies that they use, are all important to consider in the topic of alertness. As this research is performed in the context of the Dutch Railways (Nederlandse Spoorwegen, 'NS'), the research from now on is viewed from this specific railway operator. Next, DCM technology, being used in car- and truck industry, has characteristics that are relevant to consider in the context of train drivers. Why is it regarded as solution to improve alertness?

2.1. Train Driving in The Netherlands at NS

Simply put, train drivers are responsible to achieve four goals: safety, punctuality, passenger-comfort and energy-efficiency.

Safe driving is most important: For passengers, the environment and themselves, safety must be guarantied. In practice, it mainly is important for train drivers to comply with traffic signaling: drivers are allowed to drive through green and yellow signals, and must stop before red signals. Driving through a red signal is considered a significant safety incident, generally called a 'signal passed at danger', or SPAD ('STS: stoptonend sein passage' in Dutch). Yellow signals show that the next signal will be red, which means they are crucial to observe to be able to brake in time for red signals. Also, railway-road crossings are a significant part of safety, with its potential to collide with cars standing on the tracks, or people walking/biking on them. In this, the driver can sound the horn and brake to decrease the impact (although the train's speed is in many cases too high to fully brake in time). Finally, collisions with people walking on tracks are a part of train driving. Although the train's speed is often too high to brake in time for a person standing on a track, observing a person near the tracks / on other tracks can be called in to the traffic shift leader. Then, all nearby trains are asked to drive slowly, making train drivers mostly able to prevent collision between persons near the tracks and other trains.

Secondly, train drivers need to drive punctually, and if possible, control the speed comfortably. Additionally, controlling the speed with energy-efficiency is promoted.

In being responsible for these goals, train drivers control the speed, observe traffic, communicate with stakeholders such as train dispatcher ('treindienstleider') and communicate with technical assistance in case of technical malfunctions. The navigation part of traffic is mainly performed by traffic controllers/train dispatchers remotely, including traffic management and controlling the rail switches, which they communicate with on a telephone, called the GSMR.

Performing these tasks is generally not considered difficult. The main challenge come from the amount of responsibility it comes with, and from being under-loaded / the low workload, making it a challenge to stay attentive.

This challenge is made bigger by shifts often being irregularly planned throughout a week, which can start early one day, and end at night another day. Also the variety in a route can become monotonous. Although the Netherlands is relatively small, meaning that time-intervals between stations are short compared to other countries, train driving is experienced as monotonous, especially on some specific routes with little variation or tasks to perform (Such as Lelystad-Zwolle). Sustaining attention can be experienced as particilarly hard on these routes.

Maintaining this variety in work is generally seen as crucial for drivers to enjoy their jobs, and is seen as needed to stay alert. For example, when it was suggested to streamline shifts by repeating routes for every driver (called 'rondje rond de kerk'), major strikes and works council involvement led to making sure drivers maintain variety in their shifts.

Although the work of a train driver is mostly individually based in the cabin, they also interact with various other colleagues. Their team-managers ('TM') are their main point of contact to keep in touch on work-related and personal related matters. Also when a driver would be unfit to drive (e.g. from being too tired), their team manager is the point of contact. Their interaction with driver and train manager ('conducteur') colleagues is mainly found in break rooms or while handing over shifts, creating short social moments in their otherwise mostly individual job.

To become a train driver, a two year educational program must be completed, starting with a thorough selection process, including psychological evaluations and a vigilance test, testing their capability to sustain attention for the monotonous, low-workload task-environment. During their training, emphasis is given on how to guide the attention, preventing expectations (with a module on situational awareness), and how to promote alertness (with information on lifestyle and work guidelines to promote alertness) (NSR Concern-veiligheid, 2010).

Simply put, train drivers perform various highly responsible tasks, yet often have to deal with low work-load due to the monotony and sustained attention that is required.

2.2. Technical Systems in the Driver's Cabin at NS

Looking specifically at the Dutch Railways, various technologies inside the cabin are related to alertness. Although all technologies that drivers interact with have an effect on attention and alertness, some technologies are especially relevant during driving a train, which are a number of safety systems that alert drivers, and a supportive aid that help drivers to more effectively perform their jobs.

The **dead man's pedal** is a safety system near the feet of train drivers in the cabin, where a dead man's switch in the form of a pedal is located. The pedal is generally introduced to guaranty safety when the driver becomes unconscious. However, it is also generally known that train drivers automatically activate the pedal after a while, also when highly sleepy. Hence, its use to detect whether a train driver is falling asleep is highly questioned in general.
ATB ('Automatische trein beïnvloeding', Automatic train control) is the current main traffic safety system to secure safety with other train traffic. It alarms and intervenes in the speed control of train driving. It does this by alarms when exceeding the current speed limit on the specific tracks, and if not reacted upon within seconds, automatically stops the train.

ERTMS (European Rail Traffic Management System) is an European railway safety system that will replace ATB. In ERTMS, speed is managed via displays inside the train, instead of physical traffic lights next to the tracks. One practical change for the driver is that he can see on the display how which distance he/she can travel until a red light, and until which speed they can drive. Some specific train routes in The Netherlands are already managed through ERTMS, such as the high speed track ('hogesnelheidslijn', or HSL), and is slowly rolling out in the coming years.
Driver advisory systems are supportive tools that advise the driver by providing useful information to the driver. At NS, a driver advisory system is used, called 'TimTim', which is a tablet with information to support the driver in looking ahead to more efficiently control its speed. It provides real-time traffic information to the driver, as well as its current location. TimTim is currently available for all train drivers, and using it is voluntarily.
Orbit is a safety alarm system that was designed with the goal to prevent driving through red signs. It uses the train's GPS location and traffic sign locations to determine if the current train speed still allows to stop before an approaching red sign. If stopping before a red signal becomes critical, a voice alarm alerts the driver to brake immediately.

2.3. Driver Condition Monitoring as Technology to Improve Alertness

Recently, the technology of driver condition monitoring (DCM) has emerged. It is a system that monitors the driver's alertness condition, primarily used in modern cars and trucks. A DCM system can measure various aspects of the driver. One major function is to asses eye-behavior: where the eyes look (eye-gaze direction) and blinking of the eyes. Some DCM's measure activity in the nervous system (for example with EEG's)(Razak, Yogarayan, Aziz, Abdullah, & Kamis, 2022), detect distracting objects, or measure facial-characteristics to infer emotional states, or use driving aspects, such as steering wheel use.(Kashevnik et al., 2021) Eye-based measuring is focused upon in this research, as its non-intrusiveness and accuracy of inferring attention and alertness makes this types of DCM considered highest potential.

The other part of DCM's are its algorithms, that use these measurements to assess/interpret the alertness state. Typical metrices used with DCM are to measure closing/opening of the eyes to detect blinking and eye-lid closure time (Kashevnik et al., 2021), and the direction of the eyes to detect/analyze various concepts, such as saccades (quick eye-movements), fixations (maintaining a gaze), eyes of the road time (detecting how long the eyes look away from the road)(Michelaraki, Katrakazas, Kaiser, Brijs, & Yannis, 2023). Also mind-wandering has potential to be measurable, by looking at how close eye movements stay focused on one point. (Krasich, Huffman, Faber, & Brockmole, 2020)

For sleepiness, DCM's measure blinking related aspects, such as the 'absolute' opening of both eyes, and assessing the blink duration and velocity of opening and closing.

Specifically in NS, a specific DCM system was deemed effective. In this system, the eye-gaze direction can be used to capture visual attention. blinking behavior can be used to detect sleepiness and gaze behavior by fixations (more specifically the duration and dispersion) can be used to detect mind-wandering (Krasich et al., 2020).

The final aspects of implementing a DCM is how the inferred condition of the driver is used to give feedback. Of this question of how to give feedback to the driver, research is generally limited: Most researched implementations consist of a informative feedback, or simple sound or visual alarms in case of lowered alertness.(for example (Presta, Simone, Tancredi, & Chiesa, 2023), Also other options are suggested by some researchers, such as giving feedback afterwards /post-drive (Donmez, Boyle, & Lee, 2008c) (Roberts, Ghazizadeh, & Lee, 2012) to support learning to deal with safety critical situations afterwards. Also incorporating the current driving context with an alarm, such as combining the current-gps location, is sometimes investigated.(Kujala, Karvonen, & Mäkelä, 2016). All these investigations are at this time focused on car-driving.

More recently, railway operators have given interest into driver condition monitoring, largely due to the potential of supporting the driver in its challenge to stay alert in such monotonous, low workload task characteristics. For example, in the United Kingdom, DCM's are currently under investigation in its effectiveness (Leach & Tailor, 2021). However, current focus is put on researching the DCM's accuracy and reliability to detect lowered alertnes, instead of researching in what ways feedback can be given that leads to improvements in alertness, and succesful acceptance, of train drivers.

3
Exploratory Investigations

Although SPAD's are sometimes attributed to low alertness, it is generally unknown if train drivers recognize lowered alertness on a day-today basis. Also, it is yet unclear for what reasons current technology is accepted by train drivers. Hence, in this chapter, it is explored whether lowered alertness actually occurs during train driving, as to understand the extend of the problem. Also, it is explored why train drivers accept current technologies, as this gives insights that help to choose an appropriate theoretical approach for acceptance of DCM specifically. . Hence, this chapter aims to answer the following exploratory research questions:

RQ1: Does lowered alertness currently occur in train driving?

RQ2: For what reasons do train drivers accept current technology?

This chapter is structured by the methods, then occurance of lowered alertness, and finally reasoning for acceptance of current technologies.

3.1. Method

Involving real train drivers was chosen as necessary to gain a grip of factors that are important to them. Semi-structured interviews were chosen as most suitable for practical reasons of easy access and planning of individual drivers. A semi-structured approach is useful to have an open conversation in which there is flexibility on what is said. Questions on alertness (sleepiness and smartphone use) and use of technologies (use of TimTim, ERTMS and ATB) were prepared. However, the interviews were held as much as possible as a conversation, naturally discussing the topics to maintain a casual atmosphere. These interviews were held either face-to-face, via telephone calls or online video calls.

Participant drivers were found for the interview via a platform within NS where personnel can find replacement tasks during absence, (called 'bureau tijdelijk werk'), meaning the sample may be biased in some ways. The focus is on qualitative findings, thereby looking for in-depth reasoning rather than statistical significance of use.

Four train drivers were interviewed, all with 20+ year of driving experience, based in the middle of The Netherlands. For informed consent, the drivers were informed orally that they always have the possibility to quit the interview or don't answer questions, and that they will always be kept anonymous.

3.2. Current Occurrence of Low Alertness

During all four conversations questions were asked on night shifts and how they dealt with their smartphones during shifts.

Train drivers mentioned various ways in which they deal with lowered alertness. One driver considered remaining alert as the main challenge of train driving, stating that a good driver in principle can control their own focus. Two drivers indicated that they are capable of staying focused, and if low alertness appears he can work through it fine. The final driver told that he often stands up during driving or when standing still in train stations, or turned the heather down. Three train drivers stated that, although prohibited, they sometimes look at their phone to check messages, and they said to be certain that many train drivers look at their phone during driving. They related this to driving periods in which the situation is considered safe and controlled, such as during a straight train track with good visibility to future signaling. One driver remarked that the job is very boring, and that a smartphone helps to stay active. Two train drivers said to be afraid that looking at their phone could lead to missing events on the track, such as a person on the tracks.

Two train drivers also mentioned their dislike towards the monotony and when they have little variation, as they feel it has bad effects on their alertness.

Train drivers responded differently to night shifts: one found them hard to deal with, while the others said they are okay with them. With most participants, they noted little problems.

It seems that sleepiness and distraction play a role as parts of alertness, as shown from their comments on night shifts, smartphone use. The low workload and monotonous environment seems to worsen their struggle with alertness. Also their reluctance of using smartphones, yet positive effects on alertness shows that staying alert is an important and challenging part of train driving.

The short responses also suggest that alertness is a sensitive topic in the context of smartphone use and night driving. This requires careful attention on which practical topics to talk about and phrasing of questions.

The mentioning of various ways in which train drivers are occupied with alertness shows that staying alert is a significant issue for train drivers, as they showed various ways in which they experience alertness. The need to address alertness is thus confirmed, showing that train drivers struggle to stay alert during driving. This is partly by their struggle with sleepiness during night shift. Also the struggle that drivers experience with using smartphones, using it to stay alert, shows that distraction is an important aspect. The focus on tiredness and distraction is a good primer for a theoretical approach on alertness.

3.3. Current Reasoning for Acceptance

Asking questions on what train drivers think of current technology led to insights on why train drivers currently accept technology.

The driver advisory system ('TimTim') was most prominantly discussed during the exploratory interviews. Reasons for using or not using it seemed to be centered on whether drivers found the device useful (speed optimization and mileage information) and how much hassle it is to use and prior experiences. Some drivers can find a technology useful for reasons that were not intended by NS, as follows that mileage information from TimTim is not the main reason the device was designed (which is to drive more punctually and efficiently by helping the driver to plan), yet some drivers seem to use it only for this reason.

Out of the 4 train drivers, 2 actually used TimTim. Two drivers indicated that they use it to plan ahead and to optimize speed. Although one driver didn't specifically remember why he started using TimTim, he did say that he found the milage information very useful while having contact with the train dispatcher, as the train dispatcher needs to know where the train is. Reasons not to use mainly consisted of the hassle of taking the tablet with them, including battery pack, and the hassle of putting the tablet in place, together with software and connectivity problems. The driver that doesn't use TimTim said that the had bad experiences with a prior version of TimTim. For him, TimTim could be capable of much more and the limited functionality isn't useful enough against the drawbacks of using it. One driver also mentioned that not knowing how to use TimTim is a big reason.

While also discussing safety systems such as ATB and ERTMS, that train drivers stated the safety systems incredibly useful to avoid driving through a red signal, as this is most important to avoid as a driver. ERTMS was also seen as useful by its even higher assurance to prevent driving through a red signal. For Orbit, a train driver discussed that the system does not always operate perfectly, such as tunnels in which gps-signals are poor, making him dissatisfied with the system. Drivers also made some notes on ATB. They liked driving with ATB as some said that is a great safety net. Two drivers said that they like the alarm sounds from ATB, giving useful information that they need to break and it helps them to make sure they don't drive through a red sign / perform a SPAD.

Hence, exploratory interviews showed that driver's reasoning seemed to focus on whether they find the technology useful in their job, and how difficult or how much hassle it is to use them.

4
Theoretical Framework: Attention & Alertness

Distraction and lowered alertness are seen as considerable causes of incidents, and turned out to be a relevant problem for train drivers, as shown by exploratory interviews (see chapter 3). DCM systems can measure behaviors that are related to distraction and lowered alertness. It is hence interesting to dive into theoretical insights of how to approach attention and lowered alertness, and how DCM could detect this. These theoretical concepts of low alertness and attention are useful later on to find out how drivers deal with alertness. In short, this chapter aims to find out how literature views attention and alertness, and how these concepts relate to DCM systems in the context of train driving.

The literature in this chapter was found by a literary review on driver distraction and driver alertness, found in Appendix A.

4.1. Exploring Alertness in Eye-based Condition Monitoring

Although DCM is generally seen as a technology that measures driver alertness, literature does not provide clear definitions of alertness, using a wide spectrum of words in the context of DCM's, such as alertness, vigilance, arousal and attention, and also talks about lowered alertness by using drowsiness, fatigue and sleepiness. (Oken, Salinsky, & Elsas, 2006). To still provide a general definition of the word, the Oxford dictionary defines 'alertness' as 'the state of being ready to see, understand, and act in a particular situation', showing that it is seen as a condition or state, relating it highly to perception/attention and the capacity to act. In this, literature does not show one single concept related to alertness that perfectly encapsulates this state to perceive and act, using different concepts in different situations. (Oken et al., 2006).

Alertness is for example often used to describe a physiological state of arousal, that can be measured with physiological methods to detect electric activity of the nervous system (such as EEG's).(Razak et al., 2022). This focus on arousal/nervous system activity however is not considered useful for considering eye-based measurements.

It is more appropriate to explore states of alertness that can be inferred by DCM's, and to investigate visual attention, also highly applicable to DCM's.

4.2. Vigilance and Related Alertness States

A central concept with drivers focuses on the ability to sustain attention: this can be captured by the concept of vigilance. (Oken et al., 2006) (Klösch, Zeitlhofer, & Ipsiroglu, 2022) While this relevant concept of vigilance is explored, the driver's state of fatigue and sleepiness can be explored as well. These states heavily influence vigilance, and can be inferred with DCM's.

4.2.1. Vigilance

Train drivers are demanded to sustain their attention on the driving tasks, such as monitoring the tracks and speed control. Here, vigilance refers to the human's ability to sustain attention on these tasks. Vigilance is concept that was researched extensively after the second world war in the context of human operators that need to monitor radar systems: a very monotonous task that requires sustained attention.(Mackworth, 1950). For these humans, it was found that performance of sustained attention (vigilance) tasks declines over time, mostly within the first 15 minutes. This decline is typically referred to as the 'vigilance decrement'.(Klösch et al., 2022) Later, Parasaruman et Al. provided a useful definition of vigilance for human drivers:

Vigilance = the ability to maintain focus of attention and to remain alert to stimuli over prolonged periods of time. (Davies & Parasuraman, 1982) .

Hence, vigilance is about sustaining attention on monotonous tasks, and hence highly relevant to train driving, as it involves monitoring the tracks for sustained periods of time.

In driving/transportation, multiple factors are known to impact this vigilance decrement: longer times of sustained attention and less demanding tasks (i.e. low workload) are more likely to lead to a decrease in vigilance. (Klösch et al., 2022)

Measuring Vigilance with Mind-wandering

DCM systems can potentially in the near future detect when drivers become less vigilant from sustained attention during driving, by detecting mind-wandering / daydreaming. To explain why mind-wandering occurs with a lowered capacity to maintain focus, (Thomson, Besner, & Smilek, 2015) theorizes that executive control (the ability to focus attention with effort) plays a vital role in the mind-wandering to occur. As the degree of executive control (ability to effortfully focus attention) slowly decreases of time, as the effort of focusing attention makes a specific brain area tired, the mind cannot control what to focus on. Hence, mind wandering occurs.(Thomson et al., 2015)

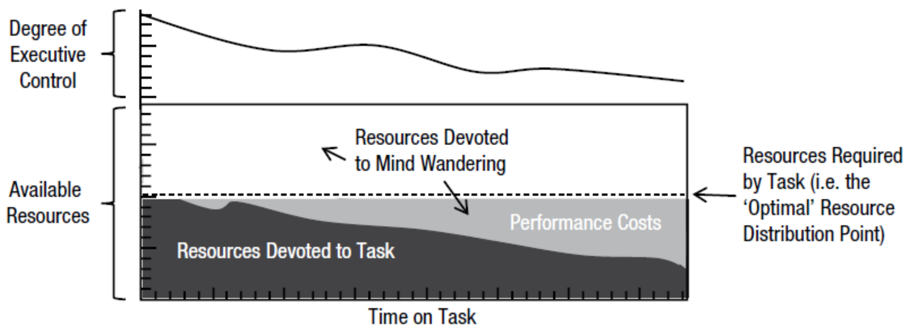


Figure 4.1: Resource control account of sustained attention explains how, over time, sustained attention leads to mind-wandering: actively maintaining attention (focusing with effort) makes the executive control 'tired' , leading to decreased cognitive resources that can focus on the task, leading to more cognitive resources on unrelated thoughts, such as mind-wandering. (Thomson et al., 2015)

4.2.2. States of Sleepiness and Fatigue

This ability to maintain focus is highly effected by the state of the human: literature generally distinguishes two types of low alertness states that influence vigilance: sleepiness, and fatigue. It hence makes sense to define sleepiness and fatigue. A good start is to analyze the definitions made in the in the European i-Dream project, as definitions were set on sleepiness, fatigue and drowsiness based on theoretical knowledge in the context of monitoring systems (Kaiser et al., 2020)

- 'Sleepiness is defined as the physiological urge to fall asleep, usually resulting from sleep loss. This can also be referred to as drowsiness or tiredness.' (Kaiser et al., 2020)

Some literature, especially in driving research, uses the term 'drowsiness', with aside from 'a propensity to sleep', puts a bigger emphazis on 'slowed reactions, reduced attention and impaired neurobehavioral performance'. (Cori, Anderson, Shekari Soleimanloo, Jackson, & Howard, 2019)

Sleepiness given as a state of a propensity to sleep, some literature distinguishes sleep from tiredness caused by tasks, called fatigue:

- 'Fatigue can be more difficult to define, despite being a related concept to sleepiness. It has previously been defined as the inability to continue a task which has been going on too long and can be due to factors such as monotony, workload (including underload and overload) and task duration'(Kaiser et al., 2020)

Some literature of mobility define sleepiness and fatigue as distinct concepts, while other literature only focus on sleepiness/drowsiness as one concept, assuming fatigue and sleepiness are similar enough in its symptons to join both. (Kaiser et al., 2020). Thus, although they are distinct physiologically, they are still highly related to each other conceptually, and als practically in monitoring situations: when sleepy, it costs more effort to stay vigilant, leading to earlier and more fatigue. Also in their perception, fatigue and sleepiness are both experienced as a feeling of tiredness, which might make it hard for drivers as well to separate them in practice.

