

Aalto University  
School of Science  
Degree Programme in ICT Innovation

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# Modelling Driving Performance using implicit interaction

Master's Thesis  
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ABSTRACT OF  
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<p>The current project has been realized in collaboration with EIT Digital and Philips Research as part of the high impact initiative in the health &amp; well-being action line. The challenge we are facing in the present work is to design a system for professional truck drivers that monitors driving behaviour and predicts vigilance degradation. The research ended with defining parameters that can model drowsiness, fatigue, stress, aggressiveness and driver inattentiveness. The final proposal includes an in-vehicle system that does not impede the drivers' primary or secondary tasks, requires no explicit user input and provides feedback that promotes driving awareness and safer on-road behaviour. The system is being designed to support user identification, personal profiles, driving performance monitoring and context-aware interaction for providing personalized and relevant to the circumstances feedback.</p> <p>In order to reach the desired conclusion, we initially conducted a literature review on advanced human-computer interaction and intelligent systems models and we present a model-based interface that supports the desired functionalities. The work also included comparison of cutting edge technologies for affective computing and driver modelling. Due to the nature of the agreement with Philips, we are not authorised to disclose any information that relate to user studies, thus the reader is presented with hypothetical scenarios for system output and user feedback that remain to be verified. These scenarios have been shaped with the help of technology acceptance and data privacy academic papers as well as deep understanding of the driving related context.</p>			
<b>Keywords:</b>	in-vehicle systems, driver modelling, implicit interaction, affective computing		
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# Abbreviations

<b>AC</b>	<b>A</b> ffective <b>C</b> omputing
<b>AIHCI</b>	<b>A</b> daptive & <b>I</b> ntelligent <b>H</b> uman <b>C</b> omputer <b>I</b> nteraction
<b>BVP</b>	<b>B</b> lood <b>V</b> olume <b>P</b> ulse
<b>CAN</b>	<b>C</b> ontroller <b>A</b> rea <b>N</b> etwork
<b>DADS</b>	<b>D</b> river <b>A</b> lertness <b>D</b> etection <b>S</b> ystem
<b>DSS-IVS</b>	<b>D</b> river <b>S</b> afety <b>S</b> ystem <b>I</b> n <b>V</b> ehicle <b>S</b> ystem
<b>EMG</b>	<b>E</b> lectro <b>m</b> yography
<b>EOG</b>	<b>E</b> lectro <b>o</b> culography
<b>EVM</b>	<b>E</b> ulerian <b>V</b> ideo <b>M</b> anification
<b>FMS</b>	<b>F</b> leet <b>M</b> anagement <b>S</b> ystem (Interface)
<b>GPS</b>	<b>G</b> lobal <b>P</b> osition <b>S</b> ystem
<b>GSR</b>	<b>G</b> alvanic <b>S</b> kin <b>R</b> esponse
<b>HCI</b>	<b>H</b> uman <b>C</b> omputer <b>I</b> nteraction
<b>HRV</b>	<b>H</b> ear <b>t</b> <b>R</b> ate <b>V</b> ariability
<b>IMU</b>	<b>I</b> ntertial <b>M</b> easurement <b>U</b> nit
<b>IR</b>	<b>I</b> nfrared
<b>IRU</b>	<b>I</b> nternational <b>R</b> oad (Transport) <b>U</b> nion
<b>IUI</b>	<b>I</b> ntelligent <b>U</b> ser <b>I</b> nterface
<b>IVIS</b>	<b>I</b> n- <b>V</b> ehicle <b>I</b> nformation <b>S</b> ystem
<b>OBD</b>	<b>O</b> n- <b>B</b> oard <b>D</b> iagnostic
<b>P3P</b>	<b>P</b> latform for <b>P</b> rivacy <b>P</b> references
<b>POI</b>	<b>P</b> oint <b>O</b> f <b>I</b> nterest
<b>PSD</b>	<b>P</b> ersuasive <b>S</b> ystem <b>D</b> esign
<b>RPM</b>	<b>R</b> evolutions <b>p</b> er <b>M</b> inute
<b>TAM</b>	<b>T</b> echnology <b>A</b> cceptance <b>M</b> odel

<b>ToF</b>	<b>T</b> ime <b>o</b> f <b>F</b> light
<b>UC</b>	<b>U</b> biquitous <b>C</b> omputing
<b>UIMS</b>	<b>U</b> ser <b>I</b> nterface <b>M</b> anagement <b>S</b> ystem
<b>WWW</b>	<b>W</b> orld <b>W</b> ide <b>W</b> eb

# Chapter 1

## Introduction

The current project is a joint work of several european institutions in the Netherlands, United Kingdom, Germany and Italy, among which the European Institute of Innovation and Technology (EIT Digital) and Philips Research. Being part of the Health & Wellbeing Action Line of EIT Digital, the objective is to create a system that will determine and predict degradation in the driving performance of professional drivers, allowing them to have a more flexible and personalized working schedule depending on their health and well-being levels.

The present work will not present the final commercial solution that will be implemented for the project, as that would violate the confidentiality agreement between the author and Philips organization. Instead, the thesis will contribute to the scientific community by investigating the technology that is available so far, both to a research and to an application level, and present an instance of such a system.

### 1.1 Problem statement

The user space in which we wish to introduce the system concerns the automotive and telematics industry. It is being designed to address professional drivers and more specifically employees of logistics' companies. To that aim, the final design should comply with the European regulations of road transport [86]. Current legislation obliges the drivers to follow an inflexible working schedule which defines the driving hours and resting times, without considering the mental or physical state of the driver, or the environmental factors that affect their driving performance. In example, by law the driver is permitted to drive non-stop for three and a half hours before taking their first break. We claim that such a scheduling is too rigid and does not maximize the efficiency of the

drivers' working potentials. In the previous example, if they were allowed to drive for ten more minutes, it would be possible to avoid traffic in the next kilometers and cover more distance without road stress. The goal of the project is to introduce a system that will model driving performance and will result in a redistribution of driving and resting hours, in a way that increases both driving efficiency and user satisfaction.

## User group

We are addressing male and female users of any age that is legitimate to drive, e.g. 18-65 years old in the EU. The education level might vary significantly, thus we do not require any particular familiarity with technology. Being a truck driver includes two general categories according to the routes they drive; long-haul ones or the distribution routes. Long-haul drivers are the ones who cover long distances and a single trip could be up to five working days or more. This type of driver may need to start their trip from their hometown, travel a significant distance to load goods, and start their journey across countries until the unloading destination. Their route may include a few intermediate stops to load or unload additional goods. They are more susceptible to fatigue problems and sleep disorders due to shift working schedule. Distribution drivers are the ones who are assigned the greater urban area of a town which they have to cover within a day's time. Their schedule requires a lot of stops throughout that day and they usually are the ones who face city traffic, long delivery delays, customer complaints and frustration from commuters and private cars' drivers.

Other than stress and fatigue, sustaining a healthy lifestyle is hindered by many factors, with tight scheduling being only one of them. Not having access to healthy food at the truck stops, or the high cost when it is available, are two main reasons, but the most important one is lack of knowledge of balanced diet and sources of good nutrition [62].

## Definition

The challenge we are facing lies in designing a system for professional truck drivers that monitors driving behaviour and predicts vigilance degradation. Talking about driving performance, it is vital to clarify the parameters that define it. First, we are looking into drowsiness and fatigue, both of which are factors that greatly affect driving behaviour and result in vigilance degradation. Stress, which often leads to aggressive behaviour, is another factor that we are going to attempt measuring. Last, we are interested in detecting driver inattention, the *eyes/mind off the road* phenomenon, and we are going



to see how we can achieve that. We are going to be concerned with system positioning, user-system interaction and connecting service.

## Limitations

When presenting a solution for logistics' companies, it would be deficient to consider the drivers alone; the line management should also be included as the drivers have direct interaction with them. The term *line management* could refer to either planners, managers or fleet owners and is meant to describe anyone who is responsible for creating the itineraries and managing the fleet. For the purpose of this thesis, the system requirements are going to be examined only from the driver's perspective and not include any input from the line management. From this point on the context of the word *user* implies the professional driver, unless clearly stated otherwise. Additional services that are not directly related to modelling performance, but they are connected to user feedback are not going to be revealed either, as they fall into the limitations of the non-disclosure agreement.

The concept of the system raises critical ethical issues as it essentially requires continuous monitoring of the users (at least during their working hours) and collection of sensitive data, such as personal preferences and physiological characteristics. We have to assume that the users are reluctant to share sensitive information with third party services or people, and we need to check the validity of this assumption. If it holds, emphasis must be given on data sharing and privacy protecting techniques to mitigate privacy violation, which will also be part of our considerations.

## 1.2 Approach

A first approach to the problem is investigating technologies that enable ubiquity. The desired solution should address two main aspects of the users' lifestyle; integrate into their working environment and provide information regarding driving performance. Thus, it is required to accommodate both personalization and universality. The system will be adopted by fleet owners for a medium/large amount of drivers. Yet, it should provide personalized experience for each of the potential users in their professional environment, which requires adapting to contextually defined interaction modules.

The research question we are called to answer is how we can create an intelligent and unobtrusive system to measure driver's performance. It is important to understand

what are the physiological factors that affect performance and how we must interpret them so that they will provide value to the users and influence healthier and sustainable working environment.

Ultimately, we aim to provoke a change of user behaviour towards a healthier lifestyle. To that end, the concept of persuasive system design (PSD) will be adopted to suggest the optimal solution. Persuasive technology is an emerging field in information technology aiming to shift the attitude and/or behaviour of users [31]. It is associated with social psychology, intelligent systems and human-computer interaction. We will take a closer look into the factors that drive humans to adopt a behaviour and the models that can adapt to individual user needs in chapter 2.

### 1.3 Structure of the thesis

The thesis is structured in a way that introduces the reader to basic and advanced concepts of advanced human-computer interaction. Chapter 2 is dedicated to an overview of the state-of-the-art research concepts that will be used as scientific axes for developing the system. Chapter 3 presents a discussion of the features that will need to be collected and how they correlate with driving performance, as well as an insight on current data acquisition systems. As in every human-computer interaction project, the user is the key figure around whom the process is being developed, thus chapter 4 takes a closer look into the system specifications from a user perspective. Ethical considerations regarding the design will be included in this part, as well. Chapter 5 sketches the system architecture of a suggested solution (not the only one), in terms of sensor technology, system behaviour and the human-machine interface. Last but not least, chapter 6 contains a synopsis of the work conducted during the thesis and formulates further research questions for future development of the project.

## Chapter 2

# Scientific Background

### 2.1 Ubiquitous computing

#### 2.1.1 Definition

Ubiquitous computing (UC), or otherwise referred to as pervasive computing, concerns the integration of computer processing into everyday objects by means of micro systems, whose existence is negligent to the user [97]. This definition is given by M. Weiser, who sees UC as *embodied virtuality*; implying the process of removing the computers out of their electronic shells and embedding them into ordinary objects. In his vision, all the technology that is required are inexpensive, low-power computers with convenient displays (when required), tied together via a micro-system network, and the software systems that implement the ubiquitous applications.

Pervasive systems are often related to augmented reality and disappearing hardware, so that they become virtually invisible to the user [35]. These attributes are very often related to wearable computers and wireless communication between the devices. The main principles that need to be defined in designing such a system is the device positioning, data security, the interaction between the human and the environment and finally the services it will provide [35]. During the thesis work, several technological approaches will be reviewed in terms of the nature and positioning of the system, the amount of interaction they require from the user, and last but not least, their level of obtrusion and privacy violation. What is very interesting as well, is to examine the dependency of the system from the hardware.

### 2.1.2 Characteristics

Embedding the system in social context raises the issue of protecting users' privacy, which stems from the fact that UC requires both explicit and implicit personal data. Thus, user acceptance might prove to be the greatest challenge that designers and developers have to face in UC. Context awareness and knowledge discovery are basic requirements for retrieving information of the users' actions and how the system is being used, which drives the system's behaviour and defines adaptations according to changes of context. The multidisciplinary development that characterizes pervasive systems covers a broader spectrum of specifications, and utilizes human-computer networks and emergent system properties to deliver more precise system applications [34].

## 2.2 Context-aware interaction

Context awareness suggests that the system receives information regarding the surroundings in which it is used and that it also adapts dynamically to the changes of the context when they occur. Apart from detecting context, the field of UC includes modeling and predicting contextual information as well as providing basic infrastructures for such applications [16].

