



Visualizing Logged Truck Data

Facilitating a Better Understanding of Driver Behavior in the Truck Industry

Master's thesis in Interaction Design and Technologies

DANIELA FRÖLICH

MASTER'S THESIS 2020

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Gothenburg, Sweden 2020

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Master's Thesis 2020
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Cover: An illustration of a dashboard of data visualizations. (Illustration by the author)
Gothenburg, Sweden, 2020

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Abstract

The user interfaces in Volvo's trucks are designed from user needs based on qualitative methods. The feature specialists express a lack of knowledge about driver behavior which forces them to guess and make assumptions. There is a possibility with today's technology to understand how a large set of users actually behave, through collecting and visualizing large amounts of quantitative data. The aim of this thesis is to explore how a visualizations of logged truck data can be designed to enable designers in the truck industry to better understand driver behavior. A Research through Design approach was followed to explore the subject. The process consisted of user research and two iterations of design, evaluation and implementation. During the user research a large set of diverse and specific needs were identified. The most important needs were that the specialists at Volvo were in need of knowing activation time for different functions and frequency of different control usages. The needs were used as a basis for the creation of a data visualization dashboard. Four key consideration areas from the process of creating the dashboard was identified. These were that users should be included early in the design process, learnings from the human visual perception should be used, colors should be carefully selected and that the number of logged trucks affect the viewer's trust in the visualization. The final prototype was implemented in Power BI. The annotated dashboard and consideration areas answers the research question which was: *What should be considered when visualizing logged truck data to facilitate designers' understanding of driver behavior?* The thesis contributed to filling the gap in research of using data visualization in the truck industry to enable a better understanding of driver behavior.

Key words: Data visualization, interaction design, data driven design

Acknowledgements

I would like to give a big thanks my supervisor Beata Stahre Wästberg, who has been incredibly helpful and supportive throughout the thesis. Furthermore, I would like to thank my external supervisor Nina Theodorsson, who has been very helpful and is the driving motivation of the thesis. I would also like to thank the employees at Volvo for including me in the team and giving me their valuable time and opinions.

Daniela Frölich, Gothenburg, May 2020

List of Abbreviations

ACC	-	Adaptable Cruise Control
AI	-	Artificial Intelligence
CC	-	Cruise Control
ECU	-	Electrical Control Unit
FCW	-	Forward Collision Warning
GTT	-	Group Trucks Technology
IDE	-	Interactive Development Environment
PTO	-	Power Take-Off
SD	-	Side Display
VDID	-	Volvo Driver Information Display
UX	-	User Experience

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1

Introduction

According to Volvo Trucks (2019) the user interfaces in Volvo's trucks are designed from user needs based on interviews, observations, surveys and other qualitative methods. Goodman et al. (2003, p. 3) describe this kind of user research as "[t]he process of figuring out how people interpret and use products and services". User research is important for understanding why users behave in the way they do (Beasley, 2013). However, users do not always behave as they tell in interviews (Nielsen, 2001). Furthermore, user studies are time consuming and often based on a small set of users (Beasley, 2013). The feature specialists at Volvo are expressing a sense of not knowing how the drivers actually interact with the controls and displays in the truck. The employees feel that they need to guess and make assumptions about the driver behavior. There is a possibility with today's technology to understand what a large set of users actually do, through collecting and visualizing large amounts of quantitative data. In this context the data is logged signals from trucks. In this thesis work data visualization will be used to enable designers to better understand driver behavior.

According to Kirk (2016, p. 52) data visualization is "[t]he representation and presentation of data to facilitate understanding". Humans have difficulties with understanding relationships and creating comparative meaning of tabular form of data. Data needs to be represented in a visual form in order for humans to understand it. Furthermore, there are challenges in that all the logged data is not related to user behavior. (Kirk, 2016) Only the relevant data should be presented in a visual and meaningful way so that the designer can understand it (The Interaction Design Foundation, n.d.) and draw conclusions based upon it.

Data visualization has been used since the mid-2000 in a similar field, the web (Beasley, 2013). Web analytics as a method that can be used to understand user behavior of websites and mobile apps, through collecting quantitative data of the user interactions (Beasley, 2013). Trucks have displays, controls and surrounding systems that can be used to collect data for understanding user behavior, similar to web analytics. However, there is a gap in research of using data visualization in the automotive industry to understand driver behavior and facilitate data driven design decisions. There are few studies that investigate the use of sensor captured data from products to collect customer needs and create design requirements (Bigorra, 2019). Hence, this thesis will take a Research through Design (see section 4.1) approach in its attempts to contribute with research that will help fill the gap. This means that an interactive desktop visualization dashboard will be designed that works as a knowledge-generating artefact. It is intended that the dashboard should be used by designers and specialists at Volvo to better understand driver behavior and facilitate for data driven design decisions.

1.1 Aim

Trucks produce large amounts of quantitative logged data. However, many designers and developers of trucks today do not have the tools that will help them understand and act upon this data. The aim of the thesis is therefore to explore how an interactive data visualization dashboard can be designed to facilitate a better understanding of driver behavior and enable data driven design decisions. Furthermore, the thesis aims to investigate the possibilities and limitations of using data visualization as a method for understanding behavior compared to traditional user studies, such as interviews and observations.

1.2 Research Question

The purpose of the thesis is to answer the following research question:

What should be considered when visualizing logged truck data to facilitate designers' understanding of driver behavior?

To answer the research question above a sub question will be answered:

What are the user needs of the visualization to further understand truck driver behavior?

1.3 Deliverables

The deliverables of the project are:

- An interactive data visualization dashboard of the logged truck data.
- Identification of user needs of the data visualization dashboard.

1.4 Delimitations

The project is limited to use the logged data from signals which was collected by the company in advance. Therefore, several areas of the truck interface will not be considered. The acquired data comes from physical buttons and computers in the truck. This means that interactions with the displays, such as the display in the instrument cluster and the secondary display will not be considered.

The data is collected from one gas truck alone and therefore all types of trucks are not considered in the implemented visualization. In the beginning it was decided that five more trucks would be used for logging data. However, the first logged truck got a short circuit due to the logging equipment. The company did not want to put more trucks at risk. Therefore data from one truck only was collected. Furthermore, since the truck transports dangerous goods it was not possible to ride along in the truck to conduct interviews and observations. The thesis takes a design approach to the data visualization and therefore machine learning and other methods for pattern recognition will not be used.

During the thesis the Corona pandemic had its outbreak. The Volvo employees were therefore short term laid off. The last seven weeks of the thesis collaboration with Volvo employees was not allowed. Because of the employees not being allowed to work the dashboard was evaluated with other users. Furthermore, all data was not analyzed and transformed by the data analyst before the outbreak. Therefore there were limitations of the available data.