Measuring Sleepiness/Drowsiness

DCM's are considered able to measure the state of drowsiness, in which it is considered that blinking behavior is an accurate measure of drowsiness. Various measures can be used, such as the blinking frequency, blinking duration, and percentage of eyes closed (PERCLOS) (Cori et al., 2019). However, literature is not completely clear on whether eye-blinking only measures sleepiness, or fatigue as well. For the aims of this thesis, sleepiness is discussed as a distinct concept of fatigue, as it is interesting to see how drivers experience tiredness, and whether measuring sleepiness is perceived differently than measuring mind-wandering from lowered vigilance.

4.3. Visual Attention & Driver Distraction

Seeing alertness as the ability to perceive and attend to information, visual attention is a useful concept to consider with eye-measurements, as eye-directions can say something about what people visually attend to. Also, it is useful to explore what it means to have a lack of attention, as incident analysis shows distraction as a considerable cause of incidents: when is someone distracted?

This section starts by exploring how eye-movements can give insights into visual attention, and then investigates how distraction can be conceptualized: when can the attention of the driver be said to be distracted?

4.3.1. Visual attention

Eyes play a crucial role in directing attention, and understanding the mechanisms involved helps understanding how eye-tracking technology works. First, it is important to revisit a general background how visual attention is build up: how do the eyes, and nervous system, perceive information?

Peripheral Vision and Foveal Vision

Eyes perceive (simply put) two types of visual information: peripheral vision and foveal vision. Peripheral vision consists of the outer area of the visual field and is sensitive to motion and general shapes, but lacks detail. Foveal vision, on the other hand, involves the central part of the retina called the fovea, which provides high-resolution and detailed vision. It is where our gaze is focused when we want to examine something closely. The difference is shown in figure 4.3: peripheral consists of a wide angle (+- 180 °), and its vision is out of focus, while foveal vision is highly focused and only covers a small area. (2°)

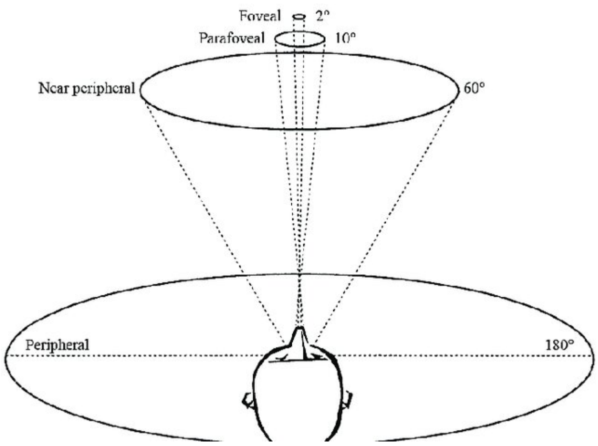


Figure 4.2: Peripheral vision and Foveal Vision illustrated. The Foveal vision of high focus is only two degrees, and guided by what is found important in sthe peripheral vision. (Ivancic Valenko, Cviljušac, Zlatić, & Modrić, 2020)

Figure 4.3 shows how the eyes perceive information: the foveal part is highly focused, while the peripheral part is blurry. The visual view is then built up by quickly scanning the picture with foveal vision, while the brain analyses and interprets this information to build a complete image. Detailed visual information must hence be literally followed by foveal vision. The eyes thus consistently move accross the visual view to built up the picture, while we interpret the picture as one whole, as the brains analyzes and combines all information. The eyes move fast between points to visually observe (called saccades) and then remains on a location to observe information (called fixations).

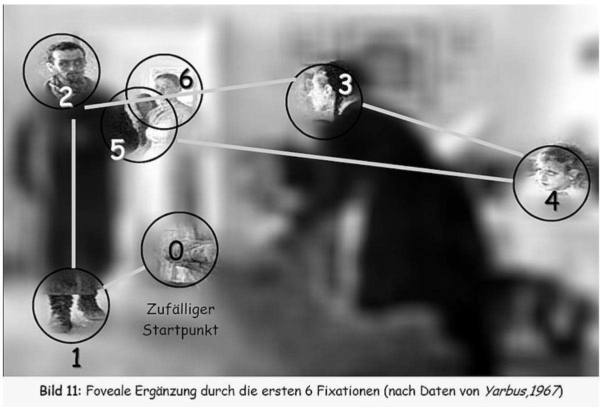


Figure 4.3: Example of eye-movements over photograph. Note that attention is guided by what is important (value), what moves (saliency). An expectation of a stimuli or attending to something with effort also guide eye-movements.

Color perception of the eyes

Next to 'sharpness' or 'detail', color is also perceived differently with foveal (+- 2 °of vision) and peripheral vision (spanning + 180 °) . This is because the foveal part of vision and the peripheral part of vision detect light with different types of photo-receptors. One type of these cells are rods: they are highly sensitive to the brightness of light. Then, there are cones, highly sensitive to color. They are distributed unequally: rods are mainly found in the peripheral vision, while cones are mainly used for foveal vision. This suggests that color can only be observed by foveal vision, suggesting that observing a change in color must be done by directly directing the small, foveal part of vision at it.

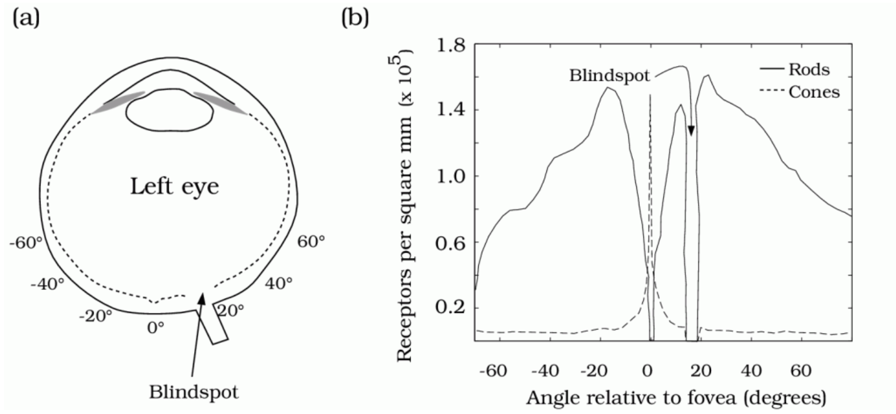


Figure 4.4: Anatomy of the eye, showing the retina (spanning the inside of the eye), which detects light, specifically showing the fovea at 0 °. The distribution of rods and cones shows that the fovea mainly consists of cones: detecting color and sharp vision, while the peripheral part of the retina mainly consists of rods: they detect the brightness of light and do not detect color.. Source of image: (Wandell, 1995)

Eye-direction as measure for visual attention

Although the eyes are a good estimate of where person is focusing on visually, the direction of the eyes is not per definition where attention is given to: you might think of /attend to something in your visual field, while not looking at it. Whether eye-directions relate to what is attended to is separate by covert and overt visual attention: While overt visual attention is the act of physically directing the eyes to a stimulus, covert visual attention is related to a mental shift of attention without physical movement. (Rai & Callet, 2018) Hence, using eye-measurements to assess where the attention is of a driver is not perfect, and an assumption must be made that the eyes directions are coincident with the driver's attention.

4.3.2. Distraction: a lack of attention

As incident research shows driver distraction a significant cause, suggesting that measuring visual attention and assessing whether he/she is distracted could be a useful function of DCM's. It is hence aimed to find out what distraction is, and what the relationship between visual attention and distraction is.

Defining distraction

In trying to grasp what inattention is, definitions were researched on driver distraction and inattention. The literary search showed different sources for defining driver distraction. (Regan, Hallett, & Gordon, 2011) (Donmez, Boyle, & Lee, 2008a) (Sheridan, 2004). One review on driver distraction discussed various definitions, and combined it into one definition to be used operationally, while being theoretically agreed upon by a group of scientists:

- Driver inattention = Insufficient or no attention to activities critical for safe driving (Regan et al., 2011)

The review discussed various aspects to consider in using any definition of driver distraction. (Regan et al., 2011)

Context specific

For one, it showed that it is hard to consider when an activity is safe: For which conditions is an activity safe, and for which unsafe? How can you determine if an event will lead to a bad outcome? Who determines which activities and when an activity is safe or unsafe? The context is thus highly important in judging whether an activity is safe at that moment.

Normative Judgment

Whether an activity is safe is also not objective: safe behavior is a subjective norm, agreed upon by a group of people, which could for example be safety specialists or managers. It implies that unsafe behavior is a judgment, made by people assigned to make that decision.

Hind-sight Bias

The review article also notes that driver distraction is a concept originating from safety incidents analysis: often it is determined in hind-sight whether an activity is unsafe, making driver distraction fallible to the hindsight bias. The article makes the point that in real life, often distraction only becomes a problem when the bad event has happened already. This makes the problem even more complex: it suggests that the line between safe and unsafe driving is vague in practice, or must be made concrete by people who have been authorized to make that choice.

Overall, driver distraction is a concept that is hard to link to actual visual attention, mainly since definitions don't specify when attending to visual stimuli is considered safe or unsafe. It is hence very much related to the specific context the driver is in. Also, determining of safe and unsafe behavior is in reality often made in hind-sight, and judged by a specific group of people, such as safety experts or management.

Hence, in practice, distraction is often made concrete by scoping unsafe behaviors to a relatively straightforward activity for safe driving, such as looking a sufficient amount of time outside the window. This is standard practice in car industry by assessing the eye-on road time, in which the threshold is typically set on 2 seconds of looking away of the road to asses unsafe attention. (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Still, this might sometimes not be ideal when cases exist in practice that differ from this practical definition of safe behavior.

In short, measuring distraction of drivers is hard as it needs to be chosen when activities of driving are safe and unsafe. This is prone to the hindsight bias, and the boundary of what is considered safe and unsafe must be chosen according to the specific context and knowledge on safety in that context.

4.4. An Overview of Alertness Concepts and DCM Measurements

The discussed concepts that are related to alertness have several similarities and overlaps, creating a highly inter-related image of how DCM measurements are related to the various concepts of alertness.

When laying out all types of measurements from the DCM system in the middle, and relating it to alertness concepts to measure, a complex image arises. Firstly, the given alertness types are by definition different types of concepts: Sleepiness is a physiological state, inattention as a 'lack of attention to critical activities', can be considered a mental state of focussing attention, yet also as a behavior of moving eyes. Whether mind-wandering is a mental state (being in a state of mindwandering), or a behavior (mind-wandering as an activity) is also not clear, as (Regan et al., 2011) defines mind-wandering as a type of inattention, while (Thomson et al., 2015) defines it as a state. Whether alertness is a behavior/action differs with the theoretical lens alertness is looked through. Sleepiness and fatigue also lead to higher chances and degrees of Inattention, making the concepts highly related to each other.

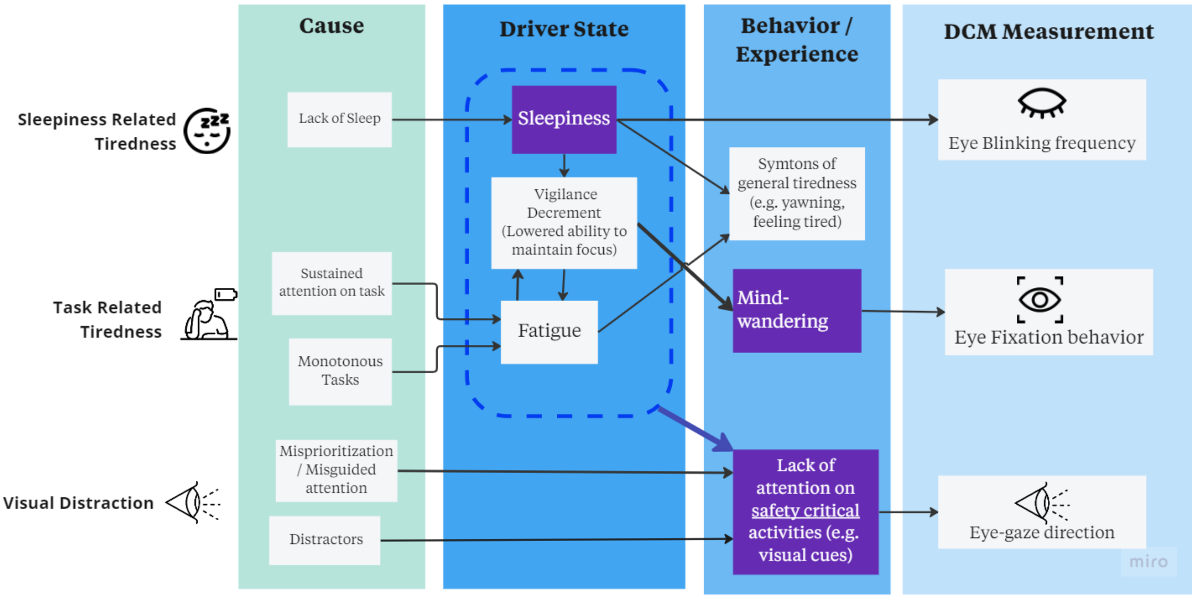


Figure 4.5: Schematic overview of discussed alertness concepts, For each alertness type, the cause, driver state and behavior is given together with how DCM measures these concepts. The figure shows that DCM measures distinct alertness types that are highly interrelated: mind-wandering is related to vigilance. The whole driver state can influence attention and lead to distraction. Concepts in purple are proposed as key concepts for further use, as they can be measured with DCM's.

5

Theoretical Framework of Acceptance

Exploratory interviews showed that usefulness of technology was important in the reasoning for current technologies. A literature reviews can explore what theories acceptance studies often use to propose insights to how technology may be accepted.

A literature review was performed on acceptance studies in mobility, shown in Appendix A.2.

5.1. Exploring Acceptance Models

A literature study on models used in technology acceptance research showed a small variety in used models. Most prominently, the Technology Acceptance Model (TAM) (Davis, 1989) is used in almost all found literature. In some cases, the Theory of Planned Behavior (TPB) is used. (Ajzen, 1991).

During the search of general acceptance models, additional models were found. This led to the Perceived Characteristics of Innovating Model (PCIM) (Moore & Benbasat, 1991).

Technology Acceptance Model (TAM)

Most widely used is the Technology Acceptance Model (TAM) (Davis, 1989), which states the perceived usefulness and perceived ease of use of the user as most important predictors for the attitude, intention to use and use of technology. Davis defines the perceived usefulness as "the degree to which a person believes that using a particular system would enhance his or her job performance." With defining useful as: "capable of being used advantageously " (Davis, 1989). Hence this definition is in the context of a job, with a focus on job performance.

Davis defines perceived ease of use as: "the degree to which a person believes that using a particular system would be free of effort." Using the definition on "ease": "freedom from difficulty or great effort'(Davis, 1989) A driving experiment on the evaluation of a feedback system asked questions on perceived ease of use by asking whether the feedback design, aside from ' is easy to use' also easy is 'easy to learn' and 'easy to understand'. (Roberts et al., 2012)

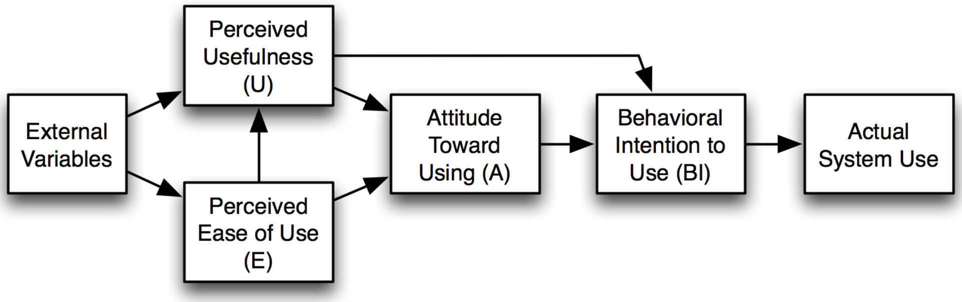


Figure 5.1: Technology Acceptance Model, explaining how a behavioral intention to use a technology is influenced by the perceived usefulness, perceived ease of use and attitude towards using the technology. With this intention, the model assumed that it will lead to using the technology, known as the intention-behavior gap. (Davis, 1989)

The technology acceptance model allows for 'External variables': variables that influence perceived usefulness and perceived ease of use. Literature shows an abundance of external variables from various contexts.

External Variable	Definition from source	Source
Result demonstrability	The degree to which an individual believes that the results of using a system are tangible, observable, and communicable.	PCIM model (Moore & Benbasat, 1991)
Output quality	The degree to which an individual believes that the system performs his or her job tasks well.	TAM extension (Venkatesh & Davis, 2000)
Job relevance	An individual's perception regarding the degree to which the target system is applicable to his or her job	TAM extension
Voluntariness of use	Degree to which the use of an innovation is perceived as being voluntary, or free of will.	(Moore & Benbasat, 1991)
Trialability	The degree to which an innovation may be experimented with before adoption.	PCIM model (Moore & Benbasat, 1991)
Subjective norm	A person's perception that most people who are important to him think he should or should not perform the behaviour in question	TAM extension (Venkatesh & Davis, 2000)
Unobtrusiveness	Driver distraction or annoyance due to warnings generated by a warning system.	(Roberts et al., 2012)
Trust	Attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability	(Ghazizadeh, Peng, Lee, & Boyle, 2012a)
Number of alerts	Number of alerts during experiment	(Roberts et al., 2012)
Image (social influence)	Degree to which use of an innovation is perceived to enhance one's image or status in one's social system.	(Moore & Benbasat, 1991)

Table 5.1: Summary of External Variables, with it's definition according to the original model, and the literary source of the variable

Perceived Characteristics of Innovation Model (PCIM)

Based on the TAM model (Davis, 1989) and the diffusion of innovation model(Rogers, 1962), The Perceived Characteristics of Innovation Model (PCIM) (Moore & Benbasat, 1991) focuses on innovations, taking the process of adoption as main focus.

For this, he defined five characteristics of innovation that influence an individual's attitude towards an innovation during the adoption process. (Rogers, 1962), PCIM aims to focus. The characteristics are as follows: (Moore & Benbasat, 1991)

- Relative advantage is the degree to which an innovation is perceived as better than its precursor.
- Compatibility is the degree to which an innovation is perceived as being consistent with the existing values, needs, and past experiences of potential adopters.
- Complexity is the degree to which an innovation is perceived as being difficult to use.
- Trialability is the degree to which an innovation may be experimented with before adoption.
- Observability is the degree to which the results of an innovation are observable to others, consisting of 'Results demonstrability and 'Visibility'
  - Result demonstrability is the degree to which an individual believes that the results of using a system are tangible, observable, and
  - Visibility

Many similarities between PCIM and TAM can be found: 'Relative advantage' and 'Compatibility' are related to the 'Perceived usefulness' of TAM, and 'Complexity' can be found similar as the 'Perceived ease of use'. Trialability can be specifically related to innovation context, and observability is by TAM conceptualized by external variables, such as result demonstrability.

Theory of Planned Behavior (TPB)

Another model found in literature for modeling user acceptance is the theory of planned behavior (TPB) (Ajzen, 1991)(Larue, Rakotonirainy, Haworth, & Darvell, 2015). The theory focuses on what concepts can influence a specific type of behavior by influencing its behavioral intention. According to TPB, this intention is influenced by the person's attitude toward the behavior, the subjective norm that person perceives of the people around him on the behavior, and its perceived behavioral control: how much control the person perceives to have on its own behavior. The model is more generally focused on modelling behavior instead of acceptance specifically. There is more emphasis on the social aspect within the 'subjective norm' concept, and on the driver's perception of own ability and extral factors ('perceived behavioral control')

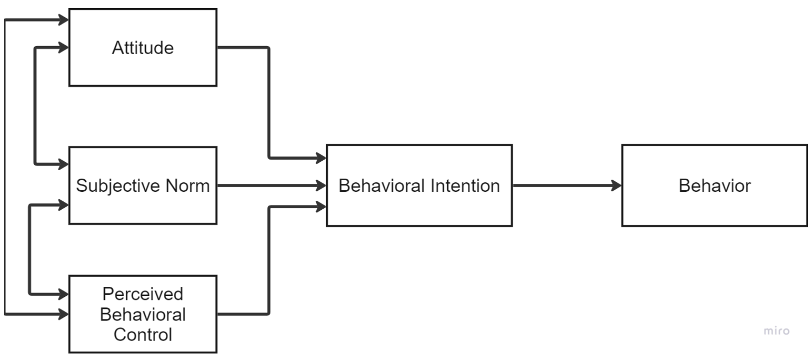


Figure 5.2: Theory of Planned Behavior(Ajzen, 1991)

5.2. Comparing Acceptance Models

Literature review included models such as the technology acceptance model (TAM), perceived characteristics of Innovation model (PCIM) and the theory of planned behavoir(TPB). These theories aim to model usage behavior by concepts that lead to a behavioral intention to use technology, which means they employ rational factors over emotional factors. It showed that TAM is widely used as a theory for technology adoption in mobility contexts, including automotive and railway industry. PCIM is used less, but the model is interesting as it uses more specific concepts compared to TAM.