### 2.2.1 Implicit interaction

Implicit human-computer interaction has been defined as *an action performed by a user, not intended to interact with a system, but which the system receives as input* [77]. Under the assumption that the computer can to a certain extent recognize and comprehend human behaviour, implicit interaction is based on the concepts of *perception* and *interpretation*. The term *situational context* implies the ability of the system to perceive the intended use, environment and circumstances under which it operates and, the mechanisms that interpret the inputs from the various sensors. A functional model, as proposed by Schmidt [77], includes the two modules of *situational context* and *context-enabled applications*, which utilize the collected information.

### 2.2.2 Situational context

In any system, the context is related to the user, the technology, the environment and to social aspects [63]. As far as the users are concerned, we need to consider, first and foremost, their primary task, in this case driving. Thus, the solution should allow

freedom of movements, minimize the level of distraction, require minimum interaction with the user and be positioned where it will not impede their field of view. Table 2.1 provides an overview of the parameters that can be interpreted as situational context that are relevant to driving performance.

Secondary tasks	Ergonomics	Environment
Route planning	Seating posture	Location
Conversation with third party	Hands on the steering wheel	Weather
Other distractions	Eyes on the road/mirrors	Traffic
	Relaxed vs. stressed posture	Day/night time
		Noise
		Interior lighting

TABLE 2.1: Situational context

In short, in terms of context awareness, there are three parameters that should be defined in the final system; ensure implicit interaction, determine the situational context, and implement adjustable features that adapt to the circumstances.

## 2.3 Intelligent user interfaces (IUIs)

Human-computer interaction (HCI) can be decomposed into two fundamental concepts; perception and interpretation [35]. When developing an interactive system, what is taken into consideration is the person's ability to perceive the usage, the environment and the circumstances under which the system is used, the mechanisms to understand sensor percepts and the applications that use the information taken from the sensors. A fundamental challenge in user-centred design is to bridge the gap between human perception and system functionality, which have been defined by D. Norman as gulfs of execution and evaluation (see fig. 2.1) [56]. Within this field rises the concept of intelligent user interfaces (IUIs). As defined by Maybury, IUIs suggest *human-machine interfaces that aim to improve efficiency, effectiveness and naturalness of human-machine interaction by representing and acting on models of the user, domain, task, discourse and media* [51]. IUIs support complex and ambiguous multimodal inputs, such as eye tracking, facial recognition, gesture tracking and so forth and are capable of selecting content and performing the appropriate actions, correcting the ambiguity of the input. As an example, an *intelligent* speech recognition system is able to recognize speech input, isolate it from the recording noise, reconstruct the language model if necessary, e.g. recognize 'give me' while having recorded 'gimme', and give the right response to the user.

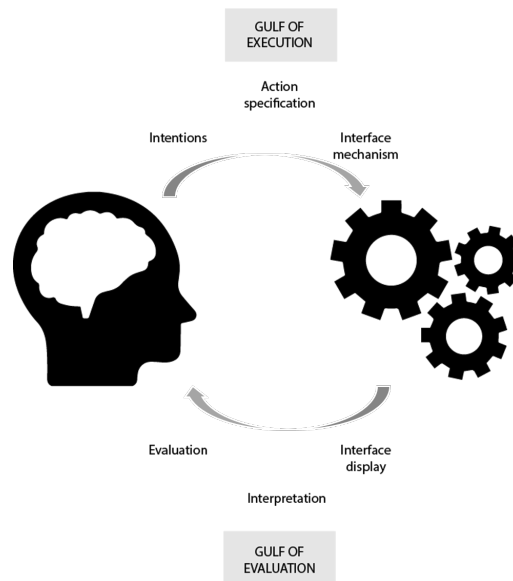


FIGURE 2.1: Gulfs of execution and evaluation

The design and implementation of IUIs takes place using user interface management systems (UIMS) and software development toolkits, that help making a clear distinction between the user interface and the applications [75], but they often merge interface code within the application framework. Model-based interfaces offer a more efficient framework by separating applications into at least four layers (fig. 2.2); application actions, dialogue control, specifications of presentation and behaviour (namely, style rules) and the primitive toolkit objects composed by style rules (namely, style program layer) [51]. We are going to see how we can interpret each of these layers in our application in chapter 5.

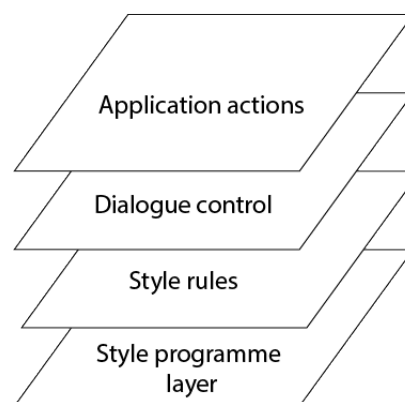


FIGURE 2.2: Layers of model-based interfaces

### 2.3.1 Adaptive and intelligent interaction

Adaptive systems are systems that can automatically adjust their behaviour according to the user, the task and the environment [8]. Adaptive and Intelligent Human-Computer Interaction (AIHCI) employs systems that are able to extract static features from the user's face, physical structure, tone of voice, physical contact, proximity to the system and appearance, and analyze dynamic features as to the attitude, posture and gesture movements, expression, gaze direction, nodding and speech fluency [35].

Duric et al. propose an architectural model for adaptive and intelligent HCI (fig. 2.3), combining interdisciplinary knowledge from perceptual cognition, machine learning, affective computing and computational modelling for embodied cognition [21].

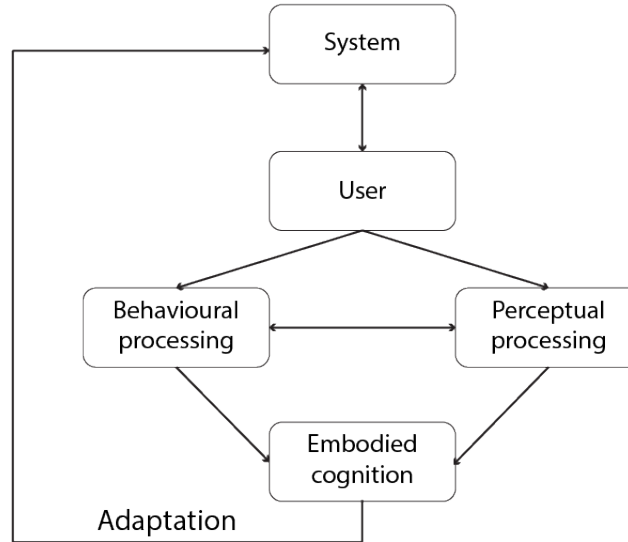


FIGURE 2.3: System architecture for AIHCI

The *perceptual module* processes cues that are directly related to the states one wishes to identify; such as face recognition, eye-gaze, eye-tracking, body posture, gesture movements, speech recognition and so on. The *behavioural module* processes information derived by the interaction of the user with the system; it could include key strokes and mouse gestures, touch input, voice commands and so forth. The connection of perceptual with behavioural processing takes place through *embodied cognition*, which includes an *embodied cognitive model* and a *model tracing function*. The model is trained not only to behave similarly to human cognition for task solving (cognitive aspect), but also to adopt affective states similar to the user's ones and to be able to perceive and interact with the environment similarly with the user (embodied aspect). The adaptation procedure can take two forms; *reactive* and *proactive*. In the reactive form, the system swiftly

the interface accordingly, after detecting change in the user's cognitive or affective state, while in the proactive one, the model is trained to predict the user's change of state and adapt to the correct interface a priori. In either case, the adaptation needs to be conservative and not perform too many alterations too often, as it will cause frustration to the user and denial to accepting the system.

### 2.3.2 Affective computing

A step further from adaptive systems lies *affective computing*. Affective systems are designed to include emotional communication between the interaction of users with computers, by being able to detect and adapt their performance according to expressions of emotion, e.g. frustration, (dis)liking, interest and so forth [65]. In her paper, R. Picard [66] argues of the challenges that one faces during the design and implementation of such systems, which concern recognizing, expressing, modelling, communicating, and responding to emotion. Although we are mentioning them here for reasons of completeness, we are not going to see them thoroughly as the project will not reach the implementation phase within the limits of the thesis.

## 2.4 Persuasive technology

Given the nature of the solution we wish to promote, it is highly possible that some form of behavioural adaptation might be required, thus collaboration with the users is of utmost importance. To that end, we explore the options of persuasive technology; a concept developed by B.J. Fogg which describes developing interactive information systems that aim to change user's attitudes or behaviour [31]. Persuasive System Design (PSD) is directly connected to four disciplines within the information technology field; human-computer interaction, computer-mediated communication, information systems and affective computing. Equally important are elements from psychology and rhetoric so as to develop a more comprehensive idea of designing persuasive systems [90].

### 2.4.1 Behaviour model

Fogg suggests three categories for the factors that drive behavioural changes [32]. The *core motivators* indicate what drives a person to perform some action, with the more prominent ones being pleasure/pain, hope/fear and social acceptance/rejection. The next category concerns the *ability* the person has to perform the action and can refer to time, money, physical or mental effort, social deviance or uncommon behaviour. Ability



can also be interpreted as simplicity of the system, in the sense that the simpler a system is, the easier it will be for the user to interact with it. The final factors, *behaviour triggers* prompt the person on when to act. They can be in the form of a cue, a facilitator or a signal. Fig. 2.4 displays the linear relationship between the ability and motivation of the users. The *target behaviour* is a function of ability and motivation; if the ability or the motivation is low, then the target behaviour is not likely to be achieved. Low ability could reach the target behaviour, if the motivation is also low, and of course the desired effect is accomplished when both ability and motivation are high enough. In order to facilitate high values in ability, we adopt simplicity factors, while for high motivation we are investigating the core motivators. The triggers are vital to achieve the target and they should have three characteristics: be noticed, can be associated with the behaviour, and they happen when one is both motivated and able to perform the target behaviour.

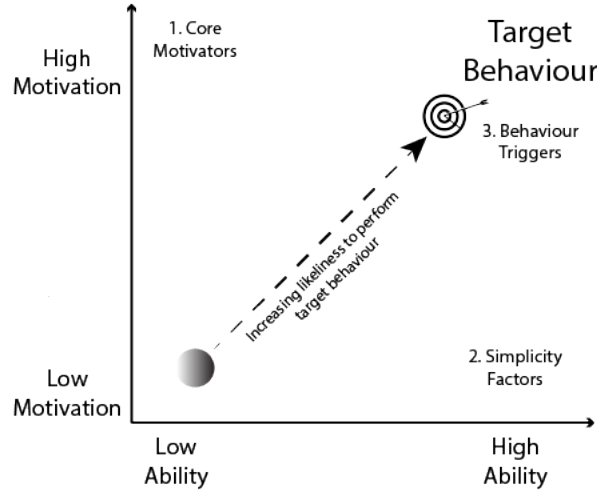


FIGURE 2.4: Fogg's Behaviour Model [32]

### 2.4.2 PSD principles

Persuasive systems aim to *reinforce*, *change* or *shape* the user's attitude and/or behaviour [57]. H. Oinas-Kukkonen and M. Harjumaa describe in [57] how they have concluded in the formation of principles to ensure the efficacy of such a system. They have identified seven key issues that summarize the overall view of the designer's perspective of users, the persuasion strategies and actual system features (table 2.2).

- 
- Information technology is never neutral.
  - People like their views about the world to be organized and consistent.
  - Direct and indirect routes are key persuasion strategies.
  - Persuasion is often incremental.
  - Persuasion through persuasive systems should always be open.
  - Persuasive systems should aim at unobtrusiveness.
  - Persuasive systems should aim at being both useful and easy to use.
- 

TABLE 2.2: Designer’s perspective of users’ &amp; systems’ behaviour

Taking them into consideration, they have concluded in 28 design principles, which are grouped into four support categories/themes (table 2.3). The categorization suggests the part of the system that each principle refers to. Regarding the *primary task support*, the aim is to make the system simple and customizable, so as to attract each user individually according to their personal needs. *Dialogue support* aims to both motivate and suggest to users for means achieving the target behaviour. *System credibility support* ensures that the user trusts the system, has increased feeling of security and privacy, thus making the system more attractive and usable. Finally, *social support* adds features to the system that encourage social interaction and motivate users to adapt their behaviour to the target one.