Volvo also have confidentiality rules which limited the thesis in some ways. External tools for data collection through enquiries could not be used and photos were restricted. The tool that will be used for visualizing the data is Power BI, see section 2.2.1. The tool has design limitations that needs to be considered in the thesis. All design details cannot be configured and customized.

1.5 Stakeholders

The stakeholders in the thesis are presented in the following sections.

1.5.1 Chalmers and Chalmers employees

Chalmers University of Technology has an interest in the project, since the thesis aims to contribute with research of value for Chalmers. The examiner and the supervisor wish that the student should learn, contribute to research and for the project to be successful.

1.5.2 Volvo Group Trucks Technology

Cab Engineering at Volvo Group Trucks Technology (GTT) are responsible for developing the cabs for the different truck brands. At Cab Engineering, the department of Ergonomics & Driver Interface is among other things responsible for setting human machine interaction and user experience related requirements for most functions that the truck driver's use." (Volvo Trucks, 2019). Volvo GTT wishes that the project is successful so that the employees can create products with high user experience that meets the truck driver's needs.

1.5.3 End-users

The designers and developers at Volvo have an interest in the visualization dashboard being of use so that they can base their design and development decisions on quantitative logged data. Furthermore, they aim to further improve the user experience, fulfil the user needs and provide a more user-friendly and safer user journeys and user interfaces. They could use the visualization dashboard as support to achieve these goals.

1.5.4 Volvo Truck Drivers

The drivers of Volvos trucks are affected by the thesis outcome, since it affects the interface of the vehicle and they will be affected by the data gathering.

1.5.5 The Student

The student has an interest in the project being successful so that it can be used in practice for making design decisions. She also aims for contributing to research and achieving a master's degree in Interaction Design and Technologies.

1.6 Ethical Considerations

Ethical issues and regulatory and legal requirements concerning data use will be considered. The General Data Protection Regulation (GDPR) will be followed during the user research phase. GDPR is created to protect the individual fundamental rights (Datainspektionen, n.d.). The ethical considerations were considered through meetings with legal staff and researching GDPR's home page for consultation of how and if data can be collected. Recordings will be stored on a secure disk for two weeks and thereafter deleted. The interview forms will be constructed so that only necessary information is collected. Sensitive data will not be collected and the participant's names and personal information will be anonymized.

Although data science creates big opportunities to improve life and environment it also brings ethical challenges (Floridi and Taddeo, 2016). Data ethics is a term that focuses on the ethical issues that collecting and analyzing large amounts of data brings (Floridi and Taddeo, 2016). The ethics of gathering data how drivers use the truck functions will be considered and discussed.

2

Background

This chapter outlines the context of the report. Firstly, describing trucks and truck interfaces, secondly the term data visualization, dashboards, prototyping tools and finally related work. Related work is investigated to grasp what has been done before and understand how the gap in research of data visualization in the automotive industry can contribute to.

2.1 Trucks

The thesis is conducted at Volvo Trucks, which is the largest supplier of heavy trucks in Europe (Volvo Trucks, 2020). A truck is a motor driven vehicle that is used for transporting goods. Trucks have many different usage areas such as for tipping, tanking or working as a crane or car carrier. Because the trucks are used in such different areas, trucks have flexible chassis that can be used to customize the truck for the driver's needs. Volvo have several different models such as Volvo FL, FM and FH. The data in the thesis is logged from a Volvo FH. Volvo FH is Volvo's long haul model, see Figure 2.1 for an example of the truck. (Volvo Trucks, 2020)

The logged data comes from the truck's Electronic Control Units (ECU's). Vehicles such as trucks use ECU's to control functions in the truck. Data from the ECU's can provide information about the vehicle, driver and environment (Massaro et al, 2017). Furthermore, this data can be used to analyze and understand driver habits (Massaro et al, 2017).



Figure 2.1 The truck exterior of Volvo's long haul truck model Volvo FH. (Retrieved from Volvo Trucks Image and Film Gallery, n.d.)

2.1.1 Volvo FH Interface

Volvo Trucks (2020) truck interfaces consist of several displays and physical controls such as buttons, switches and wheels, see Figure 2.2. It has a few digital displays, such as an instrument group in front of the steering wheel and a side display (SD), see Figure 2.2. The instrument group shows a meter for fuel, time and temperature on the left, driving information such as speed and gear in the middle and a driver information display on the right. The driver information display shows information about Cruise Control, fuel and many other parameters. Cruise control (CC) is a function that drivers can use to maintain a fixed predefined speed. The SD contains settings and information about vehicle functions such as telephone, sound, navigation and monitoring cameras. (Volvo Trucks, 2020)



Figure 2.2 The Volvo FH truck interior. The truck interface consists of many controls and displays. There is instrument group in front of the steering wheel, a side display to the right of the instrument group and several controls such as buttons, switches and knobs. (Retrieved from Volvo Trucks Image and Film Gallery, n.d.)

2.1.1.1 Electrical Switches

The Volvo Trucks (2020) truck interface contains electrical switches for extended truck functions, see Figure 2.3b, some of them being fixed and some being flexible and can be individually configured. The flexible switches are placed in groups of four. The switches can be replaced or configured in the way the user wants. Which extended truck functions the truck should have is decided by the buyer. One such truck is Power Take-Off (PTO) (Volvo Trucks, 2020) The switches are located on panels on the right and left side of the steering wheel and in a panel above the driver's seat.

2.1.1.2 Steering Wheel Controls

Three levers controlling the wind shield wipers, flashing indicators and auxiliary brakes are located behind the steering wheel, see Figure 2.3a. Two groups of controls called steering wheel keypads, are located on each side on the steering wheel, se Figure 2.3a. The left group consists of buttons that control for example Cruise Control, Adaptive Cruise Control and telephone. Adaptive Cruise Control (ACC) is a complement to cruise control which uses camera sensors and radar to maintain a certain distance from the vehicle in front of the truck. The right side keypads controls the secondary display, a driver display located in the instrument group and the stereo. (Volvo Trucks, n.d.)

2.1.1.3 Right Side Controls

A control for the electric parking break, a climate control panel and sixteen electrical switches for the extended truck functions are located on the right hand side of the steering wheel. The electrical switches can be ordered with different symbols. (Volvo Trucks, 2020)

2.1.1.4 Left Side Controls

Four of the electrical switches are located on the left of the steering wheel. The left side panel also have controls for exterior lights. (Volvo Trucks, 2020)



(a) The steering wheel with keypads. It contains buttons for Cruise Control, the infotainment system, phone etc.



(b) The group of 16 electrical switches that are used for extended truck functions located on the right hand side of the steering wheel.