Technology Acceptance Model (TAM) is a model that is used in most acceptance research, and provides a clear overview how perceived usefulness and perceived ease of use lead to usage behavior. Perceived usefulness can be a very relevant concept, with the focus on what the user believes to be useful. The focus on the user's belief is helpful as what the user finds useful is not always related to the goal the technology was meant for, as was shown in the exploratory interviews (Chapter 3) by train drivers using TimTim for different reasons. Perceived ease of use is somewhat harder to apply to feedback systems: driver's don't need to actively use a feedback system and make effort to use the technology, as such a system gives feedback on itself. An evaluative study of a monitoring system used the external variable 'Unobtrusiveness' as an extra concept to capture the amount of annoyance or disturbance an alarm yields.(Roberts et al., 2012). If the system can be turned on or off, the perceived effort of turning it on or off can also be seen as perceived ease of use. However, it is assumed that this is irrelevant, focusing on continuus real-time use.

The perceived characteristics of innovation (PCIM) is similar to TAM in its concepts, as some of PCIM's concepts are related to perceived usefulness and perceived ease of use.

The theory of planned behavior (TPB)' could be very applicable in this research of feedback systems in train, modeling behavior of using the technology. The concepts involved allow for deep insights into human behavior: it shows how the user's own attitude and capabilities, yet also its social surroundings, influence behavior. This could be relevant for train drivers as the social norms of drivers can be addressed with this theory. The theory is similar to TAM in that it leads to a behavioral intention, as the best approximation of actually performing the behavior.

Although the theory is useful and shows many relevant mechanisms for behavior intention, questions that would follow from this model can be sensitive to ask in practical settings to train drivers: Questions would relate to what users think the norm is, possibly leading to participants feeling judged or judging other participants. For this reason, this model is not used as theory to base questions on. In less vulnerable research settings however, such as anonymous surveys, the TPB model could be useful in modeling usage behavior.

In general, the models that are found seem to have slight different focuses: TAM focuses on technology use, PCIM focuses on relevant factors in the innovation adoption process, and TPB focuses on specific behavior.

5.3. Technology Acceptance Model (TAM) as Theoretical Approach

All models aim to influence the user's intention to use a technology, assuming, or given as a best approximation that it will lead to actual usage behavior (known as the intention-behavior gap). In other words, all theories that are discussed originate from goal-directed behavior by making a conscious choice to use the behavior. This is grounded in assuming rational decision-making by choosing to accept such a technology, making the implicit assumption that affective and motivational factors have little influence.

Comparing these rational-decision making theories, the TAM model is expected to be most useful as a theoretical perspective on acceptance in the case context, as it is used most extensively in current acceptance research and its concepts are more comprehensive than PCIM. Additionally, TAM can easily be fitted to case contexts by matching external variables (including concepts from PCIM or other acceptance concepts, such as trust and output quality).

Hence, literature showed perceived usefulness, perceived ease of use, and intention to use might be relevant concepts to model acceptance of DCM feedback systems with. Especially perceived usefulness of DCM's is interesting, given that driver alertness is such a sensitive and complex topic.

6

Methodology for Current Alertness Strategies and Acceptance Factors

For knowing what is required from a DCM feedback system to promote acceptance, understanding how train drivers experience alertness is important as it shows in what ways such a DCM can help. Already knowing that low alertness occurs, the next step can be taken to investigate how drivers experience and deal with alertness in current train driving. This leads to the following sub-question:
RQ3: How do train drivers currently deal with low alertness in practice?

To understand low alertness, literature showed sleepiness, mind-wandering and distraction as suggested concepts of low alertness that drivers deal with, and can be measured with DCM systems.

For acceptance, it can be investigated what acceptance factors are relevant for specifically DCM feedback systems in train driving:
RQ4:: What acceptance factors are important in the context of train driving with DCM technology?

Previous insights from exploratory interviews led to adopting the technology acceptance model (TAM), as it provides insights into acceptance of drivers by its perceived usefulness and external variables. The goal is hence to see whether their acceptance can be modeled by TAM, find which external variables are relevant, and research if any other acceptance factors are relevant.
To answer these questions, it is needed to gain insights into train driver's perspective on these subjects. From the exploratory interviews, alertness showed to be a sensitive topic to train drivers, as short answers and reasoning were given by train drivers on how they deal with night shifts and distraction. Also, how DCM relates to various forms of alertness showed much complexity, both by their conflicting definitions and theories, and high overlap in practice. Even more, acceptance theories have been used in scientific research on feedback systems, yet only in the context of car- and truck driving. Additionally, such models generally focus on rational decision models. It is not yet clear how these models, such as the 'technology acceptance model' (TAM), fit within the context of train driving. Because of all of this, a methodology is required that is appropriate for researching this sensitive and (theoretically and practically) complex topic. This means that a method is needed that allows to explore the full range of experiences on train driver alertness and perceptions on potential feedback design options.

6.1. Focus Groups as a Method

Focus groups could very well be appropriate. Focus groups are 'group discussions organized to explore a particular set of issues' and are fitting for 'exploring people's talk, experiences, opinions, beliefs, wishes and concerns.(Kitzinger, 2005) Its **qualitative approach** allows to 'reflect the full depth on how points of view are constructed and expressed.' (Kitzinger, 2005)' An approach that allows full-depth insights can be considered appropriate, as many aspects of the problem is unexplored territory: how drivers deal with alertness, and reasons why they accept technology is unknown, which means it is of value to remain open for new insights, and to understand their reasoning on a deeper level. For example, although is could be interesting to know whether perceived usefulness is important (which would require a quantitative approach), in-depth understanding why this concept is important, and gaining input of new insights other than this concept, is believed to be of high value to understand the complex topics of alertness and acceptance in this DCM train driving context

Group dynamics also play a vital role in these group discussions. Focus groups can give insights into the group dynamics, while the group dynamics can create different reasoning than individual techniques such as interviews. Whether focus groups are suitable for **sensitive topics** seems to be disagreement upon. Although there are many voices that refrain from bringing people together on a sensitive topic, some research even suggests that 'Sometimes people may be more willing to talk openly about issues when in a group of people with similar experiences than they would be in a one to one interview' (Farquhar & Das, 1999).
'Revealing dimensions of understanding that often remain untapped by more conventional data collection techniques, such as interviews', is another advantage of focus groups (Kitzinger, 2005). This is partly because 'group participants may actually develop particular (new) perspectives as a consequence of talking with other people who have similar experiences.' (Farquhar & Das, 1999) This can then allow for a shift, for example as hearing other's deal with the same problem can shift an attitude of 'self-blaming' towards a more self-respecting attitude. Revealing new dimensions, and possibly being appropriate for sensitive topic could be very applicable to alertness, as exploratory interviews showed train drivers sometimes blame themselves for getting distracted or tired.

Although there are conflicting viewpoints on whether focus groups can open up discussions on sensitive topics, or can impair the social safety and atmosphere, it is interesting to choose focus groups as it may shift their viewpoints on alertness to new perspectives on their alertness, which provides extra depth to their perceptions.

In other words, a focus group can be an appropriate methodology to get insights into the full depth of perceptions of train drivers on how they deal with alertness, and how they perceive a potential feedback technologies. Bringing together drivers with similar experiences might allow them to shift their attitudes (e.g. from self-blame towards self-respect), gaining a deeper understanding of how they perceive alertness and why they would accept potential feedback technologies.

6.2. Focus Group Set-up

The focus group was designed by setting up interview questions, reading literature and consulting various individuals. The people involved and their feedback that led to changes in set-up are listed in Appendix B.1.
To set up the focus group, questions were designed, a basic set-up was thought off, and some tools were used for some specific parts, such as using a case example and using design concept probes.

Questions to ask during focus group

Creating questions to ask to train drivers during focus groups were made from the research questions and theoretical concepts, shown in B.2. For the research question of alertness context, straightforward questions could be written, that asks for their experiences with low alertness, recognition methods and coping strategies. For researching driver acceptance factors however, it is impractical to directly ask what factors are important to them; it must be extracted from a discussion that is relevant in the context. For this, it was chosen to ask questions on possible feedback design concepts and questions on to the DCM system. The questions on feedback methods and the DCM system were separated, as feedback design and DCM measurement questions are expected to bring about different acceptance factors. Explaining DCM as a camera and eye-tracker could involve privacy and trust factors. For this reason, they are asked separately: first feedback methods, followed by measuring with DCM, as it is expected to be a more sensitive topic. A drawback from this choice is that it can be experienced as unclear how the feedback methods detect lowered alertness. However, it is deemed more important to start with a less sensitive topic than clearness of the full feedback method concepts.

Two train drivers were explained with the emphasis on DCM being a camera that measures the eye's behavior, while the office employees and two other drivers were given the emphasis on eye-tracking. Describing the system as a camera is technically correct as it's an infrared camera, however the only data that is exported is eye-tracking data, no visual images are captured. Hence, the association with a camera could bias their attitude. For this reason, after conducting the first focus group, the explanation was changed towards a device that measure where the eyes look, such as is being used in car and truck industry

Basic set-up

An important aspect of focus groups is to hear all voices, both receiving experiences and opinions of participants who like to talk, and participants who find it harder to express themselves. For this reasons, a tool is useful that as a first step helps participants think about and answer the questions individually, without being influenced by the other participants. For this, using posters with questions is useful, on which participants can give their answers on post-its. The answers on the post-its then help the facilitator guide discussion.

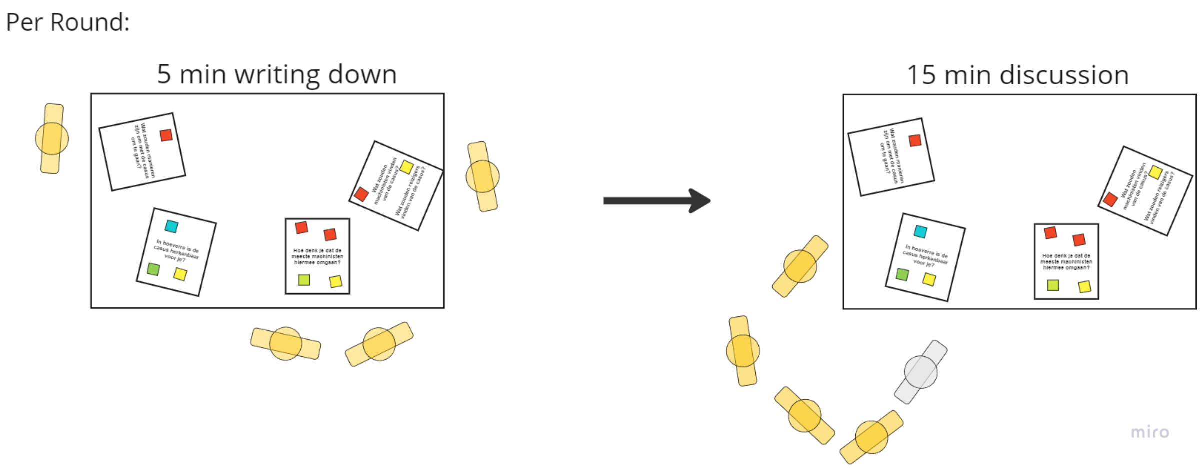


Figure 6.1: Focus group schematic of workflow for every round: individually answering questions on post-its, and discussing them in the group

An amount of four train drivers per session is seen as optimal. This was chosen partly as then group dynamics can lead to creative solutions, while still leaving much time to speak to every participant. Experience shows that groups of more than 4 train drivers are often harder to keep the topic focused.

Case example

In the first part, a case example is shown in order to make the topic of alertness approachable to discuss and open up the conversation of how train drivers deal with alertness. .The example consists of a train driver who experiences sleepiness, mind-wandering and a distracting event. The contents of the case-example was consulted by asking a team-manager for good examples, which led to using the GSMR telephone as example for distraction, and choosing a specific route that is considered as monotonous, and time that leads to sleepiness and is realistic. The case example can be found in Apppendix B.3.

Design probes of feedback systems

To discuss their opinions towards DCM feedback design, design concept probes were made to guide the conversation. To come up with these concepts, various design aspects of alertness feedback systems were found in literature:

An European program that studied feedback technologies for mobility defined important aspects, including message modality, and message functionality/goal.(Christos, Michelaraki, & Yannis, 2020) Additionally, some research on distraction feedback in driving defined various feedback timing aspects, including real-time and post-drive. (Donmez, Boyle, & Lee, 2008b). A literature review on active tasks that was also found useful in partial automated train driving, various secondary tasks were found that could engage the driver to improve vigilance. (de Bakker, 2024): extra tasks can hence help to engage the driver in the driving task. In the end four aspects were used that made up the concepts: DCM measurement type, feedback modality, feedback goal and feedback timing.

	Option 1	**Option 2**	**Option 3**	**Option 4**
Use of DCM measurement	Sleepiness detection C1	Eye gaze direction C2	Mind-wondering detection C3	
Feedback Modality	Visual C2	Auditory C1	Haptic	
Feedback Goal/Message	Informing C2	Alerting/Warning C1	Increase task engagement C3	Intervening C1
Feedback Timing	Real-time C3 C1	Post-drive C2		

Table 6.1: Morphological overview of possible design aspects with their options. Each option for each design aspect is listed in a random order . The colored names C# show which probing concept it was related to, thereby forming the probing concepts.

The designs that came out are as follows:

- Concept 1: An alarm goes off when you are too sleepy
- Concept 2: You can see on your phone if you looked away in specific situations
- Concept 3: If your are in deep thoughts, you receive an extra task to keep you engaged.

The concepts were written down on the posters, and combined with questions of perceived usefulness and intention to use (see Appendix B.2).

6.2.1. Sampling strategy

Finding sufficient participants was done in several ways, separating train drivers and NS personnel.

Train drivers

Train drivers were found in two ways: two train drivers were found through 'Bureau tijdelijk werk', an office within NS that matches employees who are unable to do their job, with side-jobs in order to keep them active. Taking part was voluntary, while they were asked by their team-managers to participate. Still, the voluntary aspects means the group might be biased towards drivers that are more positive towards changes in work-environment, and more open to talk about alertness.

Additionally, participants are found from a group of testing train drivers. This group used to be regular train drivers, yet now are full-time involved with driving trains as part of tests and experiments. They have experience with various new technologies and experience technologies throughout the testing process. With these experiences in mind, testing train drivers' attitudes and perceptions might be different from regular train drivers. For example, they might be more aware of limitations of new technologies that are tested.

NS personnel

NS personnel were asked to take part in a focus group especially made for personnel. These were invited based on their experience with train drivers, and personal connections within NS. Although they are highly selected on their function and experience, they came into contact with many train drivers, and hence can voice attitudes through experience with many drivers. Sampling in this way does have effects on framing the questions and answers from their own expertise (E.g a safety expert might frame questions from a safety perspective). This means that certain perspectives that train drivers do experience might be missing in the answers. Or put differently, their expertise might mask the driver's opinion. (E.g. a safety expert might be positive towards a design aspect as it influences safety, while drivers feel otherwise). To mitigate these effects, the aim of voicing train driver needs must be clear. Additionally, a wide range of function types helps, by widening the ways participants are involved with train drivers. This opens up more perspectives of train driver experiences.

6.2.2. Validity

Validity of focus group is effected mostly by the role of the influencer, social safety, group bias, and clearness of questions.

Influence and role of facilitator

It is highly important that the facilitator minimally influences the responses of the participants. For this, he/she must be as unbiased as possible towards the answers. To achieve this, the facilitator tried to refrain from giving value or judgment to answers ('That is a good answer') as much as possible. This could sometimes conflict with making sure participants are made at ease. For this, it was explicitly mentioned at the start that they are appreciated as driver experts, and that their opinions are valued and needed. This allowed the facilitator to respond more neutrally.

Social safety

There is a possibility that train drivers are unwilling to answer questions honestly for a variety of reasons. For example, they might feel uncomfortable as they generally perform their job on an individual basis, or might want to project the image of a perfect train driver. These aspects could be made worse in a group setting such as a focus group instead of individual meetings. For this, it is important to maintain an open atmosphere. This was done by asking questions that are non-judgmental and made non-personal, such as using a case example and emitting questions on social norms (What is the norm? etc). Next, an open non-judgmental atmosphere was actively created by the facilitator, stating to be respectful, that they are the experts on their field, and the general open attitude of the facilitator. The role of the facilitator was thus also to enforce a safe atmosphere by making sure all participants are heard, and intervening behavior that could pose negative effects on the social atmosphere.

Group bias

While talking in groups, opinions of a participant could be influenced by other participants. In order to mitigate this effect, there is an individual part in every round to write down answers on post-its, before discussing them in the group. As participants write down answers on the same poster, there is still a slight risk of copying other's opinion on post-its. However, it showed too much hassle to add another phase of writing individually. During the focus group pilot, the individual parts showed a good method of mitigating group effects.

Clearness of goal and scope of answers

In order to receive valid responses, the context of the research goal and organizational origins of the facilitator is important. In order for them to give valid answers, it must be made clear that the research is exploratory (design concepts are preliminary and have the goal to open up the conversation). Also, the context of the human-machine interaction team must be made clear, as the goal of the team is to analyze the effect technologies on the train driver's job. This helps train drivers understand why they are asked to help, and what input from them is needed.

6.2.3. Reliability

In order for the focus groups to show reliable results, various choices were made.

Standardization of questions

In order to present the questions in a uniform way, the questions were written on posters and stated on a PowerPoint presentation. This makes it more consistent on how questions were presented to the participants.

Data collection

Focus group sessions were recorded on audio, and posters with post-its were photographed. Taking care to analyze (transcript and code) in a consistent manner was done to promote reliability.

6.3. Ethical Risk Management

In order to safeguard ethical use towards the participants, an ethical application on the human research ethics committee of TU Delft was approved. This consisted of an ethical checklist to make clear the ethical risk mitigation plan, the informed consent form to inform participants on their use of personal data, and a data management plan that shows how the data is used and stored.

Ethical risk mitigation plan

The ethical checklist was filled in, identifying risks, with mitigation actions. The most important risks and mitigation actions are shown in the next table:

Identified Risk	Mitigating Action
Train drivers are interviewed as part of their job, and might **feel pressure to take part** in the research.	Make clear they are allowed to quit anytime without any consequences to the train drivers.
Train drivers are **dependent** in the long-term on conclusions: feeling of threat or pressure to conform could be possible.	Be transparent on MMI background and goals. It is important to be transparent on research outcome, and to be clear on realistic job implications this may have on their job.
Re-identification of train driver's answers and involvement in the research could have effect on them within the company, such as **reputational risk**.	Re-identification is prevented by anonimisation, leaving out indirect personal information and protecting personal data within the MMI team. In addition, questions are framed in a way that don't concretely ask for uncondoned behavior (smartphone use, sleeping during driving).

Table 6.2: Ethical risk mitigation of most important aspects that effected the focus group operation.

Data management plan

A data management plan was made to report on how the data is handled after the focus group. Making sure participants remain anonymous, personal data is only available to the MMI-team at NS. With this, personal information is stored separately from anonymous information, such as results. Only the author can link results to participants. Within NS, the participants are kept anonymous.

Informed consent

As participant's personal data was used, informed consent forms were filled in to get consent for use of their data, while informing how the data is gathered, how the data is used and what the data is used for. The informed consents are stored within the MMI team at NS. The informed consent form can be found in Appendix B.5.

6.4. Demographics

In the three focus group sessions that were held, four train drivers and four office employees took part: two sessions in which two train drivers per session participated, and one session with four employees from NS.

Session 1	Session 2	Session 3
2 general train drivers	2 testing train drivers	4 office employees

Table 6.3: Amount and type of participants in the held focus group sessions.

The office employees from NS are all involved with train drivers during their jobs. Three employees are involved as human factors specialists, of which one specifically focuses on safety, one on human factors research, and one who has a bakground in train driver education. Additionally, a team manager took part, responsible for managing a big (+30) group of train drivers. This manager also used to be a train driver. Working experience in their specialties ranged from of 0-10 years (2 employees), and 20+ years (2 employees).

The train drivers consisted of two 'regular' train drivers, and two testing train drivers, meaning that they are involved as train driver in driving tests for new technologies. Two train drivers are based in the west part of the Netherlands, while two others are based in the central part of The Netherlands. Two train drivers have between 0 and 10 years experience, while two train drivers have 20+ years of experience driving.

	Train drivers	Office Employees
Experience (yrs)		
0-10	2	2
10-20	-	-
+20	2	2

Table 6.4: Years experience of participants

6.5. Analysis Process

Answering the research questions consisted of themes of alertness, and acceptance from what was said during the sessions (recorded by sound recordings) and what was written on post-its that were placed on the posters.