Primary task	Dialogue	System credibility	Social
Reduction	Praise	Trustworthiness	Social learning
Tunneling	Rewards	Expertise	Social comparison
Tailoring	Reminders	Surface credibility	Normative influence
Personalization	Suggestion	Real-world feel	Social facilitation
Self-monitoring	Similarity	Authority	Cooperation
Simulation	Liking	Third-party endorsements	Competition
Rehearsal	Social role	Verifiability	Recognition

TABLE 2.3: Persuasive design principles

### 2.4.3 PSD model

The context of persuasion in the PSD model consists of three core elements; the *intent*, the *event* and the persuasive *strategy* [57, 90]. The intent includes the *persuader*, who is the system designer, and the attitude or behaviour *change* that is intended to take place. The event defines the *use context*, that is the dependent features that shape the problem domain; the *user context*, which is the user who is going to be persuaded, and the *technology context*, which defines the implementation of the system from a technological perspective. Last but not least, the persuasive strategy includes the *message* with respect to the form and/or the content that the system aims to accomplish and the

*route* through which the message will be delivered, either that is direct, indirect or both. From a software architectural point of view, the components of the event and the strategy are conceptualized according to the model proposed by T. Alahäivälä et al. [1], illustrated in fig. 2.5. On the conceptual level (upper layer), there is the *use* and *user context*, while on the technical implementation level there is the *user-system interaction*, *social interaction* and *system-mediated messages* (lower layer).

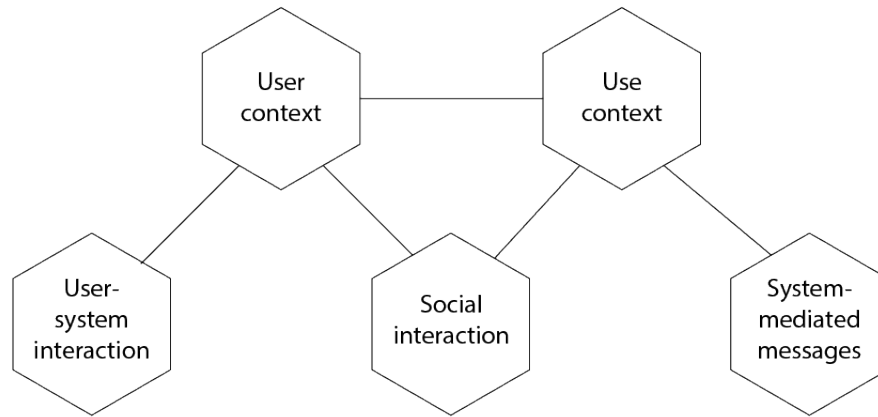


FIGURE 2.5: Architectural components of PSD Model

Several case studies [10, 54, 81] revealed the effects of learning in the behavioural change process. Social learning affects cooperation and together, they influence perceived persuasiveness, which regulates engagement and behavioural intention [81]. Reflective learning supports learning from past experiences both for improving new ones and for encouraging continuous learning [10], thus contributing to long-term behavioural or attitudinal changes.

In the present scenario, we aim to discover how designers can introduce persuasive technology in environments where the interaction with the user should be as minimum as possible, e.g. under driving conditions. Emphasis will be given on implementing the dialogue support part, so that the target behaviour will be achieved without the system distracting the users from their primary task.



## Chapter 3

# Data Acquisition Systems (D.A.S.)

In an effort to assess the required technology for the final system, the procedure is broken down into three phases; the input, the process and the output. The *input* is comprised of the required information that the model is fed with that can be collected either from the vehicle or from the user's physiological parameters. In the following pages, we shall see what kind of characteristics we can acquire from each source and how they can be used to create a user model.

### 3.1 Driver recognition

Initially, the system needs to identify the driver and access their personal profile, thus the first aspect to be considered is user recognition. Currently, the identification task takes place via a personal smart card that the driver inserts into the tachograph unit. However, malfunctioning smart cards have been reported by the International Road Transport Union [43] to be a frequent event. Moreover, the card can easily be lost or forgotten as it is an additional item that the driver needs to carry. Applying biometric recognition in our system composition would be an effective way of mitigating those problems.

In this section, an overview of different biometric systems shall be given and we will see how they could be integrated into the final system. The general model of a biometric system includes data collection, signal processing, data storage and decision making (fig. 3.1). Identification can be achieved by verification of appearance or behavioural

characteristics. Appearance characteristics can be hand, fingerprint, eyes and face, while behavioural could be signature, voice, grip and so forth [49]. But how do we choose the ideal biometric characteristic? According to Wayman et al., the choice is dependent on five qualities of the feature extraction process: robustness, distinctiveness, availability, accessibility and acceptability [96]. Being robust means that the characteristic does not alter on an individual over time, while distinct suggests that is not similar to the corresponding one of other people. Availability implies that it can be found on every user of our user group and accessibility that it can be captured by our system. Acceptability is directly related to user acceptance and whether or not they consent in capturing the particular signal/feature. There are various quantitative metrics developed for evaluating these qualities, which will not be presented here as it would take the discussion out of scope. We are, however, going to talk about acceptability measures as it poses a major topic of discussion in our project, and for that we are going to examine the Technology Acceptance Model (TAM) [3] in the user acceptance chapter 4.

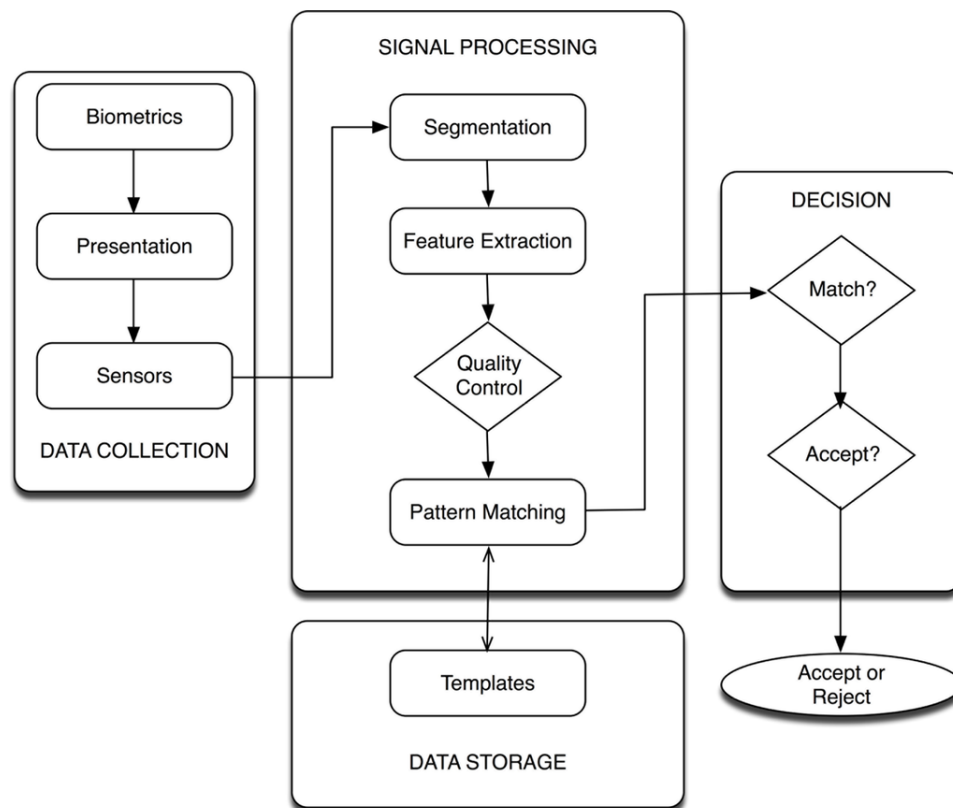


FIGURE 3.1: General model of a biometric system [18]

### 3.1.1 Fingerprint identification

A fingerprint recognition system could be integrated to a wearable item, such as a glove, which could also include the sensors we need for measuring the physiological characteristics for the fitness index. Alternatively, the recognition sensor could be integrated into the vehicle itself, for example on the engine start button or on the steering wheel. The implementation process is segmented into seven stages as displayed in fig. 3.2, that correspond to the previous modules of a biometric system [96].

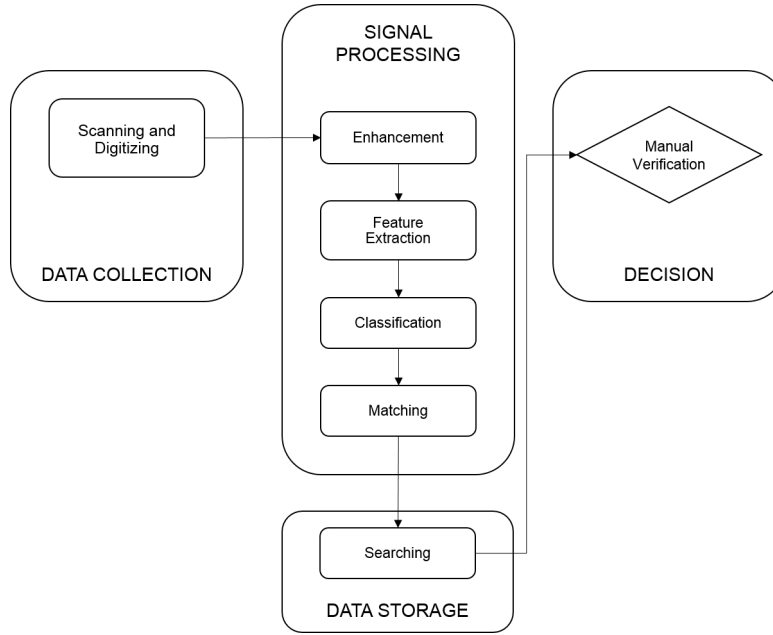


FIGURE 3.2: Implementation stages for fingerprint identification

### 3.1.2 Iris recognition

Iris recognition is realized with eye tracking technology, which suggests a physically unobtrusive means of collecting user data. More details on eye tracking will be explained in chapter 5, but here are some issues regarding iris recognition. First, for more accuracy in the results, the images acquired need to have sufficient resolution and sharpness [96]. Moreover, there needs to be good contrast in the iris pattern, without making the illumination levels unsafe or uncomfortable to the human eye. The iris must be well framed in the acquired image, without however discomforting the user. This, in combination with specular reflections, optical aberrations and other kinds of disturbances that might result from additional artifacts, suggest the avoidance of using wearable devices as much as possible. There are two solutions to overcoming these issues. One is by using passive sensing, which requires active participation from the subjects to position themselves for centering and focus, and the other one is active sensing, which requires less subject

participation. Given the position of the driver, which is both relatively still and always looking forwards, active sensing should work without implications. Fig. 3.3 displays a flow chart of an iris recognition algorithm [60].

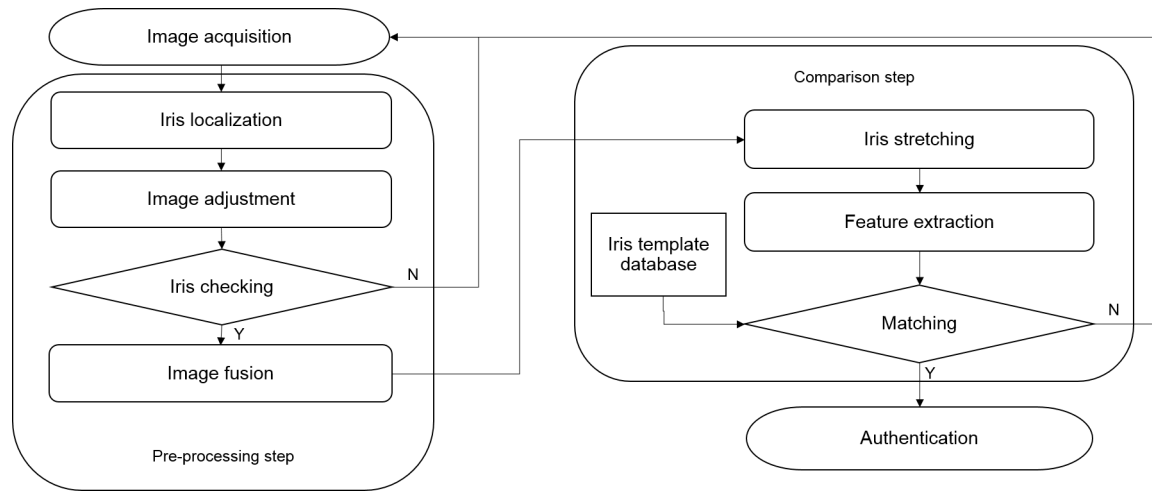


FIGURE 3.3: Iris recognition system flow chart

### 3.1.3 Face recognition

A face recognition process is completed in five stages as displayed in fig. 3.4, which include face detection, representation and classification [49]. Current systems can successfully detect faces where attributes like color, position, scale, orientation, pose and expression vary significantly. Such a system can also be adopted for our solution, as it can be integrated in a non-obtrusive device, much similar to the eye-tracking one.