Figure 2.3 Details of the Volvo FH truck interface. The steering wheel has keypads and the instrument panel have flexible electrical switches. (Retrieved from Volvo Trucks Image and Film Gallery, n.d.)

2.1.1.5 Panel above the Windscreen on the Driver's Side

A panel is located above the windscreen on the driver's side, see Figure 2.4. The panel contains electrical switches and a tachograph. The tachograph records the driver's so called drive and rest times and speed. (Volvo Trucks, n.d. Drive and rest times are regulations of the driver's shift and break times (Transportstyrelsen, 2019).



Figure 2.4 There is a panel above the windscreen on the driver's side. The panel consists of a tachograph which records the driver's speed and drive and rest times and electrical switches for extended truck functions.

(Image by the author)

2.2 Data Visualization

In this thesis work data visualization will be used to enable designers to better understand driver behavior. There exist several related terms to data visualization one of them being information visualization. Kerren et al. (2008) describes information visualization as a relative new area which focuses on using visualization to support individuals in understanding data. According to Kirk (2016) the difference between data visualization and information visualization tends to be in output, the information, or the input, the data. Furthermore, it is common to use the term information visualization when it regards work that visualizes abstract data like trees. (Kirk, 2016) Since it is not abstract data that will be visualized in the thesis, the report will refer to the term data visualization.

The logging of the truck's ECU's results in millions of rows of tabular data. Kirk (2016) explains that the tabular form of data is difficult for humans to create comparative meaning and relationships between data points. Our eyes and minds are not capable of translating text and numbers into qualitative and quantitative meaning. The data needs to be represented in a visual form for humans to understand it. The representation is the combination of marks, such as points and areas, and attributes, which is the appearance of these marks in regards to color, size and position. The presentation regards to interactivity, annotations and composition. The goal of the visualization is to facilitate understanding. The viewer goes through the stages of perceiving, interpreting and comprehending when attempting to understand a data visualization. Visualizations can be exploratory or explanatory depending on the purpose of the visualization. (Kirk, 2016) The data visualization in this thesis will be exploratory.

Ware (2012) states that visualization has derived from being an internal construction in the mind to an external artifact that can support decision making. However, since the human brain perceives specific things immediately, such as color, intensity, hue, size and orientation, data visualization is complex (Gardner Archambault et al, 2015). In order to create effective data visualizations understanding of the human perception is therefore needed (Few, 2009). Therefore, the human perception is researched and described in chapter 3.

2.2.1 Data Visualization Tools

There exist several software programs that can be used for creating data visualizations. In this thesis Power BI will be used since the tool is provided by Volvo. Power BI is according to Microsoft (2020) a data visualization tool that can be used to create interactive visualization dashboards. The dashboard can be shared or published online. The dashboards can consist of several visual objects. The visual objects that can be created are among others different types of diagrams,

charts, maps and graphs. (Microsoft, 2020) Another data visualization tool is Tableau. Tableau is an important data visualization tool according to Mahalakshmi and Suseela (2015). With the use of the program the user can get insights from the data by creating graphs, maps, charts and other graphics (Kahn and Kahn 2011). Which tool the data visualizer chooses affects what kind of visualization that can be made (Kirk, 2016).

2.2.2 Data Analysis

Before the data can be visualized it needs to be prepared to get in the desired form. According to Nelli (2018) data analysis is the process of transforming the data and extracting desired information is called data analysis. Python is according to Nelli an easy to learn programming language that can be used for data analysis. An Interactive Development Environment (IDE) can be used for working with the code. (Nelli, 2018) There exists many IDE's for Python. One of them is called PyCharm which according to PyCharm (2020) is an IDE for professional developers.

2.2.3 Charts

There exist endless of variations of charts. In this thesis a dashboard consisting of several visualizations will be designed to enable analysis of driver behavior. To design a visualization that enables analysis such as comparisons, finding patterns, trends and correlations one must be aware of which charts are best suitable for what type of analysis. This section describes some of the different types of charts, their advantages and disadvantages.

2.2.2.1 Comparative Charts

This section presents some of the charts that according to Kirk (2016) are useful for comparison, see Figure 2.5.

Bar charts consists of line marks (bars) which height or length is used to represent the value for different categories displayed on one of the axes. Tick marks and gridlines can be used to improve the accuracy of the reading of the values. The quantitative value on the axis should always start from zero and the full value should be displayed. This is because of the perceptions of the bar's height can easily be distorted if the quantitative value is alternated. Bar charts can be displayed horizontally or vertically. Bar charts can also be clustered, *clustered bar charts*, meaning that they have major categories with sub categories within. The clustered bar chart's value axis should also start from zero. Furthermore, Kirk advises that more than three sub categories can become overwhelming. (Kirk, 2016) Ware (2012, p. 169) explain that humans have difficulties with estimating volumes and therefore quantities should be represented by length or height according to the following guideline:

"[G5.17] Ideally, use glyph length or height, or vertical position, to represent quantity. If the range of values is large, consider using glyph area as an alternative. Never use the volume of a three-dimensional glyph to represent quantity."

Dot charts show quantitative values with the use of dots according to Kirk (2016). The dots are located on a scale that indicates the value of each category. More dimensions of categories can be added to dot charts with the use of for example color or symbols.

A *proportional shape chart* displays quantitative values for different categories with the use of different sized area marks. The size of the area represents the value of the category. Kirk advises that proportional shape charts should only be used when the range of quantitative values are diverse, since it can be difficult for the perceiver to compare the size of an area.

A *bubble chart* displays quantitative values with the use of different sized circles (bubbles) representing different categories and optionally sub categories. Bubble charts can

advantageously be used with interactive features such as revealing annotations. Kirk advises that the bubble charts should only be used when the range of quantitative values is diverse. The value axis does not need to start at zero and if it does not it should be clearly labelled.

Range charts uses bars to display the minimum and maximum distribution of quantitative values. The chart displays one bar for each category which length represent the range of the category's minimum and maximum value. The value axis does not need to start from zero. (Kirk, 2016)

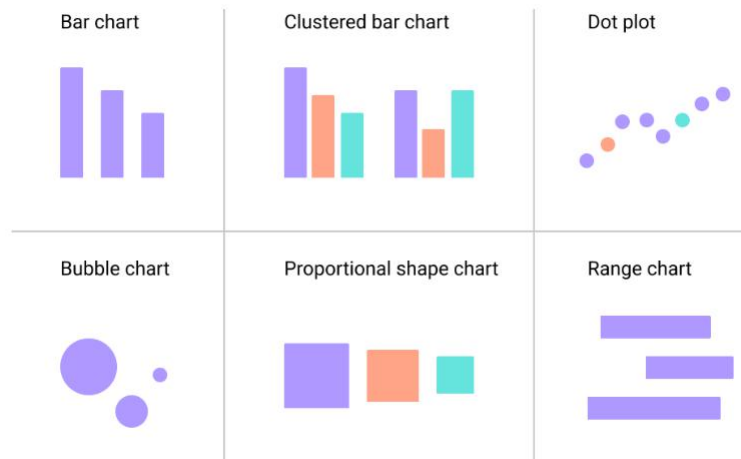


Figure 2.5 A sample of charts that can be used to enable comparison of values.