To make sure that all relevant aspects are found that were discussed, it was needed to transcribe and code all the responses. To make results traceable, the transcription presents what respondents answered, who answered them and at what time within the recording. For time efficiency some parts were excluded, such as the introduction and explanations of questions. One transcription was transcribed as complete as possible as reference for supervisors.

Coding was done by first setting up a coding structure according to theoretical concepts of acceptance and alertness, and job characteristics that are relevant for the goal of forming design requirements. The coding structure was then optimized during two iterations of coding, iteratively forming the final coding tree. These iterations were necessary as new aspects appeared relevant, and the elaborateness of aspects differed between sessions. (An aspect may be discussed elaborately in one session, with only a brief discussion in another). In this, it was aimed to focus on what the sessions had in common, while keeping some amount of uniqueness of every session. The final coding tree can be found in Appendix B.6.

7

Results: Current Driver Alertness

Already knowing that drivers do recognize lowered alertness during driving, it was also needed to understand how drivers deal with alertness:

RQ3: How do train drivers currently deal with low alertness in practice?

During the focus groups, it became apparent that train drivers deal with alertness in a multitude of ways: they are aware of various aspects of low alertness, and they explained several ways that help them recognize that their alertness is low, as well as ways to deal with being less alert..

Results aim to show what aspects were named, and how many participants named these aspects. This amount is often notated as (x/4, x/4), by showing respectively how much of the train drivers, and how much of the office employees mentioned this aspect.

7.1. Perceptions of Types of Low Alertness

Answers to the case example at the first round already gave insights into which alertness concepts participants recognized (i.e. sleepiness, mind-wandering and distraction), and what they associated the concepts with. As a starter, all participants found the case example recognizable in general. What about the concepts of sleepiness, fatigue and not attending to important events?

Sleepiness and Fatigue

All train drivers and office employees recognized the general feeling of tiredness. This tiredness was in most cases attributed to sleep related aspects. All train drivers recognized being sleepy, as they all related to the difficulty of irregular shifts, as the location and time of shifts change continuously. The office employees all recognized the driver's challenge to sleep well with these irregular shifts. Also night shifts in particular were recognized. Other than the shift irregularity, drivers answered aspect that were related to the interplay between work circumstances and personal life circumstances, such as personal events in the private time that could cause being sleepy the day after. Some also stated that resting after a shift, during the daytime, interferes with their personal lives.

Interestingly, participants (3/4, 1/4) related sleepiness much to their responsibility: they make comments that they feel responsible to take measures to not be sleepy, and feel in control to take such actions.

Feeling tired attributed to the monotony of tasks and it requiring sustained attention was also recognized, all be it often hard to separate from sleepiness. Variety in shifts, such as changing routes, on the other side, lead to ' more alertness'. They do mention 'zoning out' (2/4), 'being in deep thought' (2/4, 0/4), thoughts that wander away (0/0, 1/4) and 'attention too much separated' (0/0, 1/4).

Specifically mind-wandering due to task monotony and sustained attention were only recognized by office employees. Some train drivers did recognize mind-wandering, but related it more to intense thoughts and worries on personal or work related situations. Two train drivers also discussed the automaticity they experience during monotonous shifts, experiencing that they correctly carry out all tasks, without being actively aware of what they're doing, not remembering what had happened.

When asking specifically whether they experience mind-wandering, most train drivers related daydreaming to (personal or work-related) circumstances or events that require attention in the mind and lead to thoughts. (3/4, 2/4)

Distraction

The train shift leader calling on the GSMR (telephone) in the case example, intended by the author as as a distracting event, was reacted to mostly as not being distracting. One employee reacted that it might distract the driver, however all train drivers did not perceive the GSMR as something bad at all: it can activate the driver, as a call happens unexpectedly and can be quite important, even being a nice activating event. After asking whether the GSMR can distract them, two train drivers noted that it is not so much about distraction, as it is their job to keep their attention distributed, and prioritize what to attend to.

Additionally, attending to important events was sometimes often related to rules and regulations, such as prohibited use of smartphones and situations in which GSMR use is prohibited.

Also missing yellow signals was not recognized: all drivers stated that yellow signals are that salient, that it is impossible to miss them. Some even explained that yellow signals are perceived without directly looking at it, from the corner of the eyes.

Interpretations

It seems that train drivers are much aware of being tired, and attribute this tiredness for a big part to being sleepy, being less aware of becoming tired from the driving task itself. Mind-wandering seems to be perceived as unrelated to alertness: they associate it with disturbing thoughts. Distraction seems to be a sensitive topic, as drivers feel highly responsible to correctly attend to important information, talking about attention distribution and prioritization, rather than what could distract them. They also highly relate it to rules they have to comply with (not using smartphone or GSMR), either focusing the topic on how to manage attention, or focusing on whether they comply with rules. Train drivers also feel some visual stimuli are very hard to miss, such as the salient color of yellow signals.

7.2. Ways to Recognize Lowered Alertness

During the focus groups, participants mentioned various methods to recognize lowered alertness, and showed diverse ways of dealing with these situations of lowered alertness.

These ways of recognizing low alertness consist of ways in which the driver self-assesses internally, and ways in which they use external stimuli as a cue that they are less alert.

Internally within themselves, participants noted symptoms of tiredness and losing some kind of awareness as cues for lowered alertness. Although participants described a general feeling of tiredness, such as feeling the need to rest, and more specifically the tendency of eyes to close was named by 2/4 train drivers and 1/4 employees. They also stated being less aware on tasks (2/4, 1/4), and being unaware of where you are (3/4, 1/4) as self-notifying cues of losing awareness.

External to themselves, participants said they know to be less alert from noticing there performance decreases: Many explained that missing information was a big cue for knowing you are less alert, as 4/4 train drivers and 2/4 employees stated. This included not being sure what color the sign was that they drove by, or the dead man's pedal causing an alarm sound (3/4 train drivers and 1/4 employees), having missed the light notification.

It was notable that there was discussion on how well the dead man's pedal helps with detecting low alertness: Many participants (3/4, 3/4) said that drivers after some driving experience 'automate' the dead man's pedal. Other technical systems used to recognize low alertness were the ATB alarm going off (2/4, 3/4). Lower reaction time was also named by 1 driver and 1 employee.

Interpretation to recognition methods
Various methods help train drivers in recognizing they are less alert. Mostly named were missing information, such as signals, and receiving feedback from dead man's pedal and ATB, and realizing that you are unaware of where you are, showing that drivers use mostly driving related aspects to assess whether they are less alert.

7.3. Strategies to Cope with Lowered Alertness

A multitude of coping strategies were named which showed that train drivers have a multitude of methods to increase their alertness.

Change cabin environment
One important methods is to change the surroundings of the driver, more specifically by creating more or less stimulation/activation of the senses inside the cabin. A lower temperature in the cabin was named by every driver and two employees, as they said it makes them become more alert. In case of a great amount of lower alertness, asking the train manager (HC) to join the cabin was helping a lot for 3 out of 4 drivers, and all employees agreed. More generally, two train drivers noted that minimizing comfort helped to stay activated. Social talk was also named by two drivers to help greatly, as they experience it as a pleasant way of activation, on the condition that they talk to a person they enjoy talking to. There were also aspects that were related to decreasing the amount of stimuli. Three employees noted that a dark cabin at night is more comfortable, making drivers more able to keeping their attention on the tasks, as tiredness could decrease their capacity to stay focused. Some employees came to the conclusion it depends on the driver at that moment if they need more or less stimuli to stay active.

Self-activation
Another way of dealing with low alertness was to activate yourself. Simply making even more of an effort to focus on driving was named by three train drivers, which was also accompanied by statements of responsibility: a train driver is responsible for their own alertness, and just pushing the limit of your focus was a major way of keeping attention sufficient, like motivating yourself (' Focus, you can do this').

Train drivers and employees also said physical movement was effective (2/4 drivers, 1/4 employees), such as stepping out of the cabin during train stops, sitting in an active posture, or standing instead of sitting while driving. Eating and drinking also helped for 2 drivers and 1 employee, while another driver also noted the tiredness after eating as something that doesn't help.

Another way of self-activation that was named was to engage yourself by actively participating in tasks. Talking aloud in relation to a driving task was found helpful by 3 out of 4 train drivers and 1 employee, in which calling aloud signs (described as the 'point and call' method) or pointing to other objects, and running through checklists were stated. Some drivers also said that it helped to think about something task-unrelated, such as hobbies, during driving.

Another strategy that helped to keep themselves engaged according to two train drivers, was to challenge themselves to perform even better at driving. This meant for them that they aimed to keep their driving speed exactly the same, or tried to decelerate as smoothly as possible, without passengers noticing the train's deceleration.

Interpretation of Coping Strategies Train drivers have adopted a multitude of ways to keep themselves alert, as controlling the temperature in the cabin seems to be much used. It seems to be that sometimes drivers need more stimulation (e.g. talking to colleagues and taking a walk during stops), but other times require less stimulation to focus (e.g. dark cabin). This might be highly dependent on the situation and individual preference. Hence, it could highly vary between individuals and situations if train drivers require more, or less stimulation when being tired. Methods taught during training are widely used as well, such as physical movement during stops, and using ways to actively participate in driving (e.g. speaking aloud what you see). Also notable is that sometimes drivers use simple willpower.

8

Results: Acceptance Factors

To understand for what reasons train drivers would accept a DCM feedback design, the following question was asked:

RQ4: What acceptance factors are suitable in the context of train driving with DCM technology?

The focus groups, and its analysis, led to a wide spectrum of factors that drivers mention to be important for accepting DCM feedback. Results aim to show what aspects were named, and how many participants named these aspects. This amount is often notated as (x/4, x/4), by showing respectively how much of the train drivers, and how much of the office employees mentioned this aspect.

8.1. Perceived Usefulness

Train drivers and employees made many comments that are considered part of perceived usefulness. To structure all responses, they were categorized in what they recognized to be the problem ('Problem Awareness'), if they find the goal useful, and what the relative advantage is of the technology to achieve those goals.

Problem Awareness

As explained during the alertness results in the previous chapter (chapter 7), train drivers recognized some types of alertness more than other types. Whether they recognized it was also given as reason on whether they found a feedback system that measures that type of alertness useful: Tiredness as a form of sleepiness was recognized by all participants, while tiredness from tasks was less recognized. Mind-wandering was related to intrusive thoughts on personal lives, thus not seen as a problem of alertness. Also distraction was not so much recognized. It was either related to keeping distributing attention and prioritizing what needs to be attended to, or to complying with rules that are part of driving. Either way, they did not perceive a system that measures whether a driver is attending to important event, as useful. For example, detecting whether a drivers looked at a yellow sign was not seen as a problem, as they say that yellow signals are hard to miss in the first place.

Goal of Technology

Also as part of the focus group, participants were shown design concept ideas, containing various goals of the feedback in them. In this way, goals within the concept were to inform the driver, alarm the driver, intervene, or engage the driver with an extra task, such as listening, talking and moving.

All participants in some way discussed what function of such a system they would like: as a safety system or a supportive system. Discussing these goals, opting for any of the goals was firstly related to whether the goal is to pro-actively prevent situations, or to re-actively react to situations. Re-actively, all participants liked the idea of using action, or vehicle -based detection, as one employee noted that perhaps multiple smaller mistakes could be good fitting measure of alertness and safety.

For the employees, this led to the discussion of whether the feedback should be a safety system, or a supportive system, by discussing that you would like to alert the driver beforehand, yet detecting unsafe-events is could be more reliable when it happened already from concrete actions:

> (A first employee) Its very easy to use the driving strategy as a basis (for measuring alertness related aspects).
> (Another employee) Yeah right, that happens..
> (The first employee:) And actually, that's not what you would like to do with this. Actually you would like to support the driver with it. Saying: I will wake you up, or make you alert, such that you can decide your own driving strategy. It shouldn't be about prescribing the driving strategy to the driver. That's what makes (giving feedback on alertness) so hard.

One pro-active goal, train drivers made many comments that signified they want to be informed by supportive devices, such that they can actively use it.

However, what if the situation requires the immediate attention from a safety perspective? From safety reasoning (such as falling aspeel completely), participants more re-actively move to from a need to inform to strongly towards 'alerting' and more alarming ways of giving feedback.

This led to mainly employees discussing the boundary between informative warnings and alarming 'safety' warnings. The measuring aspect led discussions that showed a paradoxical trade-off: more reliable information means using more concrete measurements, creating the tendency to use information while it already happened, leading to more re-active feedback systems.

Three employees concluded that multiple feedback moments are useful: as an informative warning, and as an alarming warning signal. The gradation in goal was linked by them to the gradation in feedback message from the signal gradations in messages also came up, with the dead man's switch and ATB given as example, also as tools that first alert non-invasively (light alarms), then become invasive (alarm sound), before intervening.

Also for getting an extra task to keep you alert, all drivers said that they don't see the reason why, and want to understand the goal.

Relative Advantage

Although many drivers did perceive a problem with tiredness, and agreed with the goal of giving feedback, some belief deeply that the current technology is already good enough at that job. For example, all participants deemed the dead man's pedal very useful at alerting them if tired, yet also experience that they, without conscious action, automatically activate the pedal. Based on this 'automaticity' (as some described their feet hitting automatically), all participants agreed that the dead man's pedal could improve. However, not everyone agreed on whether the added benefit of a new technology was worth the trouble: some saying it might be useful, while others found any other benefit not needed.

> (A first driver): (..) You can hear the sound of the dead man's pedal, you know it when you hear it.

> (A second driver): Hm, I don't think the dead man's switch is the holy grail in intervening within my job. But that's my opinion.
> Facilitator: So the dead man's switch kind of works, but...
> (The first driver:) It's kind of effective, the dead man's switch. It does what it should do, right? If you pass out, then your feet drops from the pedal, and the train will surely stop. It's more that you can become in a state of..
> (The second driver:) Yes, indeed with being tired, i think that.. I can imagine that colleagues use it kind of instinctively.

Also comments were made on intervening, that stopping the train has certain costs, such as delays and the train shift controller calling in, that are only outweighed by big benefits or needs, such big safety situations.

For an eye-gaze system that checks if all signs were seen, all train drivers and one employee with driving experience noted that they find yellow signs particularly hard to miss due to the striking color of it. One train driver also noted that they don't need to look directly at the signal, describing how their periphery of their vision catches the bright yellow color before they actively look at it.

Two train drivers also mentioned that they cannot think of specific experiences in which an eye-tracker would have helped them cope, not seeing the relative advantage in terms of their experiences with unsafe situations.

Interpretation of Perceived Usefulness

It seems that next to the design being perceived as advantageous, often train drivers did not see the problem as relevant, and found various goals of the technology appropriate for different reasons. These goals sometimes contradicted each other, as pro-active feedback is perceived less reliable, while re-active feedback is seen as more reliable, yet also less useful if the alertness is already too low. Especially in comparing design concepts with the dead man's pedal and their own capabilities, the relative advantage came up by discussing whether the advantage of using DCM is big enough.

8.2. Acceptance Factors related to Perceived Usefulness

There are several factors from literature that impact the perceived usefulness (see table 5.1), of which the most relevant turned out to be the reliability and accuracy of the system ('Output Quality'), whether the technology is applicable to the job context ('Job relevance'), and whether the results can be demonstrated ('Result demonstrability').

Output quality: accuracy and reliability

During the sessions, many questions arose of how sleepiness, mind-wandering and visually missing certain tasks would be measured. (As DCM was only explained at the final part of each session). The accuracy and reliability concerns for all train drivers, and also two employees. Train drivers were for many alertness types unconvinced that it is measurable, one driver doubted if mind-wandering could be measured by staring:

> (A train driver:) And you were talking about staring. But train drivers of course stare at the red signals outside throughout the day.

Also for using the eye-gaze directions, train drivers had doubts whether measuring eye-gaze directions was reliable to know whether looking at events is correctly captured by the device, such as detecting if drivers look outside the window or look at signs.

For all participants, the reliability and accuracy were mentioned often together with the threshold sensitivity of an alarm or alerting system.

Three train drivers deemed it also essential to be able to cover specific situations. For example, three drivers describe Orbit as unreliable, describing experiences as receiving loud alarms at irrelevant situations, such as driving low speeds during parking. On this issue, train drivers agree with each other.

> (Facilitator:) Wat are your experiences with Orbit?
> (A train driver:) No, it doesn't work well.
> (Another train driver:) I understand the idea. But how it is calibrated, it startles you.
> (The first train driver:) That's right.

All office employees made comments that reliability of the technology is a self-evident need.

Job Relevance

Several factors were named that were related to whether DCM feedback is applicable to train driving.

In a discussion on the use of post-drive feedback (feedback from the shift received afterwards) or real-time system, all participants from two sessions (2/4, 4/4) perceived no usefulness in such a design. Reasons were that there is no perceived need to do anything after successfully completing a shift is done enough apps already. Also, as the proposed goal to learn attention methods during post-drive feedback was not seen as useful: drivers are glad when they safely finished a shift, and feel no need to look back and reflect (2/2). Also office employees did not resonate with the goal of learning about your distractions post-drive, as they see the real-time safety aspect as more important.

Job aspects also came up when participants expressed their hesitance towards the DCM intervening as feedback, by stopping the train (6/6 expressed hesitance to intervene and was not discussed during one session). Two train drivers said that there is no use in stopping the train if not alert, as it doesn't help your alertness. Employees were more willing to consider intervening, although they carefully consider to use an alarm for safety-related purposes.

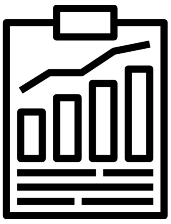
> (An employee:) I would almost say, if someone is this tired, I would even say intervene. Although I'm not a fan of intervening.
> (A second employee:) An alarm should already be enough.
> (A third employee:) Yeah
> (The second employee:) Because if you start intervening, you have to think on a different safety level .(...) And then it already becomes a big thing, right? An unexpected stop must be called in at the traffic dispatchers.

One employee also noted that when considering eye-directions and its feedback, train drivers don't learn standardized 'viewing strategies', such as they are used in car-driving with handling mirrors. Because of this non-standardization, he noted, it may be hard to even decide where the eyes should look at certain times.

Some aspects related to comparisons to the car industry. For example, drowsiness mitigation systems in cars were naturally brought up by all train drivers and some employees (4/4, 2/4). An office employee noted the neutral communication style that car-drowsiness detection systems emit ('Tiredness detected'). Two train drivers explained that they have a neutral attitude towards the sleepiness systems in cars, but that they completely ignore what it says, as they say they know themselves if they are able to drive a car.

When asking whether eye-tracking could be interesting as it is used in car and trucking industry, the differences between car / truck driving and train driving came up, such as the immediate effects of making mistakes (mistakes in steering directly lead to unsafe situations in car driving, while steering is not applicable in train driving.

Also feedback on driving/action-related measures were by some drivers preferred over using eye-directions, which they related to their experiences with car-industry, in which they perceived steering-wheel measurements as a nice measurement. Also, the involvement of real effects of their actions seemed to be relevant.



Result demonstrability

Train drivers also made comments that related to their need for concrete information whether such systems show results. One driver said that he/she want to see prove in the future whether using such a system would actually lead to less safety incidents. It was also asked by some participants whether such a system is already proven useful in car-industry.

Many drivers mentioned that seeing reported safety effects would help them (3/4, 1/4), for example that incident numbers would need to be measured throughout years before implementation, and that proof should be given from other industries such as the car industry. Also someone noticed that he thinks Orbit is a good system as he heard many SPAD's were avoided because of this.

Interpretation of factors that lead to perceived usefulness

For reliability and accuracy, many answers showed a general tendency to use reliable data, getting more into measuring behavior when it already happened. Participants seem to be critical, sometimes even doubtful whether behavior is actually measurable.

Various job aspects in driving are relevant to how drivers perceive DCM as useful. Shift-based work after which drivers want to get home led to little perceived usefulness of post-drive feedback, while literature from research in car-driving on distraction feedback suggested post-drive as a non-intrusive feedback method, in which learning safe driving habits in safety-critical situations could be useful. It is not known whether car-drivers accept post-drive feedback, as this literature focused on driver performance, not on driver acceptance. (Donmez et al., 2008a).

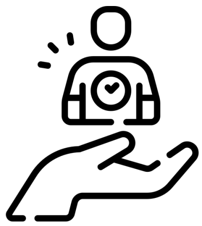
The difference between the nature of car-driving and train driving might also be relevant here: train drivers drive as part of a very responsible job and involves a less complex environment than car-drivers. The goal of educating yourself on distraction might be different for voluntary leisure use in car driving, than professional use for which train drivers are thoroughly trained already.

Real-time was thus seen as more useful to directly give the train driver information, support or safety constraints.

Demonstrating results also showed to be relevant to a big portion of participants. Especially safety benefits, such as prevented SPAD's because of the technology, seems to be highly relevant.

8.3. Competence and Autonomy

Apart from factors on the usefulness of a technology, train drivers and office employees also mentioned many aspects related to the driver's competence and autonomy of a train driver, specifically in their responsibility as a driver, their capabilities to stay attentive, and their attitude towards over-relying on technology.