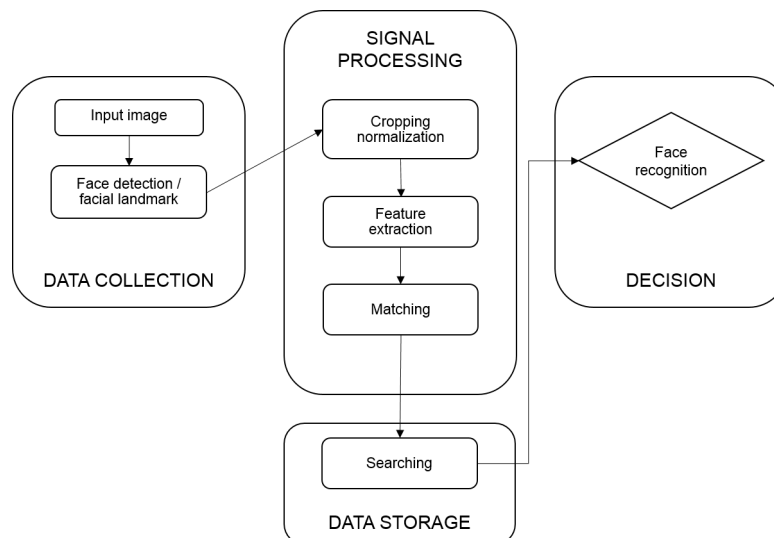


FIGURE 3.4: Face recognition process



At this point rises the question of what the best biometric feature is. Unfortunately, there is no clear answer to the question, but there are some metrics that can aid to the decision that relate to the five feature qualities mentioned earlier [96]. The performance of the algorithm in use, otherwise measured by its accuracy, is a significant factor. However, at times it might be necessary to find a trade off between performance and usability; it would not make sense to implement an optimum algorithm into a system that the users would not accept. Ease and cost of integration play also a significant role in the selection process. Using an algorithm that would cost dearly to implement, rather than enhancing an already existing system, might not always be the best course of action. Finally, resilience is also something to consider. In general, a good plan of action would be to consider a *track record* of the technology used in similar applications, to see what can be maintained, what can be improved and what needs to be changed. For our purposes, we shall choose the biometric system that integrates best with the overall design without adding further sensors in the implementation (see chapter 5).

### 3.2 Vehicle information

All vehicles in the automotive and aerospace environment utilize the CANbus (controller area network) protocol, which allows multiple connections of individual systems and sensors, as an alternative to the conventional multi-wired connections [70]. A vehicle data acquisition system (VDAS) collects information from the CANbus, regarding the general condition of the vehicle, fuel system monitoring, climate control and suspension, as well as brake and engine monitoring. Particularly for trucks, the Fleet Management System Interface (FMS-Standard) (fig. 3.5) has been developed as an interface between the CANbus and the truck manufacturer for acquiring all available vehicle data.



FIGURE 3.5: FMS gateway

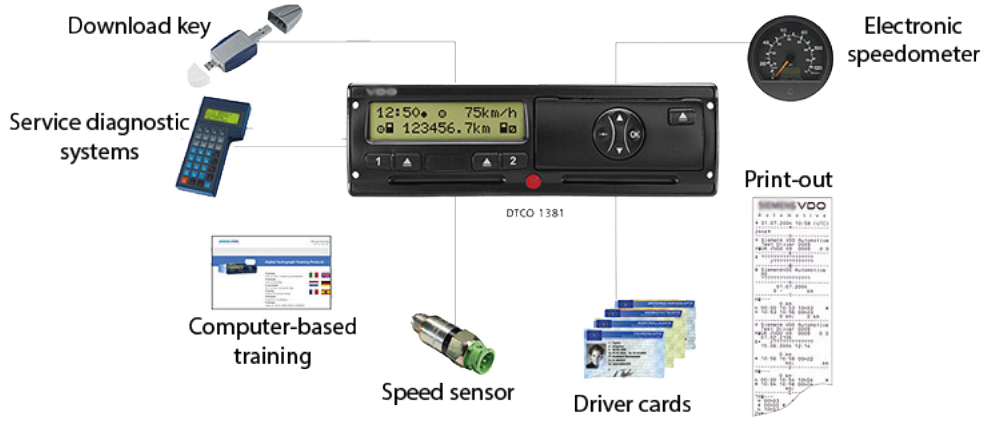


FIGURE 3.6: Components of a digital tachograph [12]

With the current regulation system, all buses and heavy vehicles are obliged to register their working hours and kilometers driven, to ensure that the drivers are getting the rest they require [85], so as to prevent fatigue, ensure road safety and guarantee fair competition between transport companies [29]. The driving and resting hours are monitored via a tachograph [28, 29], which is also connected to the CANbus protocol. The digital tachograph came to replace the analogue one and is equipped with an electronic speedometer, a speed sensor, display, printer, and a real-time clock (fig. 3.6). That way it can register the date of the trip and the vehicle registration number, if the driver is travelling alone or with a co-driver, the distance travelled and vehicle speed [69]. The data from the tachograph can be accessed either by the employers or by enforcement authorities to ensure that the drivers conform with the legislation regarding working hours.

The International Road Transport Union (IRU) has issued a report regarding practical and technical problems of a digital tachograph [43]. These issues refer to methods of data recording and transmitting, malfunctioning drivers' smart cards, unfriendly interface design and, finally, administrative issues. They refer to issues regarding data recording, as the time is calculated in minutes, not in seconds, which requires more memory allocation, and card data overwriting. It takes a long time to download the data from each vehicle unit due to low transmission speeds, which can have a significant impact on fleet owners. The interface of the digital tachograph is much different from any other on-board unit, and additionally its position high over the driver's head makes it easy to forget changing recording activities, e.g. driving, resting and so on. The proposed system design takes into consideration these problems and attempts to mitigate them.

### 3.3 Driving behaviour

Driving behaviour or style plays a significant role on fuel consumption and vehicular emissions [100]. It can be determined by steering wheel movement and position of the vehicle on the road. Johnson and Trivedi present a platform for driving style recognition that utilizes the sensors that exist on a smartphone [44] to detect the way the vehicle is being maneuvered; in particular, motion sensors (i.e., accelerometer, gyroscope), position sensors (i.e., magnetometer, GPS) and camera. Hong et al. have expanded this platform to an inexpensive sensing platform to model aggressive driving behaviour [40]. In addition to the aforementioned motion and position sensors, the Bluetooth sensor is used to communicate with an on-board diagnostic reader (OBD2) and an inertial measurement unit (IMU) mounted on the steering wheel, as illustrated in fig. 3.7.

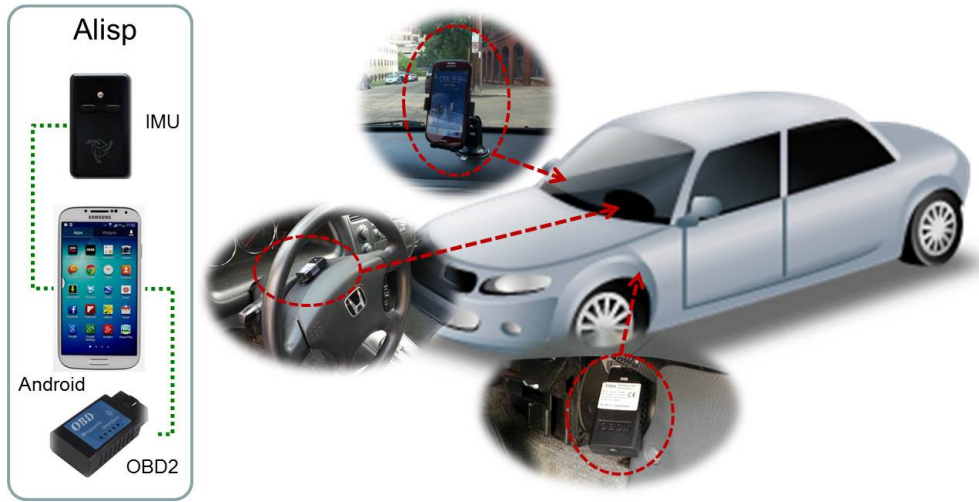


FIGURE 3.7: Overview of smart phone-based sensing platform [40]

The OBD2 derives information from the vehicle's electronic board, regarding engine coolant temperature, engine load, RPM, throttle position and speed, while the IMU captures wheel movement via accelerometer, gyroscope and compass sensors. The overall features extracted from the sensors, that have been used to model aggressiveness, include change of speed, longitudinal/lateral acceleration of the car, change of engine RPM and of throttle and steering events. As it turns out, acceleration is a very good indicator for aggressive style and that is evident by higher g-forces for both acceleration and deceleration. Furthermore, the change of speed and engine RPMs or throttle positions suggest inconsistent driving style for the aggressive drivers.

This is only one example of modelling driving behaviour using various sensors. An exhaustive list of parameters that can be used is provided in [94] and also apposed

in Appendix A. Many automotive companies have introduced assistance solutions that associate several of such parameters with driver vigilance and recommend a course of action. Although at this point we are entering a marketing territory, which is out of the scope of our work, taking a closer look into them will help us generate a better overview of the potentials of our system.

Mercedes-Benz has already introduced the *Attention Assist* solution [15], which employs a *lane keeping assist* system to prevent the vehicle leaving its lane, proximity control systems to maintain safe distance with leading vehicles, and drowsiness detection system that prompts the driver by visual and audio cues to take a break [14]. Connected to the vehicle's electronic unit, the system registers the steering behaviour, e.g. steering wheel movements and steering speed, and creates an individual driver profile, which is used to analyze driving behaviour. Additional to the previous parameters, Attention Assist in buses registers vehicle speed, longitudinal and lateral acceleration, travelled time, control signals as well as change of drivers. Fig. 3.8 displays the sensors that are used in the private vehicles.

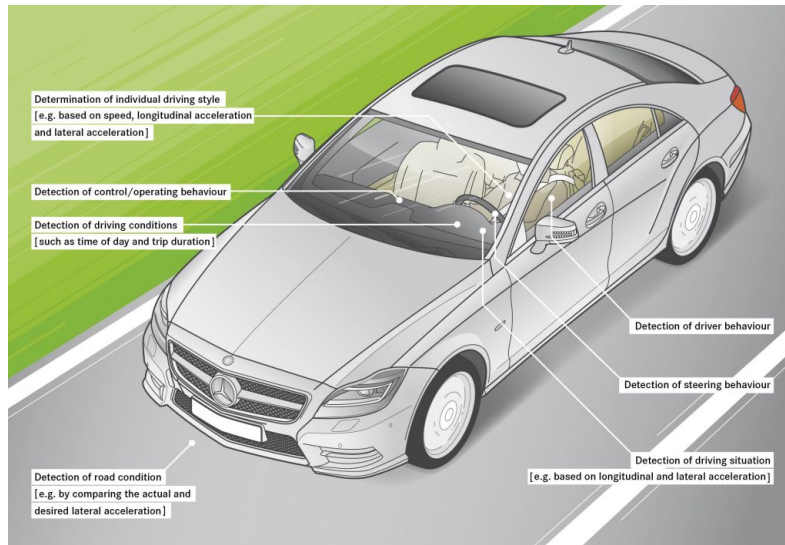


FIGURE 3.8: ATTENTION ASSIST Drowsiness detection system

Another major automotive company, Audi, has introduced the *Rest Recommendation System*, which registers steering, pedal and gear-lever movements to create the driver's profile [2]. Once the driving behaviour starts diverging from the registered one, the driver is prompted to have a break. On a consumer electronics level, CarVi [11] has announced a driving assist device that mounts on the windshield and is equipped with a high resolution front-view camera, a triple axis accelerometer and wi-fi connectivity to pair with the user's smart phone. The camera records the trip, monitors changing lanes and distance from the leading vehicle. By learning the user's driving patterns, it

creates a personal profile where it stores driving style and provides recommendations for improving ones' driving skills and reducing fuel consumption.

### 3.4 Physiological characteristics

Perhaps the most important metric for suitability of driving is the alertness of the person behind the wheel. Fatigue and drowsiness are just some of the factors that can influence one's ability to operate a vehicle safely, by slowing down reaction time, decreasing awareness and leading to misjudged actions [5]. The professional trucking industry has already taken precautions for shift scheduling to fight sleep deprivation and lack of alertness [24]. Even stress causes bad decision making in miscalculating other incoming vehicles or distraction.

A proactive in-vehicle information system (IVIS) should be able to provide and predict these symptoms by measuring physiological characteristics of the driver and determine with high accuracy, if they are in a condition to drive or not. In order to model such features, we will need to employ affective computing principles as mentioned in chapter 2.