2.2.2.2 Distributive Charts

One of the charts that according to Kirk (2016) can be used to show distribution is the *univariate scatter plot*, see Figure 2.6. In a univariate scatter plot a series of quantitative values for different categories are distributed along the plot. This type of chart gives the perceiver an understanding about the range, the clusters and outliers of the data. Color can be used to emphasize certain values that are of interest. (Kirk, 2016)

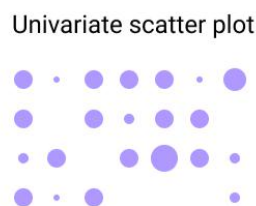


Figure 2.6 An univariate scatter plot can be used for showing distribution.

2.2.2.3 Part-to-whole Charts

This section describes some of the charts that according to Kirk (2016) can be used for showing part-to-whole relationships, see Figure 2.7.

A *pie chart* is a circular chart that uses sectors to display a part-to-whole relationship. Spence (2005) explains that the usefulness of pie charts has been debated over by statisticians over the years. He states that although prejudices against the chart it is effective for estimating a single proportion or a small number of proportions.

A *waffle chart* displays part-to-whole relationships with the help of squares arranged in a grid layout according to Kirk (2016). Waffle charts are useful for showing a single part against a whole. Furthermore, they are most useful when the categories of the bars are placed in order since it improves the viewer's ability to estimate the size of the different parts.

A *stacked bar chart* displays part-to-whole relationships of quantitative values in different categories. In order for the perceiver to estimate the size of each category the charts should be ordered on the size of the different stacks. (Kirk, 2016)

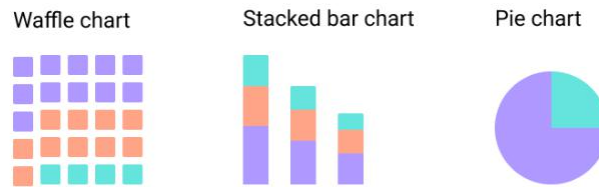


Figure 2.7 A sample of part-to-whole charts.

2.2.2.4 Correlation Charts

One type of plot that is useful for showing correlations is the *scatter plot*, see Figure 2.8 (Kirk, 2016). A scatter plot displays quantitative values by the use of points representing different categories. Scatter plots are useful for exploring eventual relationships between two measures. Distinguishable colors can be used to set apart the different categories. (Kirk, 2016)

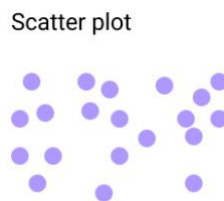


Figure 2.8 Scatter plots can be used for showing correlation.

2.2.2.5 Trend Charts

This section describes some of the charts that according to Kirk (2016) are useful for showing trends, see Figure 2.9.

A *line chart* displays quantitative values with the use of lines representing different categories. Line charts are often used for showing changes over time. The slope of the lines can show trends. Furthermore, interactivity can be used to enable the user to focus on one line at a time.

A *connected scatter plot* displays points that represent quantitative values that are connected with lines. The plot is useful for showing relationships between two measures over time. Generally the connected scatter plots are difficult for the untrained viewer to understand and therefore guides of how to read the chart needs to be used if the chart is implemented.

Horizon charts used joined-up lines that connect quantitative value points along a y-axis. These kinds of charts can be used to show the change of quantitative values for different values over time. A horizon chart are showed on a series of rows of which each shows how values of a category have changed. Furthermore, an advantage of the horizon chart is that it can be used to display several categories in displays such as dashboards where the space is defined. (Kirk, 2016)

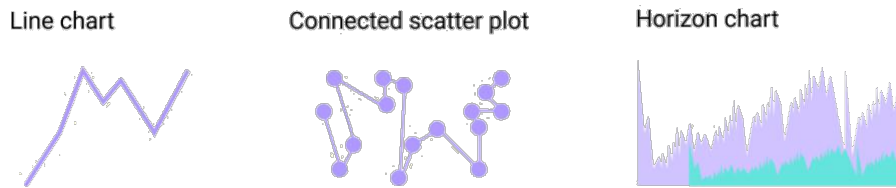


Figure 2.9 A sample of charts that can be used for showing trends.

2.2.4 Material Design Guidelines for Data Visualization

Google have created Material Design principles for Data Visualization (Google, n.d.). The principles are created to make decision making easier for users. The guidelines state that bar charts can be used for ranking ordered lists. Ordered bar charts display bars horizontally, which allows for horizontal text labels for the bars. Visual encoding is the process of converting data into a visualization. Attributes such as shape, color, size and length can be used to distinguish quantitative and qualitative data. Color can be used to distinguish categories or represent quantity. (Google, n.d.)

2.2.5 Interactive Visualizations

Ware (2012) describes that epistemic actions are interactions that are performed to uncover new information. The interactions can consist of loops of zooming and filtering. Interactive visualization contains three feedback loops which are data manipulation, exploration and navigation and problem solving. If the first manipulation stage is delayed it can cause disruptions in the performance of tasks. (Ware, 2012)

2.3 Dashboards

In this thesis a dashboard will be designed. According to Few (2005) a dashboard is a display of information that is arranged to enable users to achieve objectives by viewing the dashboard. A dashboard can contain display media such as graphs, maps, tables and icons (Santiago, Rivera & Shanks, 2015), see Figure 2.10. Chiang (2009) argues that in order to create a successful dashboard stakeholders should be involved in the beginning of the design process. He explains that these stakeholders can be the end users who will use the dashboard and the business analysts.



Figure 2.10 An illustration of a dashboard consisting of graphs, tables and icons. (Illustration by the author.)

2.4 Prototyping Tools

In the thesis prototyping tools will be used to create interactive prototypes. There exist several prototyping tools on the market. Figma is a program that can be used to create animated prototypes (Figma, n.d.). There exist several plugins for Figma that focuses on accessibility (Lowry, 2019).