Responsibility: being competent and have control to carry responsibility
Responsibility was something that became a topic throughout many discussions. One aspects of this responsibility is that two train and two office employees said technologies shouldn't be 'patronizing' ('betuttelend') to the driver. Competence to stay fit to drive was also noted by all participants. For example, two train drivers argued the extent to which the driver should be capable of taking care of their own alertness. During a discussion on whether to use eye-tracking, two drivers said:

> (One driver) It's not that I've got a problem with it, but I think that I don't need it. Because I'm good enough myself, I can take care of my own body.
> (Other driver): Although the fact that everyone, every train drivers experiences moments that they are tired.

When asked what they think about supportive devices, two train drivers did not fully agree on whether it is the driver's responsibility to deal with the situation without technology. One driver related his responsibility to his honor of his job, and that it is his final responsibility to drive safely:

> (A first driver:) And that's what I'm being payed for, and what I was hired for. And I also think that's a matter of honor. I think train driving is not just some profession.
> (Another driver): But still, there could always be situations that, especially at the beginning of a driver's career, that..
> (First driver): True, but I do not think that you can solve everything with technical supportive tools. You can try to seal off everything, but you are also responsible as a train driver. (...) I also think a train driver could be called out on it: listen up. Make sure you are fit to drive, take care of your own body. We're going for a psychological evaluation. (....)

This responsibility was thus also related to staying fit, and having final responsibility.

Responsibility was also found during discussions on giving drivers an engaging extra task.Two employees and two train drivers said they don't need something else to start them engaging in driving: train drivers should be well competent in noticing their alertness and re-engaging themselves by coping strategies (as discussed at section 7.3)

Also, comments were made by all drivers and 2 employees that information to the driver as support is highly preferred in using technologies, giving examples that TimTim helps in anticipating traffic (2/4, 0/4) and the driver-machine interface from ERTMS (2/4, 0/4) (specifically the end-of authority visualization) helps them visualize when they need to break. Their reasoning included that they like that it is the driver's choice if they want to use the information and that they find a supportive tool ('hulpmiddel') useful and harmless if they can choose to use it. All drivers made comments that the driver should be able to chose if they want to use the information, and what to do with it, for example when explaining how some use driving with ERTMS:

> (A first driver): Let me explain it like this: it's always possible to close the curtains, and you can use the driver machine interface. You see the end-of-authority: you can see the distance decrease, and you can control the train within 10 centimeters before the end-of authority with the curtains closed.
> (Facilitator:) So that works nicely?

(Another driver:) Well yes, because you can stay in control yourself.
(The first driver:) You are in control yourself.

They also relate their responsibility to their need to stay in control. Even more, a driver made a strong comment on staying in control:

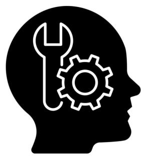
(A driver) 'I am in control, when I'm driving, I'm in control, not TimTim,'

Interpretation of Responsibility
Drivers seem to agree and disagree on several aspects of their to competence to be responsible. There are differences between drivers: some drivers feel that their competence as a driver suffices, or should suffice, to carry out this final responsibility. Others do see opportunities to be supported in this final responsibility, possibly by technology.

Some train drivers emphasize that they must be relied upon: it is part of their job to stay alert, be in control and take suitable action. Even if this has negative consequences, such as a psychological re-evaluation with potential to not being able to drive, it is part of your professional workmanship ('vakmanschap') to stay responsible. Other drivers are more aware of situations of potential lowered alertness, and are more open to support from technologies.

All in all, train drivers seem to value their responsibility greatly and if technologies are used, they want it to support this responsibility. Although they seem to find informative and voluntary technologies useful in their jobs, also their competence to be responsible seems to be a key motivator to perform their job, shown by their needed competence to stay fit, have honor in their jobs and feeling of being fully responsible in the end.

Attention capabilities
Aside from the driver's general competence to drive responsibly, many aspects were named that were specifically related to the driver's capability to stay alert and attentive. As a start, all participants named that train drivers should be competent in staying alert.



This can be exemplified in a discussion on whether drivers feel like an alarm, such as Orbit, is needed in the first place, as some drivers noted (2/4) noted that competent drivers would not even come near alarms from Orbit:

(One driver): And that (alarm) system, Orbit, which you named, nice supportive tool, yet not necessary at all. If train drivers are not alert enough, then that device is only useful when all else fails. And really, you do not want to hear (the alarm). Because you know, if she starts talking, you are already far too late, and the train driver is not alert enough in the first place, and didn't correctly interpret the yellow signal in the first place.

A big part of this competence related to the driver's prioritization capabilities, noted by all participants. All drivers noted that they need to keep their attention 'distributed' in order to be able to prioritize what they need to attend to. A train driver then noted that with this 'distributed' attention, it is possible to make choices accordingly. For example, if the driver is called on the GSMR, he can choose to lower the speed, in order to be able to handle the call.

Many participants (3/4, 2/4) also mentioned assessments during the selection process that tested driver's attention capabilities. Often these were brought up on discussions whether train drivers aren't already good enough to keep their attention.

Two employees noted prioritization by train drivers needing to choose whether they require more stimuli or less stimuli to stay alert, and that you need to know of yourself when you need more or less stimuli to be more alert.

All employees also agree on that train drivers are actively prioritizing their attention, and they feel like drivers are actively prioritizing on what to give their attention. The employees also, in full agreement, said that giving feedback on their attention could feel like a threat to their competence in prioritizing and this broad attention:

> (One employee): I can also imagine that, it might feel like some sort of attack.
> (A second employee): Yeah, kind of like a motion of distrust.
> (A third employee): Which could make that feeling even worse of... What am I doing?
> (The first employee:) But I can do this right? Why is this being measured? (...) What am I doing?
> (The second employee:) Yes, what's not goind well then? Just tell me right now why it's not going well.

Interpretation of Attention capabilities

As part of driver's alertness competence, train driver highly value their capability to stay alert and attentive. Their focus on prioritizing attention, and having been selected for the job during extensive vigilance testing, shows their belief that they are highly capable of staying attentive.

The big focus by all participants that, to become a driver, they were selected by passing the vigilance test, could show that driver's emphasize their attention capability, at least partly, as an inherent quality. It suggests that they belief they are suitable as a train driver because they are inherently capable to stay attentive during their shifts. This feeling of being competent to stay alert is thus a big factor in the acceptance of DCM systems.

'Leaning' on technology / Over-reliance

Drivers and employees also made comments related to the job of a train driver getting easier, causing lowered alertness:

> (One employee): Then, there is TimTimPro, which starts telling you more and more. It spells it out for you more and more what you need to do. You can see everything in advance already, you know exactly where to stop. You really don't need to think anymore. And if we talk about alertness: it is worsened because of these 'supportive tools', that's how they call them. (...) Yes, I worry about that if I'm being honest.
> (Another Employee:) And I think you're right. (Explanation on workload effects). So it's in line with what you say.

The job of a train driver getting easier was also named by train drivers themselves, also related to driver's 'building' / over-relying on technologies, on which multiple drivers agreed:

> (One driver): I think that, these days, train drivers are being pampered too much. We were trained back in the days. Like, if you see yellow, look out for the red signal. No but, just look for it. And have you seen it? Then that's it. No, I don't think it's a good development. Because they are supportive tools again.

> (Another driver:) You have to watch out that people won't start building on (supportive technologies).

All four drivers brought about their experience with technology and that there are train drivers that rely on it too much. Also 3 out of 4 office employees clearly stated they recognized the risk that drivers rely on technologies too much.
All train drivers also discussed that they think there are other train drivers that over-rely on technology, such as relying on ATB to signal if they drive too fast ('ATB rijden'), by accelerating forwards until the ATB's first warning starts.

Three drivers and an office employee stated that is not acceptable, as one driver and one employee said that he/she wished to receive no alarms in the first place. Making sure that people will not over-rely on technology was a big concern for these three drivers and office employee, relating it too poor workmanship. There was also a driver that stated that relying on ATB is for some drivers part of their workmanschip, if the driver is capable of handling it.

> (A train driver:) Well, I know that some train drivers 'drive on ATB'. They only act when they hear a sound ring.
> (Facilitator:) Do you mean that they don't think for themselves?
> (The train driver:) No, they do think for themselves, but I mean when those drivers drive through yellow signals. Then they drive through the signal, and they are, in fact, able to brake before the next signal. So they wouldn't be happy with (feedback whether you looked at a yellow signal).

Interpretation of over-reliance
Drivers seem to have mixed feelings for several supportive technologies, as sometimes it makes the job even easier, and hence harder to stay alert for. Over-relying on technologies, such as accelerating until the ATB alarm rings, is by some perceived as bad workmanship, yet also found acceptable when the driver's competent workmanship allows to use it in a proper way.

Relying too much on technology came back by all participants, it shows that they find it important that driver carry out your tasks as a well-trained, but mostly well capable driver as they were all selected based on their attention keeping capabilities.

Their need to not over-rely, or even dislike towards over-relying, shows that drivers find it important to do their job professionally, and want to stay actively in control. Explaining this major dislike towards 'easier' technologies seems to be caused by their views of what driving professionally means ('vakmanschap'). Another explanation could be that they dislike over-reliance because they struggle to keep themselves from over-relying, and keeping themselves active. For example with ATB, they might actively fight the tendency to over-rely on ATB, disapproving of drivers who do over-rely on it. All in all, over-reliance seems to be an important aspect to consider when designing an DCM feedback system.

8.4. Trust Towards the Organization

Presenting participants that alertness is proposed to be measured with the DCM, explained as either an eye-tracker or camera that measures the eyes, led to various discussions on what they find important in such a measuring device. Most answers that were given were related to the interaction between NS as an organization.
Three out of four train drivers expressed concerns to NS with the use of measured information, describing them as privacy concerns, or fear that the measured data will

be used against them. All office employees also noted this by saying that measuring alertness could feel as distrust or even an attack towards train drivers on their capabilities as a driver. Two drivers also noted this feeling of an attack towards their capabilities. Two drivers said that they think during incident investigations, for example in the case of SPAD's, this information will also be used, and fear that the driver can be held accountable.

Train drivers did not literally say that it could feel as a threat.. They did say that there are many " if's"/ "conditions" before they would find it acceptable. Two train drivers were open to allowing eye-tracking given that all the "if's" were addressed, while one train driver stated that in the end, train drivers should be capable and responsible to do this themselves. The "if's" that were mentioned related to the expectation that NS will use the information for other goals than helping the driver in the moment itself.

> (One driver): The data shouldn't be stored, only use it for this system and for safety, also the system must work well. It needs to be a good system, because if it hinders us, then we've got another thing that hinders us during our jobs.

They seem to agree on their opinion that technologies are hindering them, and their critical attitudes towards technologies that are not helpful.

Other comments from two train drivers involved the tendency of NS to focus on technology-driven innovations, saying that the solution lies in other aspects.

On the flip side, there were comments of positive trust between them and NS. One driver appreciated that NS does say that it is okay to call in unfit if too tired. An employee also noted that he thinks NS does this relatively well compared to other organizations.

In the end, three out of four train drivers said they could be open to the adoption of such a system, given that a big amount of conditions are taken care of. All employees expressed potential for the device, while saying that it could be useful, yet they see many obstacles, such as guarantying limiting the information use and seeing many (other) 'landmines' in the process, such as the Works Council ('Ondernemingsraad'). The employees together agreed that only some portion of the drivers could find it useful, some remarking that support will grow slowly. They all agreed that the social aspect of adopting new technologies slowly makes support grow. Other conditions that were said, yet not discussed on whether everyone agreed were included that the need must be clear, that it should be able to turn off, and making sure the eye-tracker's data isn't saved.

Interpretation of Trust towards the Organization

The combination of distrust in NS to not use eye-tracking information for other goals such as individual accountability, and as perceiving eye-tracking as an attack on their competence. It seems the dynamics between drivers and office employees are tense. Prior experiences on using technologies have made train drivers reluctant to trust NS. Whether this hesitance from train drivers is deserved by NS is up for debate and might not be relevant. The dynamics between the works council could keep this distrust in place. The strong belief that NS will not safeguard their data can have big consequences on the acceptance of implementing such a individual-based measurement system as eye-tracking.

8.4.1. Interaction between participants

One thing that was noticed by the facilitator was the difference in communication between participants. The session with employees was relatively open, with much employees discussing amongst themselves, being open to suggestions of others. Train drivers mostly responded to questions from the facilitator and interactions between drivers was mostly limited to agreeing or disagreeing with each other.

Interpretation of interaction between participants

Many sensible explanations can show why train drivers and employees interacted differently between themselves. Firstly, the group sizes differed, the presence of only one other train drivers can create an atmosphere of conflict more easily. Also logically, train drivers are personally involved in train driving themselves, making the subject matter feel much more personal. The relation between participant facilitator can also be interpreted by the participants differently; employees can see themselves as colleagues, while train drivers can experience a difference in culture or hierarchy between them and the facilitator. Seeing the differences might also illustrate the interaction train drivers experience with being involved in research from the 'office'. It could be interesting to further investigate how train drivers perceive being part of the innovative process of new technologies.

9

Design Requirements for Acceptance

From the results on driver acceptance factors, recommendations can be made to deal with the case context:

RQ5: What is required from a feedback system that uses DCM data in order to promote train driver acceptance?

The results showed that with a new alertness technology, the most important questions are whether they perceive it as useful, they trust whether NS handles the information with integrity, and whether their perception of their own competence and autonomy remains intact. This suggests that, in addition to a design that is perceived as useful, the challenge also lies in making train drivers feel competent and in-control, and trust NS to handle their personal information on alertness with integrity.

From these acceptance factors, also practical suggestions can be made in the design of a DCM feedback system, taking into account how train drivers deal with alertness, and the general train driving context.

9.1. Perceived Usefulness

Perceived usefulness was a theme throughout the focus group discussion, and could be divided into whether drivers recognize the problem, whether they agree with the goal of the technology and whether the technology has sufficient relative advantage. Dealing with these factors is hence important in the design of a feedback system, and the following requirements can be made.

Problem Awareness

Since problem awareness is important, it is needed for the design to firstly deal with a problem that train drivers recognize and value:

The feedback design shall focus on solving a problem that train drivers are aware of, or can be made aware of.

To apply this in the design of an alertness feedback system, it can be suggested to focus on concepts of alertness that train drivers recognize, such as a feeling of tiredness leading to more mistakes, or the difficulty of prioritizing attention. As train drivers tend to focus on sleepiness, it might be appropriate to communicate the distinction between fatigue and sleepiness, or to simply focus on tiredness in general.

Goal of Technology

Next off, as train drivers and employees discussed various goals such as alerting for safety, information provision, it makes sense that the goal of using DCM should be perceived as useful:

> The feedback design shall be designed with a goal that is perceived by drivers as appropriate in solving the established problem

For a feedback design, this would mean that making a choice on the goal is needed, with the intended message of feedback: The goal can for example be provide information to the driver or to guaranty safe levels of alertness. This would then reflect back on the message of feedback: providing information leads to feedback with a neutral tone of voice, while guarantying safety leads to feedback that alerts the driver to prevent unsafe alertness levels. The goal of the technology is an important aspect of perceived usefulness, and must be carefully chosen.

Relative Advantage

Finally, the focus groups showed that next to being a relevant problem with an appropriate goal, new alertness technologies should be be sufficiently more advantageous than the current situation, leading to the requirement:

> The feedback design shall be of sufficient relative advantage compared to the current situation.

Applying this to alertness feedback, it is interesting to research the relative advantage of DCM compared to how train drivers currently deal with alertness. For this, they use their own judgment in combination with current technologies. For example, they use the dead man's pedal to notice that they are less alert by noticing the first visual alarm. Investigating how DCM can be more advantageous is interesting for this.

Acceptance Factor	Design Requirements based on Acceptance Factor: 'The feedback design shall... '	Practical suggestion based on context and alertness strategies.
Problem Awareness	focus on solving a problem that train drivers are aware of, or can be made aware of.	Focus on general tiredness or attention management as a problem, or make drivers aware of fatigue as a distinct problem to sleepiness
Goal of Technology	be designed with a goal that is perceived by drivers as appropriate in solving the established problem.	Make a choice on the goal and message of DCM feedback: for example, the goal could be to support the driver or guaranty safety. The message could for example be informative, alerting or intervening.
Relative Advantage of Technology	be perceived as sufficiently advantageous compared to the current situation.	Investigate the concrete advantage of using DCM over current alertness strategies and used systems in the cabin (e.g. Orbit and dead man's pedal)

Table 9.1: Design requirements from acceptance factors that make up perceived usefulness, with practical suggestions from alertness context, such as found alertness strategies and train driving context.

9.2. Factors that Influence Perceived Usefulness

Next off, the focus groups showed three important factors that influence perceived usefulness: output quality, job relevance and result demonstrability.

Output Quality

Output quality can in this context be interpreted as the reliability and accuracy of the DCM feedback. The degree of reliability and accuracy was not researched, yet it is an important factor, as it was mentioned that false alarms could be detrimental for acceptance.

The feedback design shall be perceived as sufficiently reliable and accurate to achieve the proposed advantage.

In practice, it is an important step to research how reliable and accurate DCM is, and how feedback can be given. With a higher degree for false alarms for example, it might be more appropriate to not intervene or give safety alerts, but rather to inform the driver of the data and its accuracy.

Job Relevance

The focus groups also showed that it is important to consider how well the technology fits the tasks and responsibilities of a train driver. The requirement that follows is:

The feedback design shall be relevant in the train driver's tasks and responsibilities.

In practice, this means that considering the task environment and responsibilities is important for how a DCM system may be used to promote acceptance. For example, post-drive feedback showed to be disliked in focus groups, as train drivers are unconcerned for their alertness if the shift is over already. The results also showed that long, monotonous shifts, with little shift variation (in routes and train types) are problematic for tiredness.

Result Demonstrability

And finally result demonstrability, which relates to results of safety (and if applicable performance) can be demonstrated. Train drivers liked to be informed on the safety results that DCM has achieved. This leads to the requirements:

The feedback design shall promote to demonstrate results of safety or performance

In practice, this means that obtaining results from DCM use from other railway companies, or even from car-industry, can be useful in the acceptance of such systems. It might also be useful to consider logging situations in which SPAD's were prevented by using DCM, to be able to communicate this in the future.

Acceptance Factor	Design Requirements based on Acceptance Factor 'The feedback design shall:'	Practical suggestion based on context and alertness strategies.
Output Quality	be perceived as sufficiently reliable and accurate to achieve the proposed advantage	Investigate how reliable and accurate DCM is in order to be advantageous over the driver's own capability to recognize and deal with alertness, also considering systems driver use (e.g. Orbit, dead man's pedal)
Job Relevance	be perceived as relevant in the train driver's tasks and responsibilities.	Consider the task environment and responsibilities of train drivers in a DCM feedback design.
Result Demonstrability	promote to demonstrate results of safety or performance.	Investigate other uses of DCM in railway, perform research on safety benefits of DCM use, to be able to communicate these safety benefits, such as amount of prevented SPAD's.

Table 9.2: Design requirements from acceptance factors that are related to the perceived usefulness, with practical suggestions from found alertness strategies and train driving context

9.3. Competence and Autonomy

For competence and autonomy factors, it is important to consider the train driver's competence and control to carry out their responsibility, value their attention capabilities, and help them avoid over-reliance.

Responsibility

The results showed that train drivers feel highly responsible: they feel like they need to be competent and can stay in control of the train themselves. Given that drivers do indeed have much responsibility, their feeling of responsibility is of course not very surprising. The strong emotions that were found on their responsibility do show that drivers seem to feel like their competence is in some situations not taken into account, and they fear that they become less in control. Hence, a recommendation towards the emergence of DCM alertness feedback would be to take into consideration in designing such a system that drivers can perform their responsibility: that they stay competent in staying alert, and maintain the situation of being in control of their own alertness.

The driver's responsibility makes it important that they are able to stay in control: both by their competence and getting allowed to be in control.

Hence a feedback design that promotes autonomy and control of the driver could lead to higher acceptance:

> The feedback design shall maintain or increase the amount of autonomy and competence that drivers experience that is required from the job's responsibilities.

In practice, this could mean that the feedback goal of informing allows for most autonomy as the driver can decide himself what to do with the information. Intervening with driving can be interpreted as least favorable, as it takes away control of the vehicle. Alerting the driver by using DCM as a safety system can be interpreted in both ways: the room for full control in a safe region might be perceived as having much autonomy, feeling safe in this region. However, alerting can also be considered confining and judgmental, leading to less feeling of autonomy.

Their competence can also be effected by the process of unlearning current skills to stay alert and attentive, generally named de-skilling, or skill degradation. For example, a device that detects lowered alertness better than the driver, might cause the driver to loose their current skills. Then, in case of needing these skills, it could make train drivers feel incompetent in carrying the responsibility of train driving.