Some of the most dominant features for detecting fatigue and drowsiness are evident from facial expressions and characteristics. In their work, Eriksson and Papanikolopoulos study the detection of microsleeps [24]. Microsleeps are short periods of 2-3 secs, when the person loses consciousness. Using image recognition algorithms applied on the facial area, they are able to localize and track the eyes of a driver and determine signs of fatigue. However, that system required the head to be straight (not tilted or turned), and presented flaws when the person wears glasses or has too much facial hair. It is believed that these problems could be mitigated by using a small set of face templates or by using colour information to enhance robustness. Additionally, dynamic field of view could be introduced for higher accuracy, so that once the eyes have been localized the camera would zoom or adjust its direction so as to get a clearer image. Another sign of drowsiness is the forward leaning of the head and sudden reinstatement, also referred as "bouncing" movement. It is possible to be detected via head tracking cameras.

In the industrial field, there are several solutions that exploit image recognition and computer vision technology to serve the same purpose. Seeing Machines are delivering products that track eye and head movements, and recognize facial expressions that give away fatigue [78]. In the automotive space, the solution they offer for professional drivers is called *Driver Safety (System) In Vehicle System (DSS-IVS)* and is composed

by a dashboard-mounted camera that detects head posture and eye movements [79]. Using remote tracking, the driver is not required to wear any additional accessories and the technology is not affected by environmental lighting conditions nor by (sun)glasses the user might bear. The company holds the patent rights for its facial image processing algorithm [22]. InterCore Inc. has developed the *Driver Alertness Detection System (DADS)*, which once more uses an dashboard infrared camera to monitor the eyes and facial features [42]. In private vehicles, Volvo has announced the Driver State Estimation system, which will use a dashboard integrated sensor and small infrared LEDs to illuminate the driver [92]. The sensor will monitor eye-gaze direction, eyelid closure, head position and angle and determine if the driver is inattentive or feeling tired. As a portable device, Vigo [91] offers a solution that looks much like a bluetooth headphone, with a longer extension that monitors eye-lid closure.

Eye movements can also be measured through electrooculography (EOG), which involves electrodes attached to the skin around the eye [25]. OPTALERT [58], an Australia-based company, is integrating a LED light onto optical glasses frames, which allows it to measure the velocity of the users eyelid 500 times per second. The advantages of the glasses are that they make the technology invisible and resilient to vibration, as a head-mounted display. From a usability perspective, it is customizable, offering three different types of frames and compatible with prescription lenses.

Reliable indicators about drowsiness and lack of vigilance can also be cardiac and respiratory rhythms [72]. The outcome of the research on respiratory analysis has been the development of the *HARKEN* concept [9], which embeds non-intrusive sensors on the driver's seat belt that monitor the heart and respiration activity. Vibrating sensors are placed on the driver's seat, in order to alert the user when in drowsy state. Philips's Vital Signs Camera [64] uses a technique that combines both skin colouring variations and chest movements to model heart and breathing rate. More details on this technique are given in chapter 5. The technology is currently prone to movement and ambient luminosity.

Frustration and stress are also factors that can result in aggressive driving and bad judgement. Psychophysiological measurements can be derived from physiological characteristics that suggest emotional arousal, such as galvanic skin response (GSR), blood volume pulse (BVP) and heart rate, as well as pupil size variation [61] and facial electromyography (EMG) [41]. Facial EMG measures electrical activity changes of the facial muscles, from which one can infer emotional valence. In terms of psychology, emotional valence suggests pleasant or unpleasant reactions to events or stimuli [47].

Electromyographic research is not a new concept, with Fridlund et al. having published the “Guidelines for Human Electromyographic Research” already in 1986 [33], but its significance in affective computing is increasing over the past few years. Several studies research classification algorithms for recognizing emotions using facial muscle electrical activity [46, 83]. However, this method requires placing electrodes on the user’s face in the areas that are depicted in fig. 3.9 [33]. In principle, for the system we are developing, we would like to avoid imposing anything that might be intrusive to the user, therefore it is not a solution we are willing to suggest. However, facial EMG could be used to validate image recognition algorithms that detect facial expressions, and that poses an excellent research topic for future exploration.

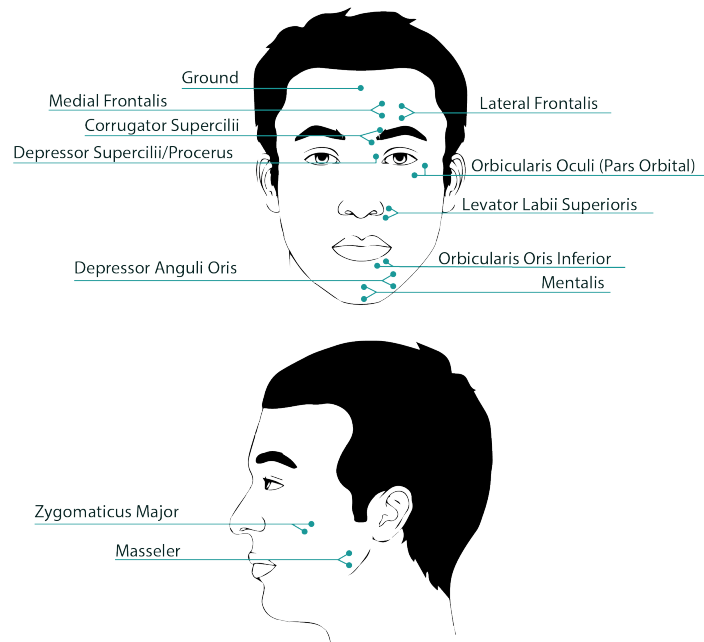


FIGURE 3.9: Facial EMG electrodes placement areas

Extracting physiological features to determine the user’s psychological state requires more sensors than what was mentioned previously for head and eye tracking. Several wristbands have been introduced in the market to measure heart rate and heart-rate variability, blood volume pulse, galvanic skin response and so forth. There are numerous activity trackers in the market, especially in the sports sector, but here we shall mention, indicatively, only some of those that combine multiple sensors. All of the following are equipped with accelerometers for activity tracking. Mio Alpha 2 and Mio Fuse [53] are the latest generation of Mio sports watches equipped with heart rate monitoring sensors, similarly to Samsung’s Gear Fit<sup>TM</sup> [76]. Microsoft Band [13] comes also with a heart rate sensor and sleep monitor. The Basis Peak [7] seems suitable for



sleep monitoring, measuring galvanic skin response, skin temperature and heart rate. Emvio [82] monitors heart rate variability and claims to be the first one to measure and manage stress levels. Empatica’s E4 Wristband [23] measures heart rate variability, skin conductance, temperature and heat flux for monitoring stress and relaxation, arousal or excitement.

In connection with the automotive industry, currently two companies are known to have attempted to combine physiological data with driving behaviour. Nissan announced in 2013 the *Nissan Nismo Concept Watch*, which would measure heart rate [27]. The company declared that they were looking into heart and brain monitoring technology, such as electrocardiogram (ECG), electroencephalogram (EEG) brainwave and skin temperature, for future wearable solutions that monitor amongst others fatigue, attention and hydration levels. A more recent solution is delivered by Fujitsu for drivers and vehicle fleet managers; *FUJITSU Vehicle ICT FEELytm* is a wearable sensor attached to the earlobe, which can measure the user’s pulse and relate it to drowsiness [48]. It can wirelessly connect to the digital tachograph and other on-board units, and it is worn around the neck to prevent the sensor from losing position.

Last but not least, a common symptom that is met amongst shift workers, and by extend professional long-haul drivers, is sleep disorder. Poor quality of sleep or shift work, disturbs the circadian rhythm, the “body clock” that regulates sleep/wake cycles. It is affected by light and darkness but it can be disturbed by environmental, physiological and behavioural changes [68]. As a result the person feels more fatigued in the daytime and suffers from insomnia at night, which is why a lot of research is being done for adjusting it. In the sports sector, *Fatigue Science* seems to be leading a successful platform that analyses data from professional athletes and provides sleep management suggestions to improve their performance [30]. The company seems to be expanding in the heavy industry as well, by offering a wristband solution and a fatigue avoidance scheduling platform.

### 3.5 External sources

In order to introduce context-aware interaction, knowledge of the environmental conditions and how they affect the user is required. Research on traffic psychology tries to identify the factors that influence driving behaviour [50, 80]. It is clear that bad weather or road conditions can influence driving safety, especially in urban environments, and could have significant effects on stress levels and driver attention. Running



against the clock to meet deadlines and competitive work environment append to that. Most navigational systems, with the most prominent being the TomTom [89] one, offer notification services on weather forecast and real-time traffic, which enables the driver to choose an alternative route so as to avoid incidents on the road. We consider that "road-awareness" is an important aspect to be included in the final system, so we are exploring the navigation options that are available as well.



## Chapter 4

# User Acceptance

This chapter emphasises on the usability perspective and looks deeper on the requirements for user acceptance. There are many methods and models to evaluate users' attitude towards a system, but the one we are going to adopt for our study is the technology acceptance model (TAM). The TAM focuses on the system's perceived usefulness and ease of use to determine users' behavioral intention [17] (fig. 4.1). In the following pages, we are presenting guidelines on in-vehicle systems design, which we are taking into consideration for the system we will present in the next chapter.

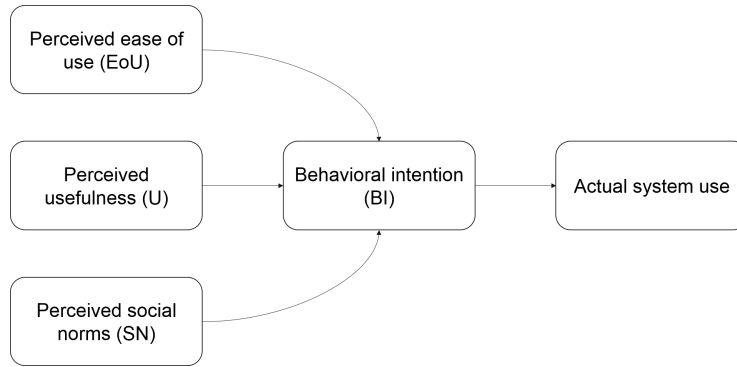


FIGURE 4.1: Technology acceptance model (TAM)

### 4.1 User profile

Earlier in the introductory chapter we saw a general description of our user group. Before going into factors that would ensure user acceptance, let us go through the daily routine of two truck drivers, one doing a long-haul route and one in the distribution routes.

The drivers learn their schedule only when it is finalized, which is done no earlier than the evening before. They usually start working at 5 a.m., which would mean that in order to get full eight hours sleep, they need to be in bed by 10 p.m.. They often bring snacks and their lunch box along, not only for saving money on eating out, but also because their route might not allow them to stop close to a dining place. First stop is usually the place where they need to load. Whether they will be loading themselves or another person will be doing this job depends on the company's policy. After loading, the distribution driver starts delivering to customers, while the long-haul one heads to the highway for their end destination. The morning rush hour starts around 8 a.m., so before reaching the third customer, the distributor is stuck into traffic which makes the schedule delayed by at least 20 minutes. That is when the first complaints of the day are heard. The long-haul one might be luckier if (s)he is not passing from the city around that time. Usually after lunch time and when getting closer to 2/3 of the working day, both drivers are feeling tired either from physical work or from driving long hours in the boring highway. It is only 2 p.m. and rush hour starts again in about two hours, which rises their stress levels once again. Now the weather is getting worse and the road is slippery, which requires extra driving attention and increased traffic. The drivers are about to reach their end of the day destination with half an hour delay due to the occurrences. But now the tachograph does not permit them to continue driving because they have maximized their driving hours. At this point, both drivers want to reach their destination but they are risking a fine. They are tired, but not to a point that they cannot drive any more, so they contact their planner to ask for instructions. The planner can either agree to take the risk, in which case the company takes full responsibility of not complying with the law, or decline it, which means the driver is obliged to pay the fine in case of police control. Either way, the driver gets stressed and one way or another finishes their working day.

The above scenario describes the most likely events in the working day of a truck drivers. It is meant to be used as a *guide* to persona development, but not as a persona itself, as its accuracy remains to be verified. Nonetheless, it presents the reader with a realistic overview of the circumstances that lead to the need for our system.