2.5 Related Work

Related work was researched to understand where and if there was a gap in the research of using data visualization to understand driver behavior. When researching related work, little work of designing data visualizations to enable designers to understand driver behavior in the automotive industry was found. However, data analytics have been used in the automotive industry to classify and categorize driver behavior. Furthermore, data visualization has been used in other fields such as the web to analyze user behavior. This section presents related work of using data analytics to categorize driver behavior and to facilitate for data driven design decisions based on driver behavior in similar fields.

2.5.1 Data Analytics in the Automotive Industry

Oliver and Pentland (2000) used what they call a SmartCar to capture video about the driver's position and view together with data from the car's brake, steering wheel angle, gear, speed and acceleration. They carried out experiments with the car with over 70 drivers in Boston. Oliver and Pentland claim that this kind of research is vital to improve driver interfaces. They proposed a machine learning framework for modelling and recognizing driver maneuvers, such as changing lanes and turning, focusing on how the context affects the behavior. Fugiglando et al (2018) have collected and analyzed data from 64 drivers in an uncontrolled driving environment to investigate how to reduce communication and computational load for drivers. Carmona Fernández et al. (2015) conducted a study to classify normal and aggressive driver behavior. They created a system that would detect aggressive behavior. The tool used parameters such as brake pedal position, steering wheel angle, throttle, velocity, acceleration and GPS to detect aggressive behavior.

2.5.2 Web Analytics

Beasley (2013) describes web analytics as a method that can be used for understanding user behavior of websites and mobile apps. Understanding behavior is done through collecting quantitative data of user interactions on the web. The use of web analytics tools has increased since the mid-2000. (Beasley, 2013)

Wiggins (2007) describes that if web analytics data is used by a design team it can improve the user experience. Beasley (2013) explains that user experience (UX) and web analytics go well together since UX professionals want to understand what users do and why they perform certain interactions. With web analytics the UX practitioners can understand what a large set of users do. However, it is not possible to understand why users behave in a certain way with web analytics. (Beasley, 2013)

Chi explained in 2002 that one of the reasons for websites having low usability is the researchers' lack of understanding of how their users find information. Web analytics attempt to facilitate understanding of web user behavior. However, the existing tools provide little insight into user behavior. Therefore, several researchers have explored the usage of visualization to help understand user behavior and identify patterns. (Chi, 2002)

3

Theory

This chapter describes the theory that the project is grounded on. Starting with Gestalt Laws, secondly affordances, thereafter color theory and finally the human visual perception. The selection of theory was chosen as a basis for the thesis since it concerns how humans interpret information. The gained knowledge from the researched theory will be used in the design phase of the data visualization dashboard. The Gestalt laws will be used in the design to enable humans to recognize patterns. Learnings about affordances will be used for showing the user which parts of the interface is possible to interact with. Color and color blindness are researched since an understanding of color perception and color blindness will make the data visualization dashboard usable by more people. Furthermore, to enable understanding by humans through using data visualization, one must understand how the human visual perception works (Few, 2009) and therefore it is investigated in the thesis.

3.1 Gestalt Laws

Pattern recognition is the human ability to recognize patterns in visual representations (Ware, 2012). Max Wertheimer, Kurt Koffka and Wolfgang Köhler was first with attempting to understand pattern perception in 1912. They created the Gestalt laws of pattern perception. (Koffka, 1935) Ware (2012) explain that the laws describe the way humans see patterns, such as groups, in visual displays, see Figure 3.1. Although the neural mechanism that are behind the laws are proved not accurate today, the Gestalt laws still have value in today's information visualization. (Ware, 2012)

Ware (2012, p. 181-189) describes eight of the Gestalt laws:

Proximity describes how object that are close together are perceived as groups.

Similarity describes how shapes of individual pattern elements can be perceived as groups. However, Ware claims that the Similarity law have been replaced by another type of perception theory describing the phenomena better. These are the theory and concept of integral and separable dimension and that they can help guide design decisions better.

Connectedness describes how connecting object with lines can be stronger than color, proximity, size or shape. This law is commonly used in node-link diagrams.

Continuity explains that humans are more likely to perceive smooth and continuous elements as entities.

Symmetry describes that objects that are symmetric are more likely to be perceived as an entity. Symmetry is a powerful principle that can be used in data visualization when attempting to find similarities in two sets of time-series data. Showing the data sets in vertical symmetry might be more effective than using conventional parallel plots. However, it is important that the representation must be small for humans to be able to perceive the pattern.

Closure describes that a closed contour is more likely to be seen as an object. It is common that humans tend to divide regions of space into "inside" or "outside" of the contour. Closed contours are used in Vann-Euler diagrams. Closure and common regions are vital in window-based interface for dividing the interface into different regions.

Figure and Ground describes the phenomena that a figure can be seen as a foreground and the ground as a background. (Ware, 2012)

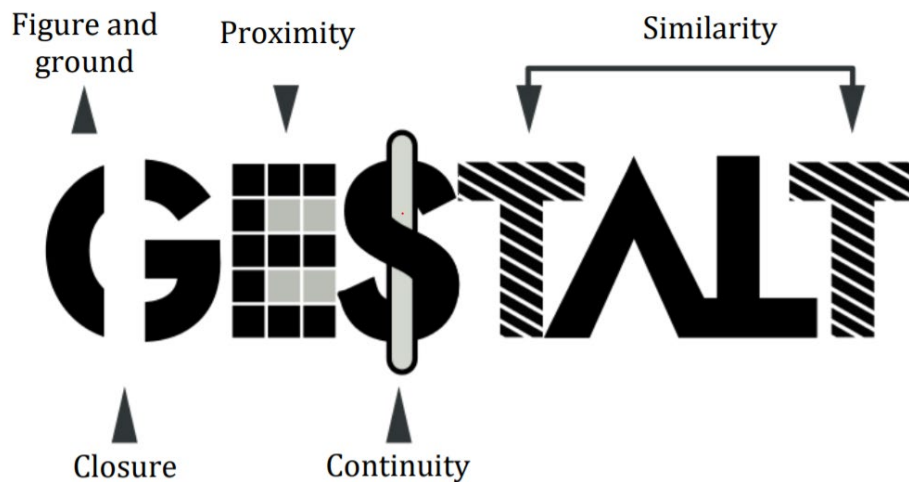


Figure 3.1 Some of the Gestalt Laws, which describes how humans see patterns in visual displays.

(Adapted from File:Gestalt.svg, S. B., Valessio, 27 May 2013, Wikimedia Commons: <https://commons.wikimedia.org/wiki/File:Gestalt.svg>.)