Attention capabilities

Results also showed that train drivers highly value their attention capabilities, which they might believe to be an inherent capability. Using such DCM alertness feedback technologies should make sure that they still value their own attention capabilities, and need to use it in practice:

> The feedback design shall assist the driver's competence of attention capabilities, instead of replacing these capabilities

In practice, the technology should not replace their capabilities to keep a broad attention and prioritize their attention. In general prioritization and distributed attention are important skills for people that operate vehicles such as trains. Hence, the technology should make sure that train drivers are helped to distribute and prioritize attention, instead of replace these capabilities.

Over-reliance on technologies

Over-relying on technical systems was by train drivers seen as poor workmanship, as it shows they are not actively involved in train driving, not keeping a broad attention and prioritizing. Hence, the feedback design should lead to prevent over-reliance and promote to keep the driver engaged in driving:

> Shall promote drivers to be actively engaged in driving, preventing over-reliance

Hence, the technology should be used in such a way that it promotes to stay actively engaged in driving, requiring the driver to actively attend to important events, and to prioritize what to keep their attention on.

Acceptance Factor	Design Requirements based on Acceptance Factor 'The feedback design shall:'	Practical suggestion based on context and alertness strategies.
Responsibility: Autonomy	be perceived as maintaining or increasing the autonomy and competence in driving	Avoid de-skilling and promote to maintain control over driving. Preferably inform and alert the driver over intervening in the train's control.
Competence & Autonomy of Attention Capabilities	be perceived as assisting the driver's competence of attention capabilities, instead of replacing these capabilities.	This can be in their alertness strategies of recognition and coping with low alertness, and in their autonomy to call in unfit to driver, or freedom in what where they guide their attention.
Competence of driving engagement	prevent over-reliance on the technology by requiring the driver to actively use the feedback	Shall provide feedback in a way that promotes drivers to be engaged in driving, such as informing the driver or requiring task-engagement in other ways.

Table 9.3: Design requirements from acceptance factors that are related to driver competence and autonomy, with practical suggestions from found alertness strategies and train driving context

9.4. Trust towards Organization

Organizational factors were definitely present in the focus groups, mostly as difficult dynamics between drivers and office organization.

The relationship between 'the office' and the operational world shows signs of distrust, mostly from the operational world towards the office. The distrust from train drivers towards NS that the technology won't be used for other goals, such as individual accountability, is very relevant, if not critical, towards the acceptance of such privacy sensitive system as DCM. It is hard to find a solution to this problem by simple communication. In every trust relationship, a focus on strengthening this trust in the long-term is needed. A start for this would be to be transparent to train drivers on the goals of the technology, and what the bigger goal is. Also explaining how privacy and individual accountability risks are managed could help in the relationship. As one step in the right direction, it is useful to communicate transparently, and how concerns on data privacy and risks on individual consequences are mitigated.

Acceptance Factor	Design Requirements based on Acceptance Factor: 'The feedback design... '	Practical suggestion based on context and alertness strategies.
Prevent individual accountibility	Make sure that measured data measurements cannot be used to make individuals accountible, most importantly towards team managers and incident investigators	Shall safeguard that data is not used for other goals than intended and communicated, and shall especially prevent individual accountability with this data. (e.g. with performance measuring and during incident investigations).

Table 9.4: Design requirements related to trust towards the organization factors, with a practical suggestion from found alertness strategies and train driving context

9.5. Discussion of Design Requirements

The design requirements for acceptance that followed are to be used by designers that design such DCM feedback systems. What are some considerations in using these requirements in practice? And what can be learned when some designers are asked to evaluate a feedback design with these requirements? Also, theory on automation design seems to have interesting similarities with the design requirements for acceptance.

9.5.1. Challenges of Putting Acceptance Requirements into Practice

This research answered the questions of which factors are relevant for acceptance, and did not aim to answer if DCM will be accepted. With recommendations that promote acceptance, discussing these recommendations' practical effect on the process of designing can show what needs to be accounted for in practice. What are the practical implications of these recommendations, and are they feasible?

Perceived Usefulness Recommendations

Making the system be perceived as useful is relatively straightforward compared to competence, autonomy and trust. It requires careful communication of the various factors. The crux lies in communicating the relative advantage of using DCM over purely relying on their own alertness capabilities. For this, it is essential to let drivers link their problem with alertness by building on a problem they recognize already (at this point feeling tired and making mistakes), or make them aware of the problem (such as human capabilities and limitations to sustain their attention for longer periods of time) with the advantage and goal of the technology, including why it works like this, and how well it works. In this, it is important to convey why it is specifically useful in train driving, and what results have been booked already with this system.

It was shown that in practice, it requires attention to make choices on how to frame the problem (build on their existing problem or create a new one) and make a choice on which goal of the technology to convey.

Competence & Autonomy Recommendations

The recommendations on competence & autonomy are more related on what the effects of an implementation are, and lead to choices on what kind of designs are appropriate. The first recommendation, helping drivers to fulfill their responsibility by promoting their competence and autonomy can seem like an open door, yet is a subtle difference in practice: what the designer intends might be quickly perceived otherwise by the driver. Example: a designer might choose to give feedback to the driver when they don't look at a yellow sign, with the aim to help the driver prevent a SPAD. However, the next time they might put less effort into actively looking for a yellow sign, as they know they will be helped. Hence, the tendency of over-reliance and also the deskilling can lead to even worse safety. Also, the intention might be to increase autonomy by safeguarding to look at signs, the driver might perceive the alarm as more restrictions (and less autonomy) in their actions.

Also, increasing intrinsic motivation by engaging drivers in their driving tasks is easier said than done. This is because being actively engaged in driving is partly done by offering tasks that help to engage them, Literature also researched technology to engage drivers, such as asking driving related questions that must be answered by voice, using A.I. language technology. (de Bakker, 2024) A problem is that drivers can easily see these tasks to increase engagement as compulsory, decreasing the feeling of autonomy, and as though they are not capable themselves to engage them in driving. Hence, they must see these active tasks as part of their driving tasks. For example, drivers mentioned that if driving is boring, they tried to drive even better, thereby getting engaging themselves with driving.

9.5.2. Design Requirements

Feedback from human-factors professionals

The requirements for promoting acceptance in a DCM feedback design were shown to a team of human factors specialists at the Dutch Railways as part of a research presentation of this thesis. During this presentation, design concept was shown, and the human factor specialist were asked to evaluate this concept in groups, using the design requirements.

The requirements right away led to lively discussions on whether such a concept is useful, right away evaluating the problem, goal of technology, relative advantage, reliability, over-reliance effects. They brought up quickly that a balance needs to be found on over-trusting, and that the workmanship of the driver is effected by replacing tasks.

Given that the human factors specialist had a lively discussion on crucial topics of the concept feedback system, it is a first sign that these requirements can be of use for them to efficiently discuss topics that are relevant for acceptance.

Feedback comments on the requirements consisted of whether over-trust and driving engagement can be said to be linked, as they related it more to the type of feedback. Over-trust in literature is mostly linkd

There was also a question whether there is a prioritization of requirements: which requirements are most important? Some stated they find it easy to evaluate the concept with their own perception, but expressed a difficulty to imagine the perception of a train driver. Hence, it showed important to make clear in the requirements that the driver's perception is central for acceptance. W

Changes made with the comments in mind are: to phrase requirements more clear to be about the driver's perception, and to adjust the over-reliance requirement from promoting task engagement, towards more generally consider options that prevent over-reliance.

During the developments of the design requirements, it became clear that some requirements are inherently difficult to make concrete in a real-time feedback system. For example, not replacing alertness capabilities is difficult with DCM as it does measure alertness, it thus inherently replaces the capability to detect own alertness. Maintaining competence and autonomy to carry responsibility can be achieved with the type of feedback: still, more support means leaning is easier. Perhaps the point can be made that in general more support leads to less competence, and the feeling of control decreases.

Comparison to Criteria from Human-Automation Design

The result that informing with DCM might be more acceptable than stepping in and intervening carries similarities with a design framework for human-automation interactions. In such a framework, information acquisition, information analysis, decision selection and action implementation are seen as types of automation / functionality. (Parasuraman, Sheridan, & Wickens, 2000). Drawing this parallel, informing the driver on their state could be viewed as information acquisition with raw DCM data, and information analysis if algorithms infer sleepiness from DCM data. Decision selection could be viewed as alerting the driver to brake in case of missing a yellow sign, while intervening by automatically braking would be action implementation. Hence, design criteria in this framework are interesting to compare to the design requirements for acceptance. These criteria in this framework can evaluate whether the amount of, or 'level', of automation for each functionality is appropriate. The criteria of 'primary effects' are related to human performance: workload, situational awareness, complacency, and de-skilling. Secondly, sufficient reliability and potential effects of automation failure are criteria. (Parasuraman et al., 2000)

Big parallels of these criteria, that assess if a level of automation is appropriate for the function, can be drawn with the proposed requirements to promote acceptance: Reliable measurements, as shown from the output quality concept, can be viewed as a major automation criterion, maintaining a feeling of competence is similar to skill degradation, and avoiding over-trust was also mentioned, framed within the concept of 'complacency'. Complacency here is mainly framed as self-satisfaction, based on non-vigilance, (Raja Parasuraman & Singh, 1993), relating it much to safety risks of automation failure, while this research mainly noted over-trust as an important need of drivers to attend to driving. During this research over-trust was thus perceived as bad workmanship, with the requirement to keep drivers engaged with driving to maintain their attention. In this way, over-trust of DCM's involves not attending to the driving task, and hence, in the context of DCM's, over-trust can be related to driving engagement. In other words: engagement in driving, does help to avoid over-trust of DCM's, while the two are generally not tightly linked. Thus, it seems that similarities of acceptance requirements and these automation requirements showed DCM's might be designed with both frameworks.

There are some differences however. Although it seems DCM feedback can be considered automation from several perspectives, DCM áre different than typical automation in some ways: Automation generally uses information on the vehicle or environment state, while DCM measures the individual driver state. This makes DCM more personally sensitive than automation, being much more sensitive data to use for performance or during incident investigations. This explains why trust towards organization was a main result in this research, not discussed as a criterion in the automation design framework.

Additionally, the automation design framework is meant to design effective human-machine collaborations, while this research focused on promoting acceptance. These acceptance requirements are thus more focused on how the drivers perceive the functionality, while the automation criteria are focused on designers. The acceptance requirements may thus help to specifically consider how to communicate with train drivers and frame the conversation, as to promote a positive attitude towards DCM.

Hence, designing a successful DCM system might consist of using both perspectives: designing as being an automation, while also considering the highly individual measurement aspect, and making the translation of how train drivers perceive such a DCM design.

10

Conclusion

This research set-out to explore in what way a driver condition monitoring system can be used to measure driver alertness in a way that promotes train driver acceptance:

How can acceptance of train drivers be promoted in the design of an alertness feedback system based on driver condition monitoring?

This objective was given form by creating sub-questions that on one side explored how drivers currently deal with low alertness, and on the other side researched what factors are important to promote their acceptance.

10.1. Current Driver Alertness

The first step that needed answering is whether low alertness occurs in practice:

RQ1: Does lowered alertness currently occur in train driving?

The exploratory interviews confirmed that some drivers at times use their smartphones during driving. Also, tiredness is generally recognized by the night-shifts and variability in shifts. Hence, it can be said that some extent of low alertness does happen in practice, confirming that low alertness is a relevant to improve safety, emphasizing the relevance of analyzing driver alertness to improve safety
To understand in which ways alertness technologies can help train drivers, the need arose to understand how drivers deal with alertness in practice:

RQ3: How do train drivers currently deal with low alertness in practice?

The focus groups showed that train drivers experience tiredness, mostly attributed from sleeping aspects. They experience themselves to be good at guiding this attention, attending to traffic signals effectively. Train drivers experience themselves to actively guide their attention, aiming to keep their attention broad, and prioritize effectively towards relevant events to attend to.

When their alertness is lowered, train drivers notice their lowered alertness by driving related aspects, such as making noticing their performance is lower, or receiving feedback from various technical systems. To cope with lowered alertness, train drivers activate themselves by a combination of willpower, and tricks to stay activated, either by actively carrying out activities, or changing their environment with more or less stimuli.

10.2. Acceptance Factors

To find an appropriate theoretical approach, exploratory interviews were used to shed light on reasoning for accepting current technologies:

RQ2: Why do train drivers accept current technology?

The exploratory interviews (mostly conversations on an advisory tablet system, showed that train drivers use technology when they find it useful and easy to use, making perceived usefulness and perceived ease of use seen as appropriate concepts for train driver acceptance. The next research question aimed to what is important in DCM feedback designs to promote acceptance::

RQ4: What acceptance factors are suitable in the context of train driving with DCM technology?

Alertness turned out to be a sensitive topic to train drivers, and the acceptance of such a technology seems to be both from usefulness reasons, and reasons that are closely related to the driver's feeling of being competent and in control of driving a train. Their trust towards the organization was also found to be critical on using a DCM. It was found that the usefulness of DCM's consists of perceiving the technology as advantageous in their jobs, as well as whether they recognize the problem, and whether they see the goal of a DCM as appropriate. It was also shown that how they perceive the reliability and accuracy are important, that technology must fit the tasks and responsibility of train driving, and that drivers find it helpful to obtain demonstrated results of safety and/or performance.

Not only their perceived usefulness and factors that influence the usefulness was found important. Train drivers associate receiving feedback to their alertness closely to their own competence and feeling of being in control: they need to feel competence and in control to carry their responsibility. They also highly value their personal attention capabilities, and are motivated to use this capability. And they feel a need to stay engaged in the driving tasks, not leaning too much on technologies.

A degree of **distrust** from train drivers towards office employees was also found, albeit from experiences of incident analysis, previous attempts to individually measure and report performance, or just the general distrust of using data that is measured.

10.3. Design Requirements

The challenge thus lies in conveying the usefulness of such DCM technology and turning around this threat to their competence, autonomy and personal privacy towards a solution that train drivers feel like helps them in their responsibility to stay alert. With the acceptance factors in mind, and understanding how train drivers currently deal with alertness, recommendations were made for designers at railway companies to use acceptance factors during their design process.

RQ5 What is required from a feedback system that uses DCM data, in order to promote train driver acceptance?

A broad set of design requirements followed from the found acceptance factors of perceived usefulness, intrinsic motivation factors of competence and autonomy, and trust in the organization. These design requirements covered many aspects of a design that are important to consider in the design process. They were also related to practical suggestions, using information on how train drivers currently deal with alertness and perform their jobs.

The challenges were also discussed of putting alertness into practice, which showed that making the design perceived as useful can be seen as straight forward. However, making train drivers experience themselves as in-control and competent was shown to be tricky with technology, as the intention of the designer can often be interpreted differently by the driver. This is the case for being able to carry out the responsible task of train driving, assisting instead of replacing alertness capabilities, and the challenge of engaging drivers in driving.

10.4. Answering the Main Research Question

The main research question was composed to investigate how driver condition monitoring be best used for train driver acceptance:

How can acceptance of train drivers be promoted in the design of an alertness feedback system based on driver condition monitoring?

The formed design requirements and their suggestions to apply them in practice led to in-depth views on what to consider for acceptance in designing a feedback system for driver condition monitoring systems. The requirements for designing acceptable DCM systems, with the in-depth reasoning in this report, allow designers to gain deeper insights into what to consider and focus on in the design process of alertness feedback systems.

The central idea in what is required for acceptance is threefold: Rational factors need to be considered that make drivers perceive the technology as useful, making them intend to use it. In addition to this, the importance of incorporating the train driver's feeling of competence and autonomy, showing that the train driver's feeling of responsibility, value of their attention capabilities and need to stay engaged in driving are keys factors to consider in designing DCM systems. Finally, the relationship with the organization was shown to be highly important, as the trust that the technology is used with integrity, especially in the handling data of DCM measurements, deemed crucial. It is thus the designer's job to adopt these design requirements and create feedback technology that driver's find useful, fosters trust in the relationship between driver and organization, and fosters their competence & autonomy.

11
Discussion

Having found answers on what to consider in the design of DCM feedback systems, various topics are still interesting to discuss further. Since much of the results are discussed within the research itself, a more theoretical discussion occurs in this chapter. It is discusses in what ways TAM, and the low alertness concepts, were applicable for this research as well as discussing other approaches that can be proposed. Then it discusses whether focus groups were indeed a fitting method. Also limitations of the method are discussed. Then, transferability of the results is discussed towards other contexts is discussed. Finally, some design directions are proposed with costs and benefits that can be considered in designing feedback systems.

11.1. Theoretical Discussion of Alertness

The found results can be linked back to the original theory, and results also suggest use of other theories.

Experiences of sleepiness, mind-wandering and distraction related theoretical concepts

According to the results, sleepiness is highly recognized by train drivers, which makes sense as shift timing and -irregularity is an inherent part of train driving. It shows that sleepiness can indeed be highly related to fatigue, and that it might not be necessary to distinguish the two concepts to model driver perceptions. This confirms the notion that often, sleepiness and fatigue need not always be distinguished(Oken et al., 2006)

Mind-wandering is poorly recognized as an indicator of becoming tired or less vigilant. This might be as attention that wanders away can be hard to notice, as mind-wandering theoretically involves a loosing ability to choose what to focus on (Thomson et al., 2015). However, train drivers did note to be 'less aware', or 'not present in the moment', suggesting mind-wandering does occur, but merely not recognized by train drivers. Perhaps to convey the concept of low alertness, general tiredness is more appropriate. (Klösch et al., 2022).

Distracting events are shown to be either framed as attention distribution and prioritization, or as not complying with rules. The first frame supports that distraction is a hind-sight concept as said by (Regan et al., 2011): train drivers are not occupied with how an event distracts them, instead they have to effortfully focus their attention in the moment itself. The second frame supports that distraction is a normative judgment (as (Regan et al., 2011) noted): being distracted is here perceived as not complying with rules, which makes sense as many distraction situations are covered with rules (no GSMR use when driving 40 km/h, no listening to music etc.). It implies that 'how to focus/guide attention' right of the bat is a better topic to discuss with train drivers than distraction.

More or less stimuli to become alert?

Results showed that becoming more alert sometimes requires more stimulation, and sometimes required less stimulation. For both reasoning, theoretical support exists. More stimulation could help, looking at it from physiological activation, alertness could be seen as increasing 'arousal' (Oken et al., 2006), or nervous system activation, increasing the alertness, leading to higher focus. On the other side, from an attention point of view, keeping attention focused also costs mental resources (as was explained for the resource account of sustained attention to explain mind-wandering (Thomson et al., 2015). Hence, theory shows that less stimuli allows for better attention management, while more stimuli activate the body. Hence, a need for both more, or less, stimulation to stay alert, can be explained by seeing alertness as nervous system activation, requiring more stimuli, or as limited available mental resources, requiring less stimuli. Giving feedback to train drivers to make them more alert, is hence difficult to understand if less stimuli or more stimuli is appropriate. This discussion on more or less stimuli could also explain one reason for driver's dislike towards an extra driving task: it could be seen as more stimuli, while they perhaps require less stimuli. Hence, this discussion might be relevant in various design option.

Visually detecting yellow signals from the corners of the eyes

It was notable that train drivers mentioned that they experience it highly improbable to miss a yellow signal, saying that they can observe a yellow signal from the corner of their eyes. This is notable, as only the small foveal part of vision detects color, as discussed in chapter 4. This means that at an eye-movement towards the sign should occur to observe the color, making DCM useful to detect if they missed it. Whether driver directly look at signals to perceive them is important to know, because if drivers perceive yellow signals in their peripheral vision, there is no use of using a DCM eye-tracker to detect if a signal was missed.

There are some explanations that explain the possibility that they do look at the signal with foveal vision, but that they are not aware of this. The yellow signals could for example be already observed with foveal vision far away, visually close to the tracks, perceiving the color right well in advance. Another explanation could be that drivers do quickly move their eyes towards the yellow signs, yet are unaware of this. The rapid eye movements ('saccades') are quick: drivers might be unaware that they did, in fact, look at the signal.

There are also explanation that could explain observing such yellow signals in peripheral vision, without foveal vision. Firstly, some literature suggest that with very bright light, color might be observable in peripheral vision (Hansen, Pracejus, & Gegenfurtner, 2009). Yellow signals are typically of high intensity, making this a plausible solution. Another suggestion might be that reflections of yellow lights onto objects, are seen bij foveal vision, making the brain correctly interpret the yellow color. When investigating use of the eye-tracking function in DCM's, it is interesting to investigate whether train drivers can observe colors of signals without attending to it with foveal vision.

Use of Dead man's pedal

It is interesting how train drivers experience the dead man's pedal: it was shown that they generally use it as a wake-up call that they are less alert. However, it was also widely agreed that the system does not work perfectly, as they 'automated' the use, automatically pressing it once every while. Hence, although train drivers know using the dead man's pedal is unreliable to detect sleepiness or fatigue, it is still used as way to notice lowered alertness. It might be worthwhile to investigate the reliability of the dead man's pedal: at which levels of sleepiness or fatigue do train drivers still automatically activate the pedal? And to investigate to what extent the pedal is relied upon by drivers to notice lowered alertness, which is interesting if it shows to be unreliable for noticing sleepiness.