## 4.2 Technology acceptance

Research on multimodal interaction while driving has provided us with useful guidelines as to which modality is more suitable for communicating messages to the users and combining modalities results in faster reactions [67]. It turns out that non-visual interaction is more effective under visually demanding tasks, which is why for higher urgency

messages audio and tactile interaction is strongly recommended (fig. 4.2). The same study showed that the differentiation in high and medium urgency warnings affected the performance of the driver in the following manner: high warnings caused faster reactions in critical situations, while medium urgency signals assisted in the overall alertness and improving driving behaviour.

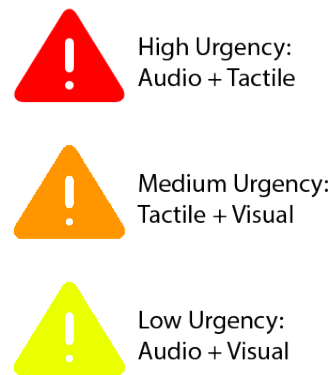


FIGURE 4.2: Suggested modality according to urgency level

Another study compared the affected performance between real-time and post-drive feedback with the aim to examine what is more efficient. The advantage of post-drive feedback is that it can contain more detailed information on safety critical situations, which supports reflective learning as we saw it in section 2.4 and results in shaping long term behaviour [20]. Real-time feedback had also significant effects on immediate performance, therefore a combination of the two can be used for communicating immediate hazard prevention and educating safer driving [20]. On the study presented in [71], real-time warnings were achieved via visual and auditory signals, while post-drive reports aimed to promote safe driving behaviour by appealing to social norm conformance. The experiment took place within three user groups; one was provided with only real-time feedback, one with only post-drive reports and one by combining the two modes. The results suggested that the last user group responded faster in unexpected road events, and they would look longer to the roadway despite the presence of a distracting device in the vehicle. Further remarks reveal that users were more susceptible to accepting post-drive feedback, as real-time one was perceived more obtrusive and difficult to use. As far as the modalities of real-time notifications is concerned, auditory signals were annoying, so users preferred visual cues. Another interesting outcome was how the level of acceptance was influenced by whether the context was mandatory or not, with mandatory use context exhibiting higher perceived ease of use.

One aspect we would like to explore for our system is providing proactive recommendations to the drivers. As seen earlier, notifying them about their status is of little use if we cannot provide them with suggestions of improving their physical or mental state. Bader et al. realized a similar study on proactive IVIS designed for recommendations and measured the user acceptance levels [3]. Their results produce guidelines for designing such systems. First, it is important to avoid information overload as well as complex interfaces. Both the input from the driver and the display of information should require as minimum interaction as possible and be comprehensible with a few glances. As such, it is important to show only relevant to the situation context and avoid long descriptions or complex metaphors. To that end, it is advised to use known metaphors that would not surprise the user or make information complicated. The driver should be able to control the level of interaction and the interface architecture should seem familiar and consistent.

Barr et al. [5] present an exhaustive review of emerging fatigue technologies and summarize a list of engineering guidelines for the implementation of an IVIS. First, when designing for a driver monitoring system, it needs to be able to acquire real-time data, process them and provide feedback at any given moment. The system should measure what is intended to, both operationally (e.g., eye blinks, heart rate) and conceptually (e.g., fatigue, drowsiness) and not vary in the measurements over time or per user. Day-time illumination can vary significantly from nighttime one, thus the system must be able to perform accurately in both conditions. In addition, the truck cabin temperature variations, humidity and vehicle vibrations should not interfere with the system's functionality either. The guidelines in which they concluded both regarding system engineering and user acceptance are presented in tables 4.1 and 4.2.

<b>System engineering guidelines</b>	
Environmental	Cabin illumination, temperature, humidity and vibrations should not affect device operation
Reliability	Minimize both missed events and false alarms
Anthropometric	Accomodate multiple drivers with minimal re-calibration
Engineering design	Robust design & require normal maintenance and replacement

TABLE 4.1: Engineering guidelines

The *ecological framework* proposed in [95] promotes comfort and safety principles for intelligent in-vehicle interfaces, and considers also cognitive factors that relate to driving. Fig. 4.3 displays the relationship between the complexity of the driving task

User acceptance characteristics	
Ease of use	Non-invasive
	Accommodate corrective eyeglasses & sunglasses
	Warning alert to driver
Ease of learning	Require minimal training
	Time it takes for the user to learn
Perceived value	User ability to retain and recall functionality
	Feedback to user regarding alertness level
Advocacy	Perceived safety benefit or increased risk?
	User's intent to purchase system
Driver behaviour	Willingness to recommend use
	Not distract from driving task or from interacting with other safety devices
	Behavioural adaptation over time

TABLE 4.2: User acceptance guidelines

and the driving situation awareness, which is equally dependent on skill level, rules and knowledge. The levels of complexity relate to the task at hand; control corresponds to the direct tasks that have to do with the control of the vehicle, guidance refers to common driving situations, such as intersections, traffic and so forth, and navigation relates to the general trip planning.

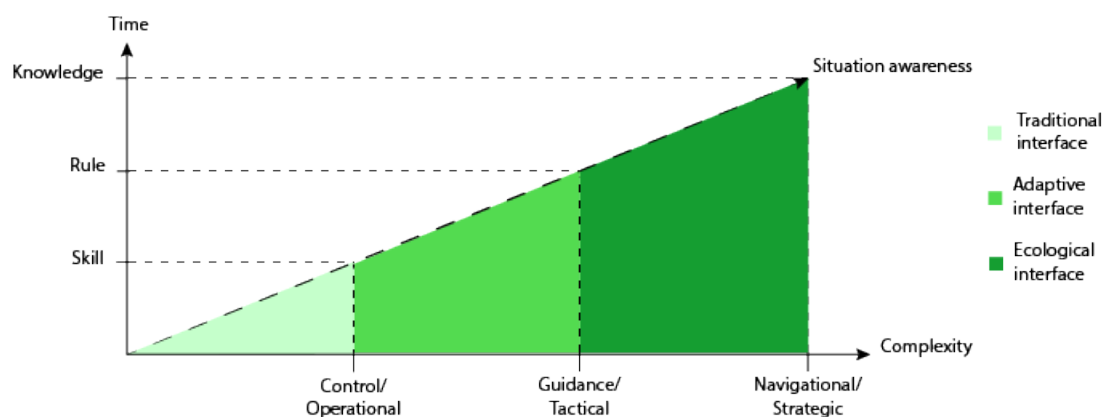


FIGURE 4.3: Framework for intelligent in-vehicle interfaces

It is important to keep in mind that in order to accommodate ease of use (EoU), we should avoid increasing the mental workload of the user while interacting with the system. There are two modes to achieve that; the input/output will either be automated or it will use a modality that is not conflicting with the visually demanding task of driving. For the latter, we will explore the multiple resources theory (MRT) proposed by Wickens [98], according to which one can predict user performance under increased mental workload due to dual-tasking. The four dimensional multiple resources model,

depicted in fig. 4.4, represents the *processing stages* of information (perception/cognition/responding), the *sensory modalities* of perception (visual/auditory), *visual channels* (focal/ambient) and the *processing codes* (spatial/verbal).

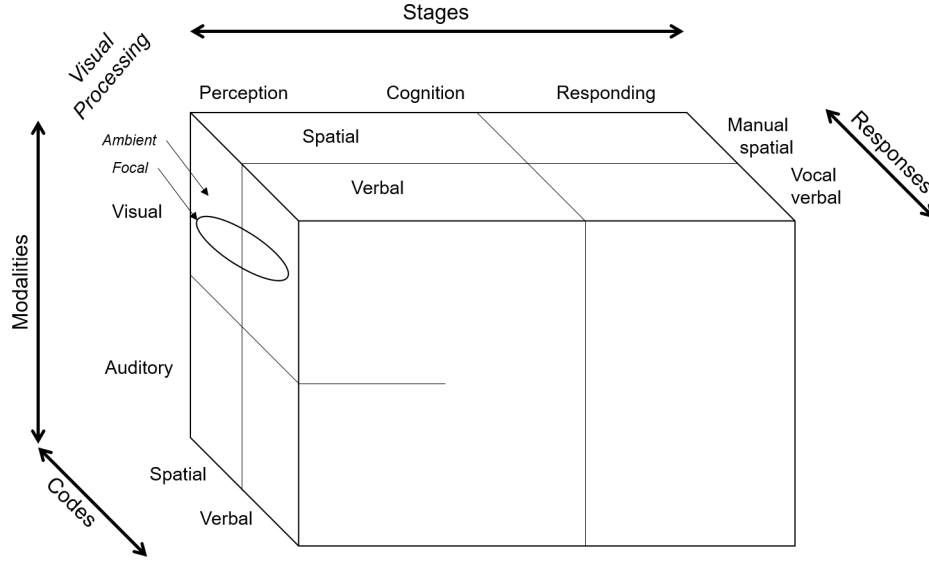


FIGURE 4.4: Multiple resources model

### 4.3 Data privacy

Ensuring data privacy is an important milestone in the realization of intelligent systems. A large amount of personal information needs to be captured in order to deliver more accurate results and more personalized recommendations, which raises the questions of how much privacy invasion that entails and who should have access to the data. Specifically for our project, we require personal physiological data from the users and share them within our infrastructure. This information could be shared with the line management as well, even though we are not considering the greater user space in the current report. So, the question that concerns us is how much of their privacy are the users willing to share for benefiting from our solution. Numerous studies have been conducted in order to discover the nature and amount of information users are willing to share and under what terms. The results suggest that in the majority of instances, users do not realize how much information is being disclosed and, once they are made aware of it, their behaviour towards the system changes dramatically [74]. Having them sign consent forms does not mitigate the problem, as they often do not fully comprehend the terms of agreement [37], therefore other methods need to be applied for raising awareness.



*Contextual integrity*, being one approach, considers privacy as a dynamic flow of necessary information rather than a static act of data sharing [55]. In that sense it creates a perceived state of keeping contextual information private, while at the same time shared within the system for its purposes [4]. The theory is based on three principles of public perspective on privacy policy; individual privacy may be subjected to government intrusion, access to sensitive personal information should be prohibited and, maintaining personal space. In the user space we are investigating, there are more stakeholders than the users themselves, as it concerns a professional setting. In other words, both public authorities and line management have and must have a certain level of access to the collected information. Yet, this level needs to be defined by *social appropriateness*, that is the context of information expected to be shared within a social setting [55], e.g. medical records can be shared with medical staff but not with the line management.

Another approach worth considering is demonstrating data transparency. Studies have shown that demonstrating the reasons why particular data is being collected and how the users benefit from it, increases users' acceptance in sharing sensitive information within the system and decreases the level of concern [59]. A way of implementing this method is by *privacy nutrition labels*, which suggest a standardization of categories of privacy practices [45]. To regulate privacy policies across the World Wide Web (WWW), the WWW-Consortium established the Platform for Privacy Preferences (P3P) [93]. Using this platform, Kelley et al. propose the *Privacy Nutrition Label* scheme, which includes the type of information to be displayed as well as the symbols and colouring to be used (see fig. 4.5). They suggest that all P3P Data Categories should be included in the privacy statement, regardless of whether they are collected, and represented in rows for easier comparison between policies. The data that are not collected should be visible but grayed out, and it should be clear for the user how they can manage data sharing. It remains to be investigated if information transparency would also build a feeling of credibility on our system, knowing what kind of information is collected and what it is used for, which is not for surveillance but for data analysis.

To gain a better understanding of the perspective of people on privacy-mediating technology, we did some further research on behaviour and acceptance of pervasive computing devices. A study by Denning et al. examined how people react in the presence of someone wearing augmented reality glasses [19]. In overall, the majority of people are either indifferent or negative to the device and their reactions stem from comparisons with existing popular technologies, such as cell phone, CCTV (closed-circuit television) and GoPro<sup>1</sup> cameras. As such, given also the scarcity of augmented reality glasses,

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<sup>1</sup>Wearable camera <http://gopro.com>

## The Acme Policy

types of information	how we use your information					who we share your information with	
	provide service & maintain site	research & development	marketing	telemarketing	profiling	other companies	public forums
contact information	!	!	OUT	OUT	—	IN	—
cookies	!	!	OUT	OUT	—	IN	—
demographic information	—	—	—	—	—	—	—
financial information	—	—	—	—	—	—	—
health information	—	—	—	—	—	—	—
preferences	!	!	OUT	OUT	—	IN	!
purchasing information	!	!	OUT	OUT	—	IN	—
social security number & govt ID	!	—	—	—	—	—	—
your activity on this site	!	!	OUT	OUT	—	IN	!
your location	—	—	—	—	—	—	—

**understanding this privacy policy**

!

we will use your information in this way

—

we will not collect or we will not use your information in this way

OUT

we will use your information in this way unless you opt-out

IN

we will not use your information in this way unless you opt-in

**contact us**

call 1 888-888-8888

www.acme.com

FIGURE 4.5: Privacy Nutrition Label [45]

people did not expect to be recorded and that on legal grounds they cannot prevent it anyhow. It was pointed out that the glasses suggest a subtler and easier way of recording, as the recorded subject is not necessarily being made aware. As far as the explicit act of recording is concerned, there are a lot of parameters that regulate the level of acceptance. These parameters are listed in table 4.3. The final topic that was raised was providing consent and control over being recorded, which suggested that people wish to give permission beforehand and be able to opt out at any point.