3.2 Affordances

To design an interactive digital interface one should be aware of the theory of how humans look for actions to achieve goals through interactions. Gibson's Theory of Affordances (1977) describes how humans perceive their environment to take actions. Gibson (2014) called the perceivable available actions for *affordances*. Surfaces afford different kinds of behavior and manipulation. (Gibson, 2014) According to Ware (2012) a vital part of Gibson's Affordance theory is that humans perceive affordances immediately. Affordances are important in information visualization since the goal of many visualizations is to guide the perceiver in their decision-making process. (Ware, 2012)

Norman (1988) also explain how objects can have affordances for different actions. However, although affordances are useful in physical interaction design, they can be tricky to apply in digital interfaces. (Norman, 1988) Cooper, Reimann, and Dubberly (2013) states that virtual manual affordances in digital interfaces are missing to explain what will happen when the action is performed. The term pliancy can be used to explain how controls show that they can be directly manipulated. (Cooper, Reimann, and Dubberly, 2013)

3.3 Color

Theory around color was researched to grasp how individuals perceive colors and how colors could be used in the dashboard to facilitate understanding.

3.3.1 Hue, saturation and value

Colors are defined by their level of hue, saturation and value (Ware, 2012), see Figure 3.2. The value refers to how light or dark a color is displayed, hue is the link to the associations of a specific color and saturation is how dull or vibrant a color is (Ware, 2012). Cooper, Reimann and Dubberly (2013) explain that a well thought out combination of the three color properties can result in

consistency and completeness of a design concept. Intense saturated colors can distract the viewer (Wilke, 2019).

3.3.2 Color Vision

Gegenfurtner and Sharpe (1999) explain that the ability to distinguish different lights is called color vision. Humans have three color receptors called cones that transform light into electrical signals (Gegenfurtner and Sharpe, 1999). The theory describing color vision is called trichromacy theory (Gegenfurtner and Kiper, 2003). Individuals with normal color vision can match any light to a mix of the three primary lights red green and blue (Gegenfurtner and Sharpe, 1999). However, Ware (2012) states that around 10% of males and 1% of the females are affected by color blindness. One way of describing color blindness is that the three-dimensional color space becomes a two-dimensional space. Therefore, color coding can be problematic for color blind persons. (Ware, 2012) Color coding categories works best for around three to five categories (Wilke, 2019).

3.3.3 Color Guidelines

Ware (2012) have created a set of information visualization guidelines based on theory of factors affecting the human visual perception. Some of these will be used during the prototyping phase to ensure that the colors are distinguishable by color blind persons. A sample of Ware's (2012, p. 447-448) guidelines that regards color are presented below:

"[G4.2] When small symbols, text, or other detailed graphical representations of information are displayed using color on a differently colored background, always ensure luminance contrast with the background."

"[G4.12] For small color-coded symbols, ensure luminance contrast background as well as a large chromatic differences with the background."

"[G4.14] To create a set of symbol colors that can be distinguished by most colorblind individuals, ensure variation in the yellow - blue direction". (Ware, 2012)

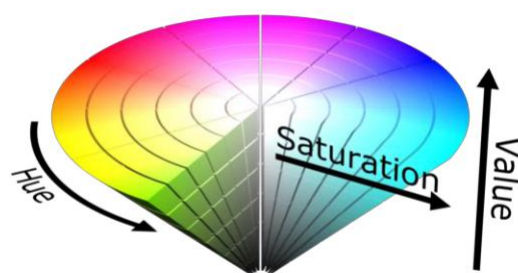


Figure 3.2 Colors are defined by their level of hue, saturation and value. (Adapted from File:HSV color solid cone.png, SharkD, n.d., Wikimedia Commons: https://commons.wikimedia.org/wiki/File:HSV_color_solid_cone.png)

3.4 The Human Visual Perception

To enable the viewers of the dashboard to perceive information that will help them better understand driver behavior an understanding of the human visual perception is needed.

Ware (2012, p. 21-23) describes the human visual perception in three stages:

1. *Parallel Processing to Extract Low-Level Properties of the Visual Scene.* In this first stage large arrays of neurons process the visual information. The stage consists of fast parallel processing and extraction of color, features, texture, movement patterns and orientation. Furthermore, it is the basis for understanding the visual occurrence of the displayed graphical elements.
2. *Pattern Perception.* In this second stage. Fast active processes structure the visual fields into patterns and regions. He explains that in this stage slower serial processing is performed.
3. *Visual Working Memory.* The third stage is the highest level of perception where objects are kept in the visual working memory. In this stage only a few visual objects can be kept in memory at a time. (Ware, 2012)

3.4.1 The Visual Search Process

Ware (2012, p. 139) describes the visual thinking process as containing two steps:

- “Step 1. A visual query is formulated in the mind of the person, relating to the problem to be solved.*
- Step 2. A visual search of the display is carried out to find patterns that resolve the query.”*

The pattern can be anything from a shape, color or complex or subtle visual pattern. It is important to understand what makes a pattern easy to find to create visualizations that answers the formulated query. The following guidelines should be followed to design patterns that are easily recognizable (Ware, 2012, p. 14):

“[G1.1] Design graphic representations of data by taking into account human sensory capabilities in such a way that important data elements and data patterns can be quickly perceived.

[G1.2] Important data should be represented by graphical elements that are more visually distinct than those representing less important information.”

Ware (2012, p. 140-141) describes that the first process in the visual search consists of three important eye movements:

1. *Saccadic movements.* The eyes move from fixation to fixation with a general dwell period of 200 to 400 msec and a movement period (saccade) lasting for about 20 to 120 msec. The general duration of a saccade when looking at a visualization depends on the design and size. If the display is compact the visual search will be much more effective since the saccades will be shorter and faster.
2. *Smooth-pursuit movements.* If an object moves smoothly the eye can track it. These movements make humans able to move head and body while locking on to an object.
3. *Convergent movements.* Convergent movements describe how the eyes diverge when an object moves away or diverge when it comes closer.

Although, how the brain decides what to look depends according to Ware (2012, p. 143) on three aspects:

1. *A priori salience.* Certain patterns appear as more important to humans which creates more neural activity.
2. *Top-down salience modification.* If a human wants to find a certain feature the sensitivity for these features are naturally increased.
3. *Scene gist.* Scene gist explains how experience affect the eye movement strategies depending on the learned scene.

After this preliminary thinking process the information continues through the optic nerve to the cortex. In the cortex there are two visual areas that can detect different properties such as orientation and size, color, depth and motion. These aspects are processed separately and therefore it is a good idea to separate these in the data visualization. Ware (2012, p. 145) therefore suggests that the following guideline should be followed:

"[G5.2] Use different visual channels to display aspects of data so that they are visually distinct."