11.2. Theoretical Discussion of Acceptance Models

The research used theory on alertness, and theory on driver acceptance of technologies. The next sections discuss the use of these theories in the research, and whether there are other approaches which can be suggested.

11.2.1. The focus on Perceived Usefulness and Intention to Use

At the start of the project, exploratory interviews and literature of driving acceptance directed the focus towards perceived usefulness, intention to use and concepts related to them (result demonstrability, job relevance etc). From conversations with train drivers, the gap between intended usefulness of designers, and perceived usefulness became clear. It was proposed to use these rational-decision methods, and focusing on how driver perceive DCM as useful.

Being advantageous as definition of PU

In the TAM model discussed in chapter 8, usefulness was defined as 'being capable to be used advantageously' (Davis, 1989).

The relative advantage compared to current systems was definitely discussed, for example in discussions on the dead man's pedal, seeing DCM not sufficiently more advantageous over using the dead man's pedal. Hence, although the definition included that the technology must be advantageous, perhaps it's also needed to consider if the technology is advantageous enough, such that it is worth the extra effort of using it. Hence, this definition of PU to be of advantage was definitely found with results on 'relative advantage' factors.

Perceived problem as a starting point for PU

However, it was also shown that prior to assessing whether something is advantageous, some design concepts were not even considered to tackle a relevant problem or a correct goal of the problem, making them not useful in the first place. (for example, getting distracted from the GSMR was not seen as a problem). This shows that it was needed consider taking a step back: usefulness might then then also involve whether the problem is recognized, and if the goal is seen as appropriate. What train drivers perceive as a problem to solve, might be viewed as bringing back the focus of design to the human: designing by putting the human central, starts of by looking at the problem the human has. It also makes visible the typical design process: that designers are asked to address a problem, for this a technology is found, and then find out that the technology does not solve the problem. Human-centered design could change this, by asking at the start what problems the users perceive. Still, it could be remarked that following up the driver's problem must not be taken too far, as it could warrant caution the other way around: asking train drivers which problems they have without deep insights into why they have these problem, might be tricky. This is because drivers may perceive problems that are not relevant, or not solvable. For example, sleepiness was seen as the major problem, while improving sleepiness is not possible during a shift (as sleepiness requires sleep). In another way, if it seems to be the case that sleepiness is the main problem, perhaps investing in other solutions could be more effective. (e.g. it could be more useful to try to decrease shift irregularities and night-shifts.) Hence, aside from the advantage, assessing how drivers perceive the problem could be an important starting point, although train drivers must be seen as experts in train driving, while designers are experts in designing appropriate technology.

Intention to use

The intention to use technology was also discussed extensively at times, showing that a positive intention to use such DCM systems might be important for acceptance. At times, train drivers did say that they found a concept useful and they would use it, as was for example often the case for the sleepiness alarm. Although that TAM assumes that an intention to use leads to actually using the system, in practice this is not always the case (known as the intention-behavior gap). This could mean that drivers find a DCM feedback system useful and are intending to use it, but that in practice there might be unexpected effects that prevent successful use. For DCM's example could be that they simply forget to use an informative display of alertness.

Intention to use, and usage behavior could also be different for non-voluntary use. If DCM becomes a safety system, the goal might not be to promote usage, as it must be used either way. Hence, the point can be made that in this case, usage behavior is an unnecessary concept. Still, a positive intention, and positive attitude towards such non-voluntary technologies cán be an appropriate goal. Some literature also discusses using TAM in non-voluntary contexts, in which some also name that system usage might not be relevant, but that the user's attitude is, leading to affective commitment of using the system. (Martins & Kellermanns, 2001) To bridge this gap to promote a positive attitude, while usage is non-voluntary, some literature (as does this research) suggests incorporating motivational theory into TAM in order to intrinsically motivate users to use non-voluntary technology. (Martins & Kellermanns, 2001).

Perceived usefulness and intention to use captures a big part of train driver reasoning in the case context. The focus on intention to use showed to be a limited concept for non-voluntary use, as non-voluntary use shifts TAM's goal to promote usage behavior with rational reasoning, towards the goal to promote a positive attitude and intention to use.

11.2.2. Trust towards organization

Trust was found as having a major effect, as results showed that trusting the organization to use DCM data with integrity is critical. A concept of trust was already found as external variable for TAM in chapter 8, even in the context of a monitoring system (based on driving behavior instead of eye-measurements) for truck drivers. (Ghazizadeh et al., 2012a). However, here trust related to trust towards whether the technology can be trusted to perform its tasks, instead of trusting an organization with sensitive data. There are examples of studies that frame trust within this organization context, as one extended TAM by relating PU with 'perceived information security', and 'inter-personal trust' (Trang, Ruch, & Kolbe, 2014). Hence, they make clear that there must be a general trust between organization and user, and that the user should feel like their information is secure. For train operators, this suggests that indeed, dealing with DCM measurements must be done with high integrity in order for users to accept such a DCM system.

11.2.3. Suggested theoretical approaches for future research

Two new perspectives to deal with this shift can be taken, incorporating affective reasoning: it can be promoted to improve the attitude with 'intrinsic motivation' models. On the other side, non-voluntary usage could be modeled by minimizing the 'resistance' of users towards the technology, which arises as users need to use the technology non-voluntarily, conflicting with a negative intention to use, or negative attitude.

Competence & Autonomy as needs to be intrinsically motivated

Drivers also found technology useful if it helps in their responsibility, with a big focus on their own competence and their feeling of autonomy and control in driving a train. Here it must be noted that train driving is already an industry in which train drivers have little control compared to other mobility types: they are already constrained by many aspects such as vertical movement on tracks, tight planning of train rides, and ride navigation by the train dispatcher. Small reductions in control and autonomy during driving have big effects on the driver's job. This need for a feeling of competence and autonomy can be related to intrinsic motivation within the self-determination theory (Ryan & Deci, 2000). The self-determination theory is a motivational theory, showing how intrinsic motivation is brought about.'Intrinsic motivation refers to initiating an activity because it is interesting and satisfying in itself to do so, as opposed to doing an activity for the purpose of obtaining an external goal.'(Ryan & Deci, 2000). It is hence interesting to use this model to explain the extensive need for train drivers to be competent and have autonomy in driving. The theory is in some cases already used in mobility research, for example in car-driving education(Watson-Brown, Scott-Parker, & Senserrick, 2020), yet is not generally used in approaches to acceptance of technology. Intrinsic motivation has, in fact, been previously used in combination with TAM (Martins & Kellermanns, 2001) to assess acceptance

Self-determination, describes needs to be met in order to allow intrinsic motivation, which two of the three are the previously discussed feelings of competence and autonomy. Also 'relatedness' is described as a need for intrinsic motivation, but was not found to be particilarly relevant in the context of this research. The feelings of autonomy and competence can thus be crucial in making train drivers feel more intrinsically motivated.

Resistance to technology as an approach for using technology in the workplace
As limitation of such usage behavior models in an operational / job context is that these models aim to predict usage behavior, although in train driving some use is non-voluntary (many technologies are simply part of the job, as the dead man's pedal and ATB is in train driving). This was also found during the focus groups: mentioned by drivers' dislike towards technological developments in general, and how the role of a driver changed.

In acceptance research on train drivers, (Naweed & Rose, 2018) reframed the problem of technology acceptance to 'resistance to technology'. Here, acceptance of railway technologies is seen as a problem in which unforeseen problems must be analyzed with new technologies, with the focus that 'resistors' (e.g. the drivers) must be taken seriously for their legitimate concerns. The research called to analyze resistance by understanding causes of resistance, understand what is being resisted (as this often remains unclear) and 'to see resistance as a constructive part of the process', using end-users as they know most about their tasks.

Although this approach might be seen as appropriate to understand forces of resistance in non-voluntary contexts, and also promote to consider perceptions of users, one might still see this approach of 'resistance' as a negative and technology centered perspective. One might say that focusing on resistance, takes a starting point of users not finding the technology useful, or intrinsically motivating. Settling to 'deal with resistance', instead of promoting usefulness and intrinsic motivation could be interpreted as either being more pragmatic, accepting that people resist technology, but can also be seen as low expectations (the designer expects that drivers won't be positive at all, only aiming to minimize the resistance). This then does aim to consider whether the interaction between driver and technology leads to positive outcomes. The concept of resistance may perhaps be tangible and practical to a designer, it might loose the focus on designing technology that is designed to be useful by the user in the first place.

11.3. Methods Discussion

The method of this specific focus group design is discussed by considering whether focus-groups are indeed useful for this topic, whether the approach can be seen as human-centered or co-design, and what limitations of this study are.

11.3.1. Focus groups as a method for sensitive topics

From knowledge on focus groups, it was not clear if focus groups are suitable for sensitive topics, as researchers can be of opinion that such group settings are easier for judgment than individual settings, while some literature (Kitzinger, 2005) calls for the benefits that focus groups have in discussing sensitive topics. According to them, it could in fact allow participants with similar experience to find support in each other, and that their beliefs and perceptions can shift during their interactions. Some elements in the set-up of the focus groups aimed to make the focus group more approachable and prevent feelings of being judged. Using a case example was one way, framing the conversation as 'a random train driver who struggles with alertness'. It made the conversation less personal and hence less sensitive. Additionally, design probes were used to open up the conversation, not asking them what they think of certain design choices, but letting them respond to pre-made design probes. It eased the conversation, and made complicated design aspects concrete.

During the focus group sessions with train drivers, both drawback and benefits were found of focus group on the sensitive topic of alertness. On the one side, train drivers can be reluctant to interact with each other, shown as they mostly respond to questions with the facilitator.

On the other side, all four train drivers shared sensitive personal experiences, showing that a safe environment was achieved. Also, beliefs and reasoning were sometimes shifted because of the interaction between them: sometimes train drivers did shift their attitudes from hearing other's experiences (e.g. one driver noting a contradictory statementnfor another driver, saying that indeed, it is inherently difficult to deal with alertness). In an individual interview, chances are high train drivers would not have made this shift of recognizing that dealing with alertness is complicated, making them self-symphatize that they are not alone in this problem.

It also happened that drivers challenged each other to shift their attitudes: in some instances, strong convictions of not seeing the use in a concept were challenged by the other driver, resulting in more in-depth insights than an individual interview would have. In some cases, this led to the drivers giving more nuanced opinions, showing more depth into why they thought that.

11.3.2. Human-centered-design over co-design approaches

The human-centered focus of this research, analyzing acceptance of train drivers, can be seen as an attempt in a bigger perspective of including end-users early on in the design process. This human centered focus has the goal to investigate the human to design more appropriate technology, both from higher safety and performance, and higher well-being of the people that use the technology. More recently, new design frameworks have been emerging such as co-design and co-creation, emphasizing this collaborative approach within the design process even more. Although they look similar, there are some considerable differences, many seeing human-centered as a more classical research approach, and co-design as designing together with end-users.

Role of researcher

Co-design is by some also highly related to a different role of the researcher compared to the classical approach of human centered design.(Sanders & Stappers, 2008). In the classical role, the researcher combines theory with research findings by researching humans, allowing human-centered design. In this proposed way of co-design, the end-users can 'play a large role knowledge development, idea generation and concept development.'(Sanders & Stappers, 2008). These difference in roles are illustrated in figure 11.1.

Co-design is often also characterized by using creativity of involved stakeholders in the design process (Friedrich, 2013) .

Human-centered-design as chosen approach

The challenge within this research was partly the complexity of theoretical concepts, and the unpredictability

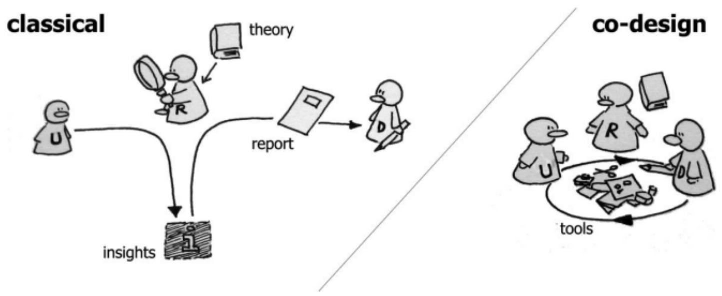


Figure 11.1: Classical roles of users, researchers, and designers in the design process (on the left) and how they are merging in the co-designing process (on the right).(Sanders & Stappers, 2008)

of acceptance of such a new technology. Still, the clear definition of the problem, and concrete question of which ways of giving feedback promote acceptance, led to making a human-centered approach appropriate. This human centered approach allowed to efficiently guide the conversation to relevant topics on which train drivers are experts, gaining valuable information. There was hence no need to make use of their creativity and together ideate and develop concepts. Also given that train drivers are experts at train driving, and the researcher is expert at researching human behavior, it makes sense that drivers provide a rich context and show their perceptions, while the researcher designs. Also with the complexity of alertness and acceptance, it can be considered important to separate these roles of user expert and research expert. Co-design attempts were made during the first focus group session, in which questions were asked to think of a solution on what would help them to stay alert. However, this was problematic: they struggled to come up with ideas, and the ideas were generally unrelated to DCM systems, and more related to safety or performance. Additionally, it was problematic as their ideas could not be designed in practice, possibly leading to other expectations.
This research can be primarily described as human centered research, as the researcher used theory in combination with perceptions and attitudes of end-users, to combine them into design requirements.

Effect of train driver input on results

It is a nice question to ask how this research employed the end-user, and to discuss implications of either adopting 'classical' human centered approaches, or proposed co-design approaches.

This human centered approach led to much impact of train drivers on the end-result of design requirements. This was both by giving insights into why perceived usefulness is important, and in which the perceived problem showed to be a relevant new aspect. And also in new factors of autonomy and competence, which were not expected beforehand. These insights call for more consideration for driver's intrinsic motivation related to driving and considering trust towards the organization, next to rational factors of acceptance found in TAM.

11.3.3. Limitations

Limitations of the current method are discussed, consisting of implications of a qualitative approach, participant group and use of design probes.

Qualitative Research Characteristics

The most important limitation must be understood from the qualitative approach of the methods and analysis. The goal of this research was to find in-depth reasoning on why train drivers would, or would not accept DCM technology, leading to factors that are relevant in the design and implementation of such systems. Therefore, it does not answer questions that can be answered with quantitative methods, such as evaluation studies that can determine to what extent train drivers will accept DCM. These methods would then also lead to some statistical significance, and statistical generalizability. Hence, this study thus also does not make claims on whether using DCM will be accepted by train drivers, and advice on whether to use it or not.

Participant group

Although ideally the set-up of methods was made to use a group of regular train drivers for the focus groups, there were issues on finding enough participants, making employees participate that have much experience in interacting with train driversThis led an amount of four train drivers, and four employees that participated. Additionally, from the group of train drivers, two are working as regular train drivers, and two are working as 'testing train drivers'.

In the results, there were various aspects in which both groups agreed. They stated similar coping strategies, and similar issues with alertness. Because of this, it could be the case that there are aspects known to train drivers, unknown to the office employees, that are missed in this research.

These testing drivers used to be regular drivers, but generally only perform testing related activities. This makes them highly involved with new technologies, possibly leading to different perceptions and opinions. Also, they might have different experiences of, and attitudes towards, how NS develops new technologies. Hence, it could be useful to validate the findings in this study, most specifically the found results on competence and autonomy.

Design probes

Remarks can be made on how the design probes were presented during the focus groups. The goal of these probes was to find acceptance factors in the context of alertness feedback systems, presenting three designs that consist of various relevant aspects. The probes were written down in one sentence on a poster, and briefly explained by the facilitator. However, two out of three concepts were generally disliked, only receiving positive responses to the sleepiness alarm. Although it is possible that the other two alarms are unfavorable, it is also possible that the concepts were explained too broadly. For example, one concept was 'if you are deep in thought, you receive an extra task'. All participants found it unclear what an extra task is, and why that would be necessary. Keeping the explanation general can have caused to prevent to find more specific aspects.

11.4. Transferability of Acceptance Factors

The detailed analysis of results gave many valuable insights on using DCM's in the job of train drivers, showing the importance of rational factors related to perceived usefulness, intrinsic motivation factors of competence and autonomy, and trust towards the organization. Already from reading the report, the reader might recognize the results to be applicable to other train driving organizations, other technologies, or for other driving domains, such as automotive, marine and aviation domains. Although the qualitative approach of this research does not allow the results to be generalized on the theoretical level, the aspects of results can be compared to other contexts, in which logical reasoning can compare situations to come up with relevant insights. In the next paragraphs, the author discussed the transferability of results to other situations of other train driving organizations outside of The Netherlands, other technologies in train driving, and other mobility domains.

11.4.1. Transferability to train driving outside of The Netherlands

DCM in the train cabin could not only be applicable to NS, but also to other train operation companies. The United Kingdom researches the use as well (Leach & Tailor, 2021), and the increasing use of DCM in truck-driving and car-driving begs the question for many train drivers whether DCM is useful. Differences between NS and other train operators can be different trains with different cabin configurations. For example, the technologies in the cabins can differ in their level of digitization, in which Dutch train driving is generally seen as perhaps more digital interfaces than other countries. Also the type of trips can differ, in which stops occur relatively often compared to many other countries. As such, the problem of lowered vigilance and lowered alertness is known throughout train driving in general. Acceptance of technology might have difference for train driving at NS than other companies by its culture by a history of opposition to change and striking, and the big role of the works council ('ondernemingsraad'). As such, trust in the organization can differ between organizations, although it must be said that strikes are also common in other countries/train companies. Staying alert is a problem in train driving in general, and its feeling of responsibility, needed driver capability to stay alert, and challenge to stay engaged in driving can be seen as relevant in train driving in general. As such, acceptance factors and design requirements are expected to be applicable to train drivers outside of The Netherlands and NS. It must be only noted that the acceptance factors of trust in organization might differ between organizations.

11.4.2. Applying acceptance factors to other technologies in train driving

Additionally, the insights that showed perceived usefulness, organizational trust and driver competence and autonomy to be important for DCM systems, might also be relevant for other technologies in train driving. Other assistance systems, such as traffic assistance and safety systems influence the competence and autonomy of drivers, and might be equally important on their perceived usefulness. To see whether these findings are transferable, the differences between DCM and other technologies can be discussed. A first might be that perceived usefulness leading to intention to use is a very straightforward and much used model. Also perceived ease of use is part of TAM (Davis, 1989), and was seen as inapplicable to DCM, as much feedback is received and various feedback methods differ little in their ease of use. For other technologies, the perceived ease of use might be very relevant.

One major difference between DCM and other technologies is that DCM measures the drivers themselves. Other assisting technologies generally measure driving-related aspects: they measure the state of the vehicle, and provide and/or synthesize information on the vehicle state to (help to) decide and act. DCM on the other side measures the driver's state, which could make DCM more personally involving compared to other technologies, making the effects of competence and autonomy, being very personal factors, more relevant for DCM. It is believed however that intrinsic motivation factors such as competence and autonomy can be of big relevance in the train driving technology acceptance in general, as autonomy is generally already low in train driving, and as competence plays a big role in the driver's responsibility. This can for example be applied to driver assistance systems (such as TimTim) and safety systems as they were mentioned to impact competence and autonomy. This was mentioned for TimTim, that the provision of information is highly appreciated, las more information leads to better trade-offs, and feeling more in control. Even safety systems can be perceived as improvements in competence and autonomy: ATB makes the driver competent in decreasing chances of SPAD's and allows to feel free within safety margins. Hence, although competence and autonomy are of particular importance for DCM, they could be relevant throughout many technologies that drivers interact with. Next, the issue of trusting the organization with their individual data is particularly sensitive with DCM compared to devices that collect driving-related information. Still, drivers also showed to be critical on other devices whether it could measure and collect their performance (e.g. measuring their punctuality with TimTim and team-managers having access), making trust a general concern with new technologies, although it might be especially relevant for DCM's.

All in all, DCM can be generally seen as more personal to the driver making a feeling of competence and autonomy more relevant, less relevant for its ease of use, and more sensitive for data use than other train driving technologies. Still, autonomy and competence might be applicable as acceptance factors for a broader set of train driving technology.

11.4.3. Transferability to other mobility types

The insights of using perceived usefulness, intrinsic motivation and trust in the organization beg the question: To what extent are these insights transferable to other mobility domains?

Car driving

Car driving already adopted DCM systems, making it interesting to explore similarities. Car driving is significantly different than train driving however, as the tasks involved with car-driving are very different, consisting of more manual control, more tasks (traffic management, navigation). Driving on a high-way can be considered most similar to train driving, due to the monotonous nature in which sustained attention is needed. Another big difference is that cars are generally not driven in a professional setting: they are often not paid to drive, they use public infrastructure, and are trained to a lesser extent than professional drivers (driver education is less elaborate than train driving, pilot or maritime officers). Goals and performance of driving are more personally driven (time-efficiency, personal safety), than professional driving (profit goals, responsibility on other persons or goods). There could be similarities in what factors lead to acceptance, as car drivers also value their own competence of staying alert immensely, and feeling in control is important as well. Yet, many factors could be missing or could be more important in car-driving, such as economical affordability, social-image. All in all, contexts differ in a high extent, and its acceptance can depend on other factors than in train driving, underscoring the need for more acceptance research of mobility technologies in professional settings.