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Place:	Public/Private/Off-limits
Behaviour:	Content (what the subject was doing)
Perception:	Gender/Appearance of the recorder
Identification	
Disturbance	

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TABLE 4.3: Parameters that regulate the acceptance of recording devices

A different study on collecting health data from wearable sensors shows users' preferences on logging and manipulating health data [6]. The results suggest that people exhibit great interest in persuasive systems that collect personal health data and they want to be able to review and control them themselves. It was evident that they want to capture it over long-term but also be able to differentiate which data would be stored and which discarded.



## Chapter 5

# System Overview

In this chapter we are presenting suggestions on the interface and functionalities of the final system, keeping in mind that the specifications need to serve two purposes; implicit input and personalized output. The user needs not to be distracted from the primary task for providing inputs to the system, and the system must identify each user and provide personal and individualized services.

### 5.1 User modelling

First and foremost, we are designing a VDAS that requires real-time communication with the vehicle's CANbus protocol. The exact data to be acquired vary according to the analysis that will be used. So far, literature and market research has shown that lateral and longitudinal acceleration, engine RPMs and steering movements suggest good indicators to model aggressiveness. Correlation between travel time and distance travelled or velocity can be good signs of fatigue or a fair indicator of the traffic conditions that apply. The number of pauses per kilometer and the duration of the stops can also give information regarding the road traffic and prove vital in measuring stress or frustration. A lane departure system can be used to model both aggressiveness and drowsiness, correlated with the lateral vehicle acceleration; abrupt changes of vehicle trajectory and harsh braking can be attributed to a driver overcoming leading vehicles hastily (thus aggressive), while slower deviation from the lane could suggest drowsy driving. This information is derived from the CANbus system alone and can be used to model driving behaviour and create a user profile; thus we succeed in the inherent nature of the feature extraction system mentioned earlier and the individuality of the solution.

However, measuring driver’s physiological characteristics suggests a validation of the previous model and increases accuracy by contributing additional features to the modelling algorithm. As mentioned in section 3.4, facial expressions, such as eyelid closure and yawning, or head posture can be processed to detect drowsiness. Fatigue can be demonstrated via heart rate variability or the features that give away drowsiness. Inattentiveness can be modelled using eye gaze direction, while emotional arousal, such as stress and frustration, can be measured through GSR, BVP, heart rate, HRV (heart rate variability) and pupil size variability.

Table 5.1 presents the reader with an overview of the technologies that can be employed to model the performance parameters as we have initially defined them. Taken the potentials of each technology into account, we present an innovative solution for an in-vehicle physiological data acquisition system that delivers optimal accuracy by collecting multiple features and analysing them using state-of-the-art computing algorithms. Exploiting the rapid advancement of computer vision techniques, a head-up multi-sensor device could extract the desired nature and amount of features for computer vision and eye-tracking technology.

	Drowsiness	Fatigue	Stress	Inattention	Emotional valence	User identification
Eye tracking	✓	✓		✓	✓	✓
Face recognition	✓	✓	✓		✓	✓
Head tracking	✓	✓				
Wearable sensor(s)	✓	✓	✓			

TABLE 5.1: Modelling performance technology

Using image recognition software, the system can monitor the face of the driver and detect repeated yawning, frequency of eye-blinking and the diameter of eye-lid opening, which suggest signs of fatigue and drowsiness. A study on advanced driver fatigue observed certain motions of the head while the driver was feeling fatigued [26]; less frequent head movement, reflexive head nod after checking the side mirrors and leaning to the side to relieve muscular tension. Such signs, as well as nodding off, swaying of head from nodding off or similar head motions, can be detected by tracking head posture. By monitoring the facial muscles’ electrical activity, we can get information about frustration and stress, as seen in chapter 3. Enrolling eye-tracking recognition software shall ensure driver inattention detection; eye-gaze direction and pupillary dilation [39] monitoring can be methods to detect the so-called *eyes/mind-off the road* effect.

## 5.2 Sensor technology

As mentioned in section 3.2, the FMS interface operates as the “black-box” that will ensure continuous streaming to the vehicle data. Such a sensor is currently the Squarell<sup>1</sup> that connects to multiple networks including the CANbus and tachograph systems [84].

As far as the eye tracking process is concerned, it requires a set of IR illuminators and a camera for real-time image capturing [88]. At the same time, the sensor will be used for user recognition via iris identification, as seen in section 3.1.2.



FIGURE 5.1: Eye-tracking sensor by Tobii [87]

3D image technology can be employed to detect more discrete facial characteristics under varying illuminating conditions. Microsoft’s Kinect Xbox One sensor [52] (fig. 5.2) is a very good starting point for exploring such technology. *Time-of-Flight* (ToF) sensors allow capturing a depth image of a scene, in other words a mapping of the distance of each point from the sensor. ToF cameras require an IR illuminator which emits light; the phase difference between the transmitted IR and the reflected IR suggests the distance of the projected point [38]. Another technique of depth measurement is by projecting *structured light* from stereoscopic cameras and using it to measure point distance via triangulation. In principle, this technique is projecting a known pattern on a surface and computes the texture/depth by measuring the deformation of the pattern [36]. Hansard et al. [38] provide an evaluation of the two methods, as well as implementations of the two techniques that complement each other for minimizing errors. They conclude in a

<sup>1</sup><http://europe.squarell.com/en/>

combined system that improves the density and accuracy of a depth map, using both ToF and stereoscopic cameras.

Additionally, the camera can also be used for monitoring heart rate using a video processing technique called *Eulerian Video Magnification* (EVM). EVM combines spatial and temporal processing to amplify subtle variations on facial features (in particular in skin colouring) that can provide critical information about physiological characteristics of the user [99]. Observing the skin colouring variations of the user's face, we can develop an algorithm that will extract heart rate and with further processing the heart rate variability, which will give information about sleepiness and fatigue.

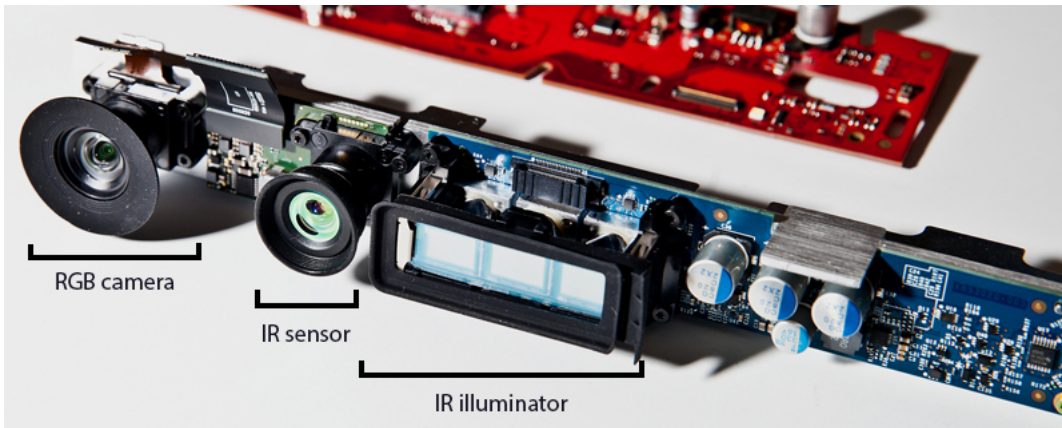


FIGURE 5.2: Internal components of a Kinect sensor

As we shall see in the next section, an important aspect of our proposal will be context-based recommendations, which in our case suggests location-based services such as POIs, traffic and weather reports. In order to achieve that, we need a GPS sensor, access to the navigation system and a data service provider.

## 5.3 System behaviour

### 5.3.1 Fitness index

Given the input features we have previously analysed, the algorithm should be able to compute the performance level of the drivers and both their mental and physical capability to continue driving. We will define this value as the *fitness index*, and we shall set three universal thresholds (preliminary defined at 70%, 20% and 7%, respectively),



which will define the conditions of good performance, not optimal but can continue driving, strongly advised to take a break and alerting state (see fig. 5.3).

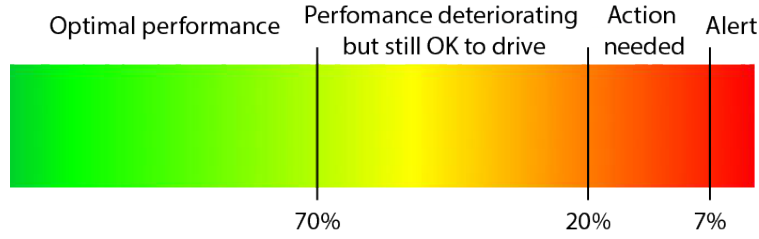


FIGURE 5.3: Performance levels

The fitness index, or otherwise the performance indicator, should be computed not only by correlating physiological with vehicle data, but also considering external contextual parameters, which are more analytically explained in the next section (5.3.2). The underlying logic is that each person behaves differently under varying conditions, and for a successful prediction we need to consider all the relevant factors that might affect driving performance.

### 5.3.2 Context-aware interaction

We assume that performance is a variable that degrades as the driving time increases, but it is also highly related to the environmental conditions such as road and traffic. Therefore, we wish to include more variables in our computing algorithm to maximize the accuracy of our predictions. Such parameters are both relevant to time (*temporal*) and space or environment (*spatial*), and they are listed in table 5.2.

Temporal	Spatial/Environmental
Age	Distance remaining
Driving experience (in years)	Road condition ahead
Time of day	Traffic condition ahead
Time of waking up/going to sleep	Weather
Time since last stop	POIs on route
Time until next stop	Cabin conditions
Driving time (passed)	Nutrition
Driving time (remaining)	

TABLE 5.2: Contextual information

Cabin conditions include temperature, music, luminosity, which are also factors we can/should be able to adjust within our system. Nutrition, even though not explicitly connected to space, is important for our database, as it includes how much energy intake the driver receives, e.g. caffeine, sugar. It is indirectly linked with the environment, as

we need to consider that the on road conditions do not always offer adequate conditions for healthy eating.

Apart from the input parameters that will help us define the fitness index, contextual information will be utilized to deliver personalized recommendations to the drivers according to their preferences. That way we will be able to calculate POIs on route and suggest which one the driver should stop at, where (s)he can find the facilities they wish, at the time they should get rest and without interfering with their schedule. Considering the traffic ahead, we could even suggest to take a break beforehand so as to avoid meeting heavy traffic, thus saving a lot of time and stress.

### 5.3.3 Application actions

So far, we have talked about how our system computes a fitness index based on multiple parameters, yet we have not discussed what it is going to do with this information. The most significant requirement is to be able to predict driving performance degradation and be able to provide suggestions to overcome it. The minimum functionality would be to alert the driver that their performance is deteriorating and they need to act, otherwise they risk unsafe driving. As discussed in section 2.3, we are attempting to fit our implementation in the model-based interface framework displayed in figure 2.2.

We previously set three thresholds regarding the fitness index (fig. 5.3). While the index remains within the “green” zone, the monitoring frequency should be low enough to prevent exhausting system resources but high enough so as not to lose major changes in performance levels. When the index reaches the first point (70%), the system should increase its update frequency as it is getting prepared for vigilance degradation. By the time the indication reaches the second threshold (20%), our algorithm has already calculated the distance and time to the immediate destination and displays a suggestion whether it is advisable to keep on driving or an action should be taken to fight fatigue (fig. 5.4a). If the driver chooses to ignore any suggestion and carries on driving on the expense of their performance, at the final threshold we employ audible notifications that alert them of low energy levels (fig. 5.4b). At this point it would be advisable to send an automatic notification to the supervising personnel, that one of their drivers is working under critical conditions and requires attention (fig. 5.4c).