Objects can be made visually distinct through having a single feature dimension such as color different from the surrounding objects. Or it can be visually distinct by having several different dimensions changed from the other objects, such as color and size. (Ware, 2012)

4

Methodology

This chapter presents a number of processes and methods that may be used during the thesis. The research of processes and methods was performed to assure that the thesis work followed elaborate methods and used already known knowledge. The research was done to achieve the best possible result in the given time frame. First processes for different areas of design and data visualization are presented. Some of these will be selected in the planning presented in Chapter 5. Thereafter, methodology for conducting literature studies are presented. Finally, methods for user research, prototyping and evaluation is presented. The aim of the thesis which is to create a data visualization that could enable designers to better understand driver behavior was kept in mind when selecting the processes and methods.

4.1 Research through Design

The thesis can be seen as a Research through Design project. Research through Design is a process where design activities are conducted to gain knowledge that contributes to research (Stappers and Giaccardi, 2017). They describe that the process of Research through Design often involves creating a prototype which generates knowledge. Zimmerman et al. (2007) claims that the approach is suitable for interaction designers as they can use their strengths to contribute to research. Gaver (2012) argues for the creation of annotated portfolios as a way of reflecting and valuing the specific nature of design practice and theory.

Forlizzi et al. (2011, p. 824) states that Research through Design “lacks clear expectations and standards for what constitutes “good” design research” and that the method would benefit from “some actionable metrics for bringing rigor in critique of design research”. Gaver (2012) argues that rather than debating over what is the “right” form of research the Human Computer Interaction community should debate over what the appropriate way is to conduct research on its own terms. The design community should aim to create practice aimed research instead of focusing on creating standardized theory. The design research community should take pride in its diversity, explorative elements and ability to create conceptually rich artefacts. Gaver (2012)

4.2 Data Visualization Processes

In this section some different processes for data visualization are presented and discussed. Some of these will be used in the thesis.

Fry (2008, p. 5-6) describes the process of understanding data as containing seven stages - acquire, parse, filter, mine, represent, refine and interact, see Figure 4.1. Acquire refers to the data collection process. Parse is the process of proving structure for the data’s meaning. Filter refers to removing all data that is not of interest. Mine means applying methods from statistics or data mining to find patterns. Represent refers to choosing a visual representation of the data, such as a bar chart or tree. Refine is the process of improving the representation to make the data clear and engaging. Finally, interact refers to adding ways for manipulating the data. Although, these steps are not followed exactly in all projects. (Fry, 2008)

Ware (2012, p. 4) describes the process of visualizing data as consisting of four iterative steps:

1. “The collection and storage of data.”

2. A stage where the data is transformed into a form that is easier to manipulate. Often it contains data reduction to show certain aspects of the data set. Furthermore, data exploration – to change the subset of data that is being viewed can be performed in this stage.
3. “Mapping the selected data to a visual representation”, which is done through the use of computer algorithms that creates the image. Furthermore, input from users can be used to change the mappings or highlight certain aspects.
4. “The human perceptual and cognitive system (the perceiver).” (Ware, 2012)

Ware (2012, p. 5) argues that “[t]he critical question is how best to transform the data into something that people can understand for optimal decision making.” Kirk (2016) describes the process of visualizing data as containing two major parts – *the hidden thinking* and *developing the design solution*. The hidden thinking consists of formulating a brief, working with the data and establishing the editorial thinking. In the working with data step the data is collected, examined and transformed. The latter major part - developing the design solution consists of representing the data in the form of charts and defining their interactivity, annotation, composition and color.

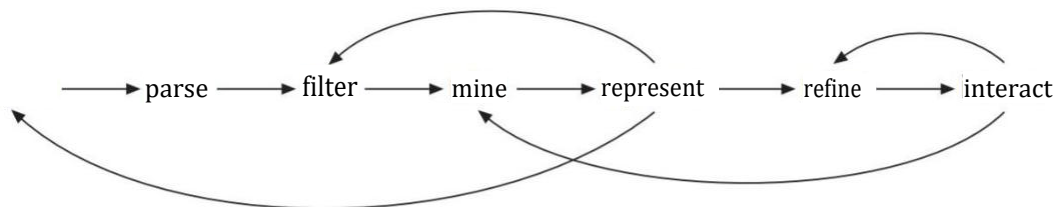


Figure 4.1 The interactions between the steps in the Seven Stages of Visualizing Data process.

(Adapted from Visualizing Data: Exploring and explaining data with the processing environment, Fry, B., 2008, Sebastopol: O’Reilly Media Inc., p. 15.)

4.3 Design Processes for Interaction Design

In this section different design processes for interaction design are presented and discussed. Some of these processes will be used in the planning of the thesis.

4.3.1 Iterative Design

Many authors describe the design process as being iterative. The design process in this thesis will consist of iterations. Hartson and Pyla (2012) presents an iterative UX process lifecycle template which they call the Wheel, see Figure 4.2. Analysis refers to understanding user needs. In the design phase conceptual design is created and interaction behavior and look and feel is decided. The implementation part is the prototyping and finally evaluation translates to testing whether the prototype meets the user needs. In a large view the implementation phase also includes production of hardware and software. The Wheel does not have to be followed in a specific order nor does all of the activities be conducted. (Hartson and Pyla, 2012)