Marine and aviation operations

Marine and aviation contexts are more similar to train driving: pilots and marine officers are firstly professional roles, requiring extensive education, receiving substantial salaries and requiring a high level of responsibility to safely transport passengers and/or goods. Also monotonous tasks that require sustained attention are very applicable during these jobs: Airline pilots mainly supervise automation systems, which can be monotonous and require sustained attention, especially during the cruising phase in a flight. Marine officers also supervise automation systems that control the ship for them, and need to be vigilant in observing traffic. Hence, problems of lowered alertness and mind-wandering might be relevant. Also the problem of sleepiness can be recognizable, as pilots and officers need to work at night and have variations in their shifts. For pilots, differences in time-zone could play a significant role.

Airline pilot's tasks are very different from train driving however, consisting of more tasks, and more variety in the type of tasks and environment, making peaks of high workload more common.

The amount of tasks marine officers have could be more comparable to train drivers, although specific comparisons are not made here.

They are also similar to train driving in their long braking distance: ships can take multiple kilometers to fully stop, creating similar challenges compared to train driving in speed control and stopping in collision problems. Also, marine officers and airline pilots need to adhere to strict schedules, creating little freedom and flexibility in their routes, just like train drivers. This makes the need to feel autonomy and control possibly relevant for them.

Their differences are mainly in the degrees of freedom: while train drivers are constrained in their sideways movement, ships can steer in all horizontal directions, and aircraft can even control the height. A feeling of being constrained in your movement and have low autonomy is perhaps less relevant in aviation and marine industry.

There can also be big differences how pilots and officers are trained on alertness and which strategies to cope with alertness are used. For example, piloting tasks are highly structured and standardized, involving many checklists and standard procedures to follow. Perhaps this focus on standardization and procedures makes it easier for the pilot to stay engaged in their tasks, compared to train drivers.

11.5. Potential Benefits & Opportunities of using DCM

The design requirements show that how train drivers perceive that usefulness, trust, autonomy and competence of using DCM in train driving should all be considered. Although it was not researched if DCM will be accepted, they provide insights to design such a system appropriately. If taking a birds-eye view, it begs the question: once the solution is feasible in its acceptance, what are its benefits and costs?

Firstly, the requirements posits that alertness must be increased in a way that is seen as useful, but also honors the driver competence and autonomy. A good suggestion might be to firstly inform the driver voluntarily, by for example simply displaying their sleepiness/tiredness level, either by eye-blinking (inferring sleepiness), or mind-wandering (inferring lowered vigilance).
Also, train drivers might use the information in combination with alertness strategies to notice different ways they are alert. Still, the perceived relative advantage is questionable, as people are, or consider themselves, to be good at inferring their alertness state. Then, having a system show you that you are wrong, could also be detrimental for the feeling of competence and autonomy.
On the other side, alertness is also such a complex problem in train driving, seen in its irregular shift timing and sustained attention that is needed, that informing a driver will not be the holy grail. As such informative displays could support dealing with alertness in general, it might be hard to show that it in specific situations prevents SPAD's, making results of SPAD's hard to make demonstrable.

Another opportunity might be to improve the dead man's pedal with DCM. Given that drivers automate the use of the pedal, DCM could help to support the driver by waking them up if critically sleepy. For this, reliability must be high, especially as false alarm rates can be relatively high if critical sleepiness does not occur often. Choosing the threshold (what level of alertness is safe) for this is tricky as well, as increasing the threshold lowers chances of use and makes it less relevant as this situation will occur less frequently, while decreasing the threshold could impede autonomy and feeling of competence.
(Parasuraman et al., 2000). Also for acceptance, over-trust might start to play a role, making it feel more allowed to be highly tired, as DCM will wake-up the driver anyway. Still, if designed reliably and tuned with care, a DCM might have potential to leave behind the old-school train technology of the dead man's pedal, as this pedal might currently over-relied upon by drivers to gain feedback on their alertness (as they also activate it automatically while being sleepy). Hence, a DCM as replacement/addition to the dead man's pedal might have potential, given that it is sufficiently reliable and well designed.

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Appendices

A

Literature Review

Literature searches were performed to find information on the case context of DCM's, theories on alertness and theories of acceptance. The goal or topic of the search, used search terms and hits are given with literature used in the thesis. Most searches were done in Scopus, while some, if mentioned, were searched on Web of Science.

Not all literature used in the thesis was found in the literature study, as they are either standard literature in the field of human factors (Bainbridge, 1983), (de Waard, 1996), (Mackworth, 1950) and (Parasuraman et al., 2000) or were found as references during the internship at NS (DutchRailways, 2024) (Verstappen et al., 2017) (Leach & Tailor, 2021)(NSR Concernveiligheid, 2010), or generally known from European-Union projects on technology in mobility. (Kaiser et al., 2020) (Christos et al., 2020).

A.1. Context of DCM's

Goal	Search terms	Hits	Used in chapter
Context of monitoring alertness	sleepiness OR fatigue OR drowsiness AND monitoring OR vigilance OR (sustained AND attention) AND driving OR driver [Reviews only]	120	A review of DCM measurements (Kashevnik et al., 2021), (Razak et al., 2022), Eye-blinking (Cori et al., 2019).
	(DMS OR DCMS OR DCM) AND (distraction OR out-of-loop)	29	Warning / informative feedback (Presta et al., 2023)
Distraction feedback concepts	design OR system AND inattention OR alertness OR distraction AND driving OR driver AND alarm OR warning AND feedback	22	Post-drive feedback (Donmez et al., 2008c) (Roberts et al., 2012) (Donmez et al., 2008b)

Table A.1: Literature search results on alertness aspects. All searches were done in the SCOPUS library. The right most column indicates what was gained from the literature with its citation.

A.2. Alertness Theory

Goal	Search terms	Hits	Used in chapter
Defining distraction	driver AND distraction OR inattention OR alertness OR vigilance AND definition	56	Inattention Taxonomy (Regan et al., 2011)
Effects of monitoring	monitoring AND vigilance AND workload OR underload	123	(Warm, Parasuraman, & Matthews, 2008)
Mechanisms vigilance	sustained AND attention AND vigilance AND decrement OR mitigation OR decrease AND control OR self-regulation	27	, Vigilance decrement (Mishler & Chen, 2023), (Greenlee, DeLucia, & Newton, 2024) Mind-wandering (Thomson et al., 2015)
Relating fatigue/sleepiness with vigilance	attention AND sleepiness OR fatigue OR drowsiness AND (monitoring AND task) OR vigilance OR (sustained AND attention) AND driving OR driver		Vigilance revisited (Klösch et al., 2022) Partially automated vehicles and vigilance(Mcwilliams & Ward, 2021) Active and passive fatigue (Desmond & Hancock, 2000)
Color perception	color AND perception AND periphery AND visual [ordered by relevance]	209	Peripheral vision & color (Hansen et al., 2009)

Table A.2: Literature search results on alertness aspects. All searches were done in the SCOPUS library. The right most column indicates what was gained from the literature with its citation.

A.3. Acceptance Theory

Acceptance theories were found by looking for literature that studies acceptance of technologies.

Search terms	Repository	Hits	Used model in literature
technology AND acceptance AND model AND user OR driver [ordered by highest citations]	Web of Science	9399	updated TAM model + extension(Venkatesh & Davis, 2000) (Venkatesh, Morris, Davis, & Davis, 2003)
technology AND acceptance AND monitoring AND driving	Web of Science	89	TAM (Al Haddad et al., 2022)
'technology AND acceptance' AND (alarm OR feedback OR alert) AND (driving OR mobility)	Web of Science	70	TAM (Ghazizadeh, Peng, Lee, & Boyle, 2012b)
'technology AND acceptance' AND (driver OR conductor) AND (railway)	Web of Science	8	TPB & TAM (Larue et al., 2015)
			TAM (Roberts et al., 2012)
adoption AND design AND users AND transportation	Web of Science	4	TAM (Crawford & Kift, 2018)

B

Focus Group Set-up

B.1. People involved in focus group set-up

Various people were involved in the design of the focus group.
Garoa Gomez Beldarrain,a PhD candidate at Industrial Design Engineering at Delft University of Technology, gave advice to adopt co-creation methods such as a generative co-design session, leading to the choice of a focus group set-up.

Supervisors gave their feedback on methodology in general and specific questions. Outcomes consisted of discarding the use of a survey before the start of the focus group, placing more emphasis on social safety in the design and deleting/editing questions that can be perceived as judgmental (such as based on normative beliefs concepts from TPB model).

Two MSc students in Communication Design for Innovation attended a pilot session of the focus group (made to the context of car-driving). The researcher's own observations led to assessing that questions led to a lively discussion. The individual aspect of writing notes often took less time than five minutes, while the discussion took much longer. Feedback from the students firstly led to changes in questions (Discarding some questions as some rounds were experienced as long. Also the last question on external variables was changed to when participants had answered the previous questions, for logical flow). Secondly, tips for improvement on the role of the supervisor were given)(balancing of creating structure versus being flexible), social safety and group atmosphere and how to show that train drivers are the experts, how to deal with the final question of acceptance aspects and clarity of instructions.

B.2. Operationalization: Questions in Focus Group

	Question	Theor. Concept	RQ
Round 1:	**Case Example**		
	To what extent is the case example recognizable?	Problem awareness	RQ4
	How could the driver notice that he/she is less alert?	Recognition Methods	RQ3
Round 2:	At which moments is it required to be alert?	Alertness Situations	RQ3
	What are ways in which the driver in the case could deal with the situation?	Coping Strategies	RQ3
Round 3:			
	Concept 1: Task engagement at mind-wandering		
	Does this seem useful for you?	TAM: PU	RQ4
	Would you use this?	TAM: BI	RQ4
	If yes, how far away/where are your thoughts on the moment you want to receive feedback?		RQ4
	What type of task? Listening (Music, podcast, audiobook), talking		RQ4
	Concept 2: Post-drive distraction app		
	Does this seem useful for you?	TAM: PU	RQ4
	Would you use this?	TAM: BI	RQ4
	Concept 3: Alarm during sleepiness		
	Does this seem useful for you?	TAM: PU	RQ4
	Would you use this?	TAM: BI	RQ4
	How sleepy? (Scale according to figure **??**)		RQ4
	What does the alarm do? (Sound, stops the vehicle, advises to stop the vehicle)		
Round 4:	Does it seem useful? If not, what is needed to be useful?	TAM: PU	RQ4
	Would you use such a camera/eye-tracker in the cabin? What is needed?	TAM: BI	RQ4
Round 5:	Which of these aspects are most important in your choice if you would use it? (See aspects in table 5.1 in chapter 8).	TAM:External variables	RQ4

Table B.1: Questions asked in the focus group (left column) with their theoretical reasoning and relevant research questions. PU = Perceived Usefulness, BI = Behavioral Intention to use

B.3. Case Example used in Focus Group

Een machinist zit in een dienst om 00:30 in de nacht, in een intercity vanuit Lelystad naar Zwolle. Zijn dienst begon om 17:00. Langzaam merkt hij dat hij best moe is, en de donkere cabine helpt ook niet mee om actief te blijven.

Hij moet een lang stuk rechtdoor rijden en vooral kijken naar de seinen. Hij raakt in gedachten: hij denkt aan zijn bed en hoe lang zijn dienst nog duurt. Hij merkt dat hij minder alert wordt, en probeert zijn aandacht weer op het spoor te krijgen.

Terwijl hij aan het rijden is, en er een sein aankomt die hij moet zien, gaat de GSMR. Het is waarschijnlijk de treindienstleider met een vraag. Hij negeert de telefoon en probeert zijn aandacht toch te houden op het spoor. Er komt straks wel een moment dat hij minder alert hoeft te zijn.

B.4. Focus Group Timetable

Starttime	Description	Time needed	Topic
-00:20	Walk-in with tea and coffee		
00:00	Welcome	00:05	Introduction of facilitator, MMI team and research, explanation of day
00:05	Informed consent	00:10	Informed consent explanation, signing
00:15	Case example explanation	00:05	Case example, questions
00:20	Start of 1st round	00:25	Experience and coping strategies related to case example
00:45	Start of 2nd round	00:35	Which situations needed to be alert? What could help externally?
01:20	End of 2nd round: -break-	00:30	
01:50	Start of 3rd round	00:30	External feedback aspects attitudes
02:20	Start of 4th round	00:30	DCM aspects attitudes
02:50	End talk	00:10	Thank you, possibility for follow-up of results and taking a look at the data
03:00	End		

B.5. Informed Consent Forms

Toestemmingsformulier voor Deelname aan *Human Factors Onderzoek*
over alertheid in de cabine en wat hierbij zou kunnen helpen

Titel van het Onderzoek: Bijeenkomst om te onderzoeken hoe machinisten omgaan met alertheid en wat helpt om op de juiste momenten alert te zijn.

Het doel van dit onderzoek is om inzicht te krijgen in de ervaring van machinisten met alertheid, en wat hierbij zou kunnen helpen. Door ondertekening van dit toestemmingsformulier, geeft u toestemming aan de onderzoeksleider om uw persoonsgegevens te verwerken voor het MMI Onderzoek over alertheid in de cabine, en de resultaten met NS te delen en te publiceren.

De workshop is onderdeel van een afstudeeronderzoek aan de TU Delft. Uw deelname is van groot belang om goed inzicht te krijgen in de ervaring van machinisten. Dit helpt om uiteindelijk effectieve hulp te ontwerpen die de werkomstandigheden verbeteren. De resultaten zullen gepubliceerd worden in het eindverslag en mogelijk een wetenschappelijke publicatie. Ook zal het leiden naar een advies aan het MMI team bij NS.

De workshop zal maximaal 2 uur in beslag nemen, inclusief pauze. U zult worden gevraagd antwoord te geven op verschillende vragen door deze eerst op te schrijven, en vervolgens te bespreken in een kleine groep (max 4 personen). Deze vragen gaan over uw ervaringen rondom alertheid, en wat u goede oplossingen zou lijken om alert te zijn tijdens het rijden.

Neem de tijd om dit document door te lezen om te kijken of u toestemming geeft voor de volgende punten. U kunt er uiteraard voor kiezen om geen toestemming te geven. Zonder uw toestemming zullen de persoonsgegevens niet verzameld worden. Wanneer u geen toestemming geeft, heeft dit nooit nadelige gevolgen voor u. Ook zal uw keuze om geen toestemming te verlenen niet geregistreerd of gemeld worden.

	Ja	**Nee**
Deelname aan dit onderzoek		
Ik heb bovenstaande informatie gelezen. Ook is aan het begin van de bijeenkomst de tijd gegeven dit toestemmingsformulier door te nemen. Hierbij kon ik ook vragen stellen.	☐	☐
Ik doe vrijwillig mee met dit onderzoek en ik begrijp dat ik mag kiezen om vragen niet te beantwoorden. Ik begrijp dat ik me op elk moment, zonder reden op te geven, kan terugtrekken uit het onderzoek. Ik begrijp dat dit nooit nadelige gevolgen heeft en niet wordt geregistreerd.	☐	☐
Gegevens en gedeelde informatie		
Ik begrijp dat er persoonlijke data (namen, emailadressen en dit toestemmingsformulier) worden verwerkt. Deze gegevens worden binnen de AVG (algemene verordening gegevensbescherming) als gevoelig gezien. Ik begrijp dat mijn persoonlijke gegevens en dit formulier los op een beveiligde locatie worden opgeslagen. Ook begrijp ik dat alleen de onderzoeksleider (Maurits), het mens-machine interactie team en zijn begeleiders aan de universiteit deze kunnen inzien.	☐	☐
Ik geef toestemming dat de workshop met audio mag worden opgenomen, welke anoniem wordt uitgeschreven na de bijeenkomst, en binnen 1 jaar wordt verwijderd. Ik begrijp dat de onderzoeksleider (Maurits), het mens-machine interactie team en zijn begeleiders aan de universiteit toegang hebben tot het audiobestand.	☐	☐

Figure B.1

Intern

	Ja	**Nee**
Ik begrijp dat er persoonlijk identificeerbare informatie en onderzoeksinformatie (geluidsopname en geschreven werk tijdens workshop) wordt verzameld. Ik begrijp dat er echter altijd een kleine kans bestaat op een gegevenslek. Ik begrijp dat persoonlijke informatie en dit formulier zo veilig mogelijk, en los van elkaar, worden bewaard. Dit alles om de kans op een gegevenslek zo klein mogelijk te houden.	☐	☐
Ik geef toestemming dat de geanonimiseerde onderzoeksgegevens (uitgeschreven geluidsopname en opgeschreven materiaal tijdens de bijeenkomst) binnen het mens-machine interactie team van NS gedeeld kunnen worden. Ook dat deze opgeslagen wordt op NS servers voor toekomstig onderzoek binnen het mens-machine interactie team bij NS. De informatie wordt niet buiten het team gedeeld.	☐	☐
Ik begrijp dat de informatie opgedaan tijdens de workshop op groepsniveau bekeken zal worden. Ik begrijp dat deze (anonieme) resultaten gebruikt zullen worden voor het eindverslag van het afstudeeronderzoek. De resultaten worden misschien ook gebruikt in een wetenschappelijke publicatie. Deze documenten zullen openbaar toegankelijk zijn.	☐	☐
Ik geef toestemming dat mijn antwoorden anoniem ge-quote mogen worden. Dat geldt voor het eindverslag van het afstudeeronderzoek en voor een wetenschappelijke publicatie.	☐	☐

Ter ondertekening:

Naam: ………………………………………………………

Email: ………………………………………………………

Handtekening: ……………………………………………

Intern

Figure B.2: Enter Caption

B.6. Coding Tree

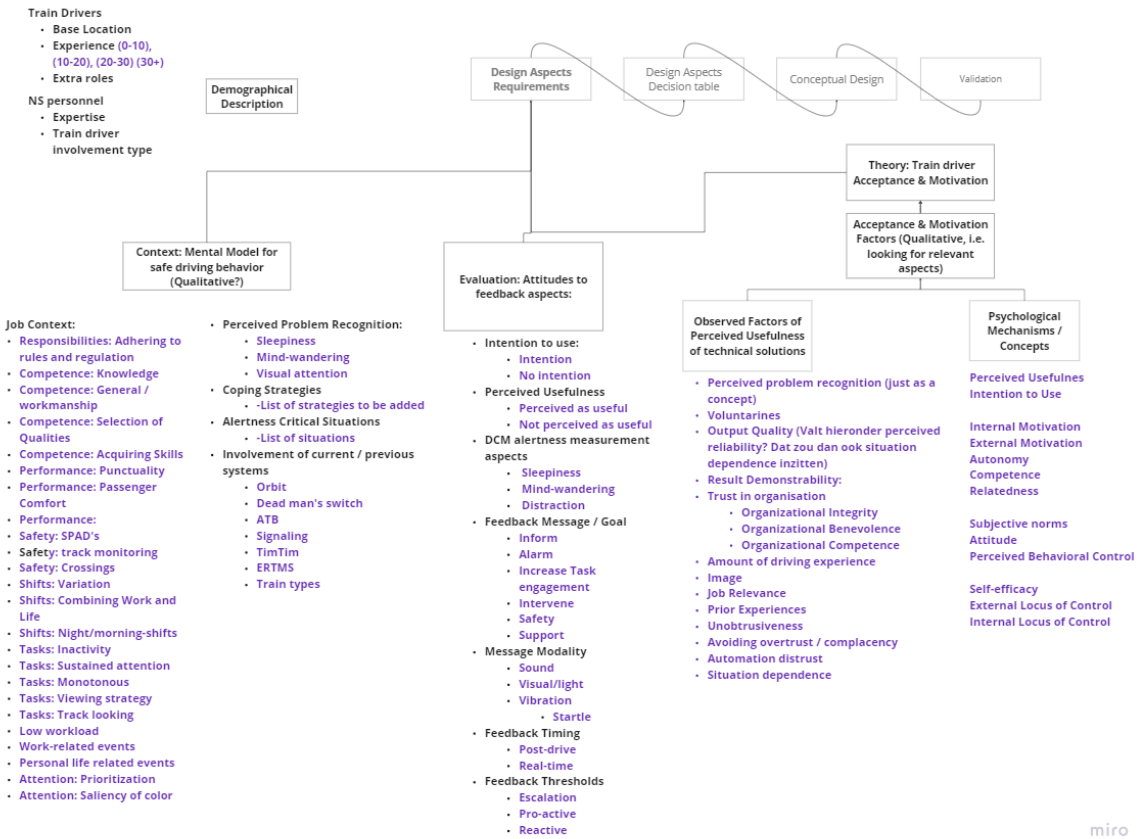

Figure B.3: Coding tree applied during coding