A scenario to be considered for future study would be to implement advanced functionalities, by establishing communication with the built-in cruise control system and

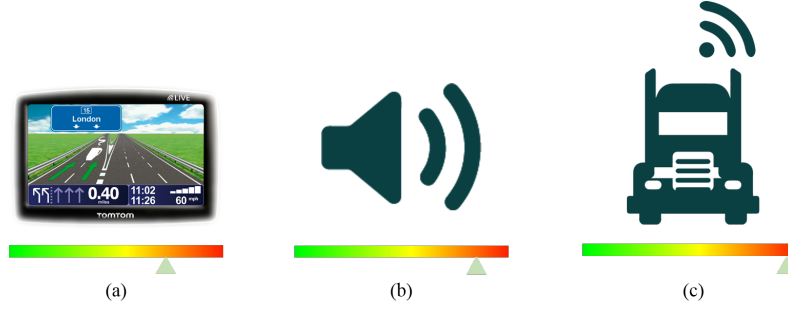


FIGURE 5.4: Application actions

automatically activating features that can help accommodate vigilance. In example, adjusting the cabin temperature affects sleep-wake behaviour [73], thus it could be used in cases of driver drowsiness. Increasing the radio volume would be another alternative to regulate driver's attention and stress levels. If we want to include multiple modalities to alert for the upcoming danger, we should follow the guidelines from chapter 4 and enable steering wheel or seat vibrations as an additional modality. In such a case, it is important to make sure that the alerting vibrations can be distinguished from road and truck vibrations, but at the same time they do not surprise the driver to the extent that (s)he might lose control of the vehicle.

### 5.3.4 Dialogue control

For the system behaviour, we have defined four different scenarios depending on the user's preferences, see table 5.3. The scenarios are based on the nature of feedback the driver wishes to receive and the user should be able to switch options as often as they wish. Such flexibility allows the user to choose the level of assistance they require from our system and affects the perceived usefulness(U) module of TAM (fig. 4.1), thus increases the possibility of acceptance. At this point it is important to note that the scenarios have been created based on hypotheses. Whether the users can fit into one or more of these cases remains to be tested on the field, however the result shall not be disclosed in the present report.

Scenario 1:	The user wishes no feedback on driving behaviour nor fitness
Scenario 2:	The user wishes feedback only for driving behaviour
Scenario 3:	The user wishes feedback only for fitness
Scenario 4:	The user wishes to receive maximum assistance

TABLE 5.3: User feedback scenarios

### 5.3.5 Style rules

In the case that the user wants to receive full assistance the system should be able to provide both real-time and post-drive feedback on the user's condition, following the guidelines presented in chapter 4. We use visual representation to make the driver continuously aware of their driving behaviour, keeping in mind the MRT model from fig. 4.4. Augmented reality can be utilized on the side mirrors and front window, pointing the margins from the lanes as a *lane assist system*. The pointers will appear when the driver turns eye-gaze on the mirror (eye-tracking required), otherwise it might interfere with the ambient (peripheral) vision and become overwhelming. In cases of excessive fuel consumption, a corresponding notification will appear in the driver's field of view, advising them of its causes (e.g. overspeeding, harsh breaking). If vigilance degradation is detected, we employ auditory signals to let the driver know that it affects their driving performance and also point their attention to the direction of the danger; e.g. if they are drifting away from the lane to the right side of the road, the sound should prompt them to look to the right where the visual signals will point out danger of getting off road. We present a post-drive report to inform and trigger behavior change and employ social norm conformance to promote more effective change. It has been observed that summative reports that present overall driver feedback and comparison with peer's performance influences long term behaviour changes [71].

As far as the physiological signals are concerned, we choose not to display by default *raw* information, e.g. heart rate values, but interpret them in a manner that makes sense to the user, e.g. energy levels. As an optional feature, one could choose to have the raw signals displayed, as well, since they are being collected. With reference to section 4.3, this feature introduces data transparency as the user can have the complete overview of which data we collect and how we interpret them. Additionally, the user shall be able to review the data history for a longer period of time and access them from personal devices (e.g. smartphone) if they wish.

### External services

Ultimately, we would like to develop an algorithm that will fuse information about traffic and weather conditions, resting stops along the route and the current and predicted condition of the driver. The aim is to present an optimized schedule for the drivers, in a way that the resting pauses would no longer be enforced by impersonal legislation but redistributed to fit the driver's actual needs, avoiding factors that might cause increased mental overload. Taking it a step further, we could employ recommender

systems that suggest to take either a short or a long break, based both on the drivers' needs and on their preferences. In that way, we would create a personalized list of preferred places varying according to own preferences or from suggestions by friends and/or colleagues, so that it can be used as a “travel book”, if the user chooses to.

The physiological characteristics can be utilized for keeping a medical history of the driver in cases (s)he suffers from sleep related disturbances. If they wish to, a service could be developed that connects their personal data with a health coaching programme and suggest a nutrition or exercising schedule.

## 5.4 Human-machine interface

We require our system to be connected with the vehicle's fleet management system interface (FMS) and retrieve data from it. The biometric sensors have to be placed in front of the driver, as close to their face as possible. Inspired by the design of the eye-tracker, we are looking at a bar-shaped array of sensors that can be mounted over the driver's head (see fig. 5.5). That way it is completely unobtrusive and the sensors will not be significantly affected by the ambient lighting conditions. It remains at the discretion of the manufacturer whether they want to include speakers in the array of sensors, or they wish to utilize the cabin's sound system to deliver the audio signals for alerting the driver.

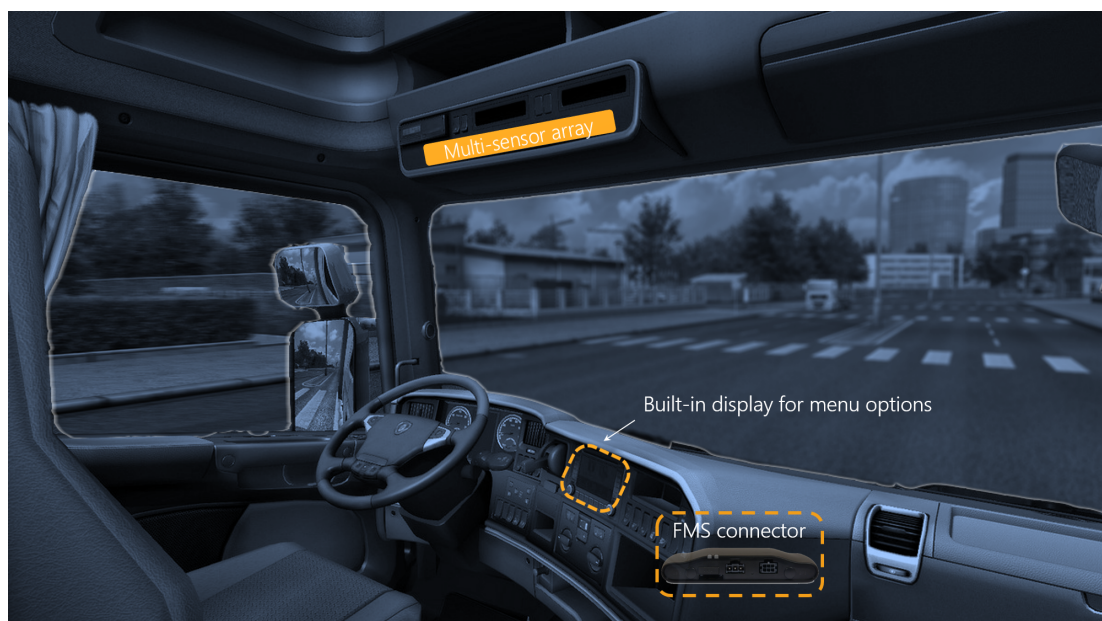


FIGURE 5.5: Interface overview

Based on the previous analysis, the reader can clearly see a strong preference in eye and face recognition technology. However, as mentioned it is not the only solution, nor necessarily the final one, which is why our suggestion is to, ultimately, make an interface independent of the hardware used and virtually invisible to the user. That would mean to use existing in-vehicle systems to provide our functionalities, which would make our system more flexible and could be installed in a wider range of vehicles. In order to do that, we need to establish access to the FMS interface, the physiological sensors and an electronic display.

We have mentioned that we wish to use visual cues to inform the driver of the system actions, for that we require connection with the navigation display, where the advised POIs would become more evident when the driver needs or wishes to make a stop. For the more advanced features of driving coaching, we need to employ augmented reality technology on the side mirrors or on the windscreen, where also the POIs' notifications could be displayed, if we choose the advanced option.

So far, we require no interaction from the driver, but we have not covered the occasion where the driver needs to adjust the system's output parameters. For that we require a display that would be either integrated within the cruise control system (much like the on-board electronic screen), or in the navigation system. As long as the driver needs to review their data post-drive, we need to make sure that either all this information is delivered to their personal smart device, or that there is a platform they can access at their convenience.

## Chapter 6

# Conclusion

### 6.1 Synopsis

The current thesis was fulfilled within the context of promoting a healthier lifestyle to professional truck drivers. The final system is meant to increase awareness on factors that influence driving performance. By redistributing driving and resting hours according to the user's actual needs, we aim to trigger behaviour change for maximizing driving efficiency.

The challenge we were asked to overcome was to deliver an intelligent and unobtrusive system that monitors driving behaviour and predicts vigilance degradation. In our context, driver's performance is measured by the levels of fatigue, drowsiness, stress and inattention. In the future, more factors could be added if proven to affect driving behaviour and can be modelled accordingly.

Our approach included extensive research in cutting edge technologies that facilitate implicit interaction within the limits of the environment of a truck cabin. In order to address the intelligence aspect, we looked into adaptive and intelligent human-computer interaction and user modelling for affective computing. The main focus was in determining the sensors' positioning, interaction between the user - system - environment and which services shall be provided.

The system is required to extract personal and contextual data that relate to driving behaviour, process them with an advanced machine learning algorithm that determines a driving performance index and finally, signal alerts and recommendations regarding

driver vigilance. The design and implementation can be better viewed if divided into two phases. The first one concerns the technology and nature of feature extraction, which represent the *input parameters*. Those include vehicle data and physiological signals. The second one, could be described as *output features*, includes features and services that would be provided as feedback to the driver with the purpose of increasing user acceptance. To that end, we followed design guidelines for in-vehicle systems and applied persuasive system design principles to ensure long-term behavioural change.

The final proposal suggests a means of ensuring implicit interaction, which we argue that it should ultimately occur regardless of the hardware used in the implementation. Second, it determines the nature of situational context that relate with temporal and spatial parameters from the user's environment. Through context-aware interaction, it attempts to describe automated features that adjust to the circumstances and to personal user profiles.

## 6.2 Future work

During the project work, various claims have been made that were based on literature research, but they remain to be verified on field studies as well. The next step should be the implementation of the algorithm. After deciding which approach we are going to adopt, we need to test our accuracy in recognizing emotions. The big challenge would be to actually create an algorithm that will be independent of the sensors used. Could that be possible?

As far as user acceptance is concerned, we have made a claim about introducing automated feature adjustments in the cabin, but we cannot know for sure how the users will react to the automation unless we test it. We have also seen four different scenarios of user feedback, and it would be wise to see which one appeals to the drivers best. A more user-centric approach needs to be followed for determining further services that we could connect our application with. Last but not least, we need to address privacy issues; are the measures we are taking regarding information transparency enough or do we need to take further actions to mitigate them?

The current project has a lot of potentials to integrate in the next generation of in-vehicle information systems, as it can effectively increase road awareness, promote safer driving behaviour, decrease mental workload and promote healthier lifestyle by connecting to external services related to life quality and well-being.



## Appendix A

# Parameters for driving style recognition

Average velocity	Standard deviation of grade
Average running velocity except stop	Standard deviation of positive grade
Stop time/total time	Standard deviation of negative grade
Positive acceleration kinetic energy change per unit mass per unit distance	Trip distance
Average acceleration	Maximum acceleration
Average deceleration	Minimum deceleration
Average positive grade	Percentage of time in certain speed intervals
Average negative grade	Percentage of time in certain acceleration intervals
Positive grade time/total time	Percentage of time in certain deceleration intervals
Negative grade time/total time	No. of acceleration/deceleration shifts per 100m where the difference of adjacent local max-speed and min-speed was $> 2$ km/h
Number of stops per kilometer	Maximum product of velocity and acceleration
Average micro-trip time(from start to stop)	Minimum product of velocity and acceleration
Acceleration time/total time	Average product of velocity and acceleration
Deceleration time/total time	Standard deviation of product of velocity and acceleration
Standard deviation of acceleration	Current velocity
Standard deviation of deceleration	Driver power demand
Maximum velocity	SOC
Standard deviation of velocity	Average positive power demand
Average grade	Average negative power demand
Maximum grade	Standard deviation of positive power demand
Minimum grade	

Source: [94]



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