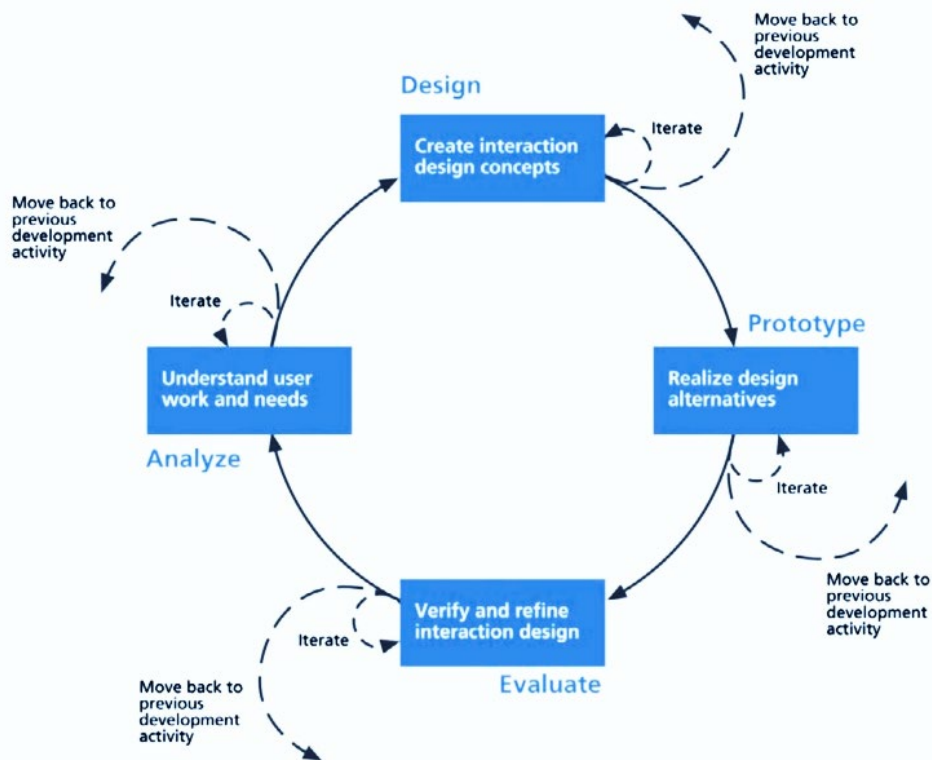


Figure 4.2 The Wheel: an iterative UX process lifecycle template. (Adapted from *The UX Book: Process and guidelines for ensuring a quality user experience*, Hartson, R. & Pyla, P., S., 2012, Waltham: Eslevier, p. 54.)

Preece et al. (1994 p. 54) presents a Simple Lifecycle Model for Interaction Design, see Figure 4.3. They explain the interaction design process as containing four activities:

Establishing Requirements. The activity of understanding the users and their needs of an interactive product is fundamental to a user-centered design approach and important in interaction design.

Designing Alternatives. Designing alternatives that meets the established requirements is a key activity in the interaction design process. The designing can be split up into two parts, conceptual design and physical design. Whereas conceptual design is outlining what the users should be able to do with the product and the physical design goes into details such as color, icons and sounds.

Prototyping. The most suitable way for users to evaluate interactive products is to be able to interact with them, which can be done through the use of prototypes.

Evaluating. Evaluations with users should be conducted to determine the usability of the interactive product or design. Evaluations involves measuring aspects such as number of errors performed by the user while using the design and whether it meets the requirements. (Preece et al., 1994, p. 54)

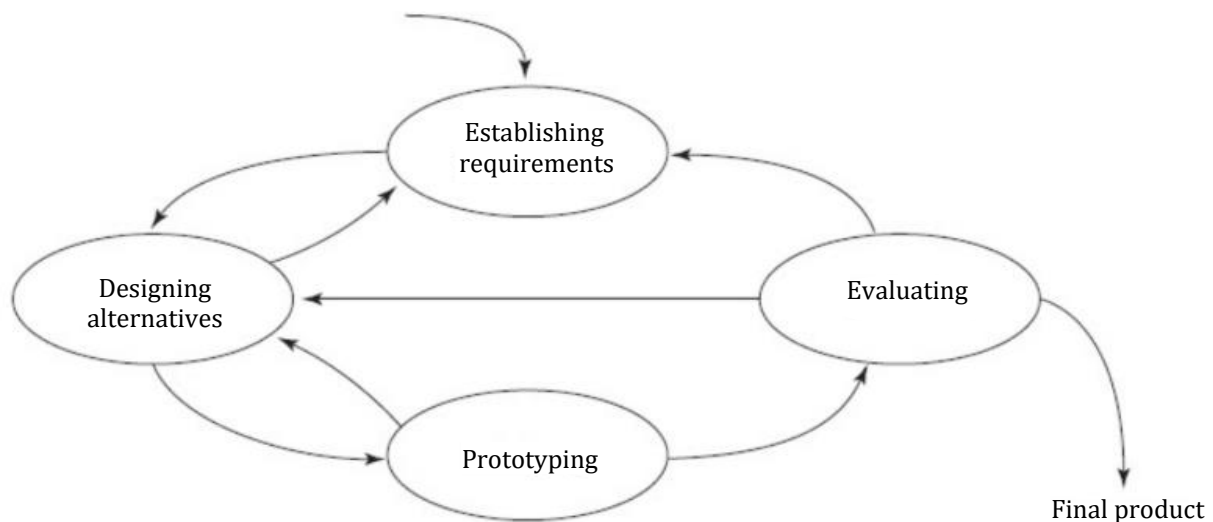


Figure 4.3 The Simple Lifecycle Model for Interaction Design. (Adapted from Human-computer Interaction, Preece et al., 1994, Addison-Wesley Longman Ltd, p. 254.)

4.3.2 User-centered Design

Gould and Lewis (1985, p. 300) defined three principles for designing for usability in 1985 which is the base for user-centered design. These are:

1. *Early Focus on Users and Tasks.* The principle refers to studying the users and the nature of their work.
2. *Empirical Measurement.* This principle refers to involving users early in the design process with using simulators and prototypes to carry out their work. Furthermore, they should be observed and the recordings should be analyzed.
3. *Iterative Design.* Finally, when problems are found during user testing they should be fixed. Therefore the design process needs to be iterative. (Gould and Lewis, 1985)

User-centered Design includes a variety of methods which involves end-users in the process and have a significant impact on the design (Abrams, Maloney-Krichmar & Preece, 2004). One example of a user-centered method is interviewing (Wilson, 2013). Preece et al. (1994, p. 268) describes user-centered design as “the real users and their goals, not just technology, is the driving force behind product development”. The consequence of the user-centered design approach is that the system will be relevant for the users’ tasks and activities instead of limiting them. (Preece et al., 1994)

4.4 User Research Methods

A user study will be performed in the thesis to understand user needs. Goodman et al. (2003, p. 3) describes user research as “[t]he process of figuring out how people interpret and use products and services”. Furthermore, the difference of a product being usable or frustrating often can depend on the conduction of user research (Goodman et al, 2003). A user study is often a combination of user research methods according Preece et al. (1994). In this section some user research methods, such as interviews, are presented and compared. Some of these methods will be used in the thesis to understand the user needs.

4.4.1 Interviews

Wilson (2013) describes interviewing as being used for information gathering about users and their needs. Interviews can be structured or unstructured. A structured interview follows a fixed set of questions and is suitable when the designer is aware of specific problems and wants to collect data about those issues. Unstructured interviews are exploratory and not based on fixed questions. A mixture of the two, semi structured interviews are useful for understanding user goals. Wilson (2013) Unstructured interviews are also called open-ended interviews (Fontana and Frey, 1994).

According to Preece et al. (1994) deciding which approach is the most appropriate depends on several factors - the goal of the interview, which questions should be answered and in which stage of the design lifecycle the interview should be performed. If the aim is to find the users first impressions of a design concept, an open-ended interview is generally a good approach. However, if the goal is to achieve feedback about a specific part of a design concept a structured interview is often a better approach. (Preece et al., 1994)

Preece et al. (1994) and Nielsen (2001) agree that an issue with interviews is that the interviewee's do not always act as they say. Participants might forget what actually happened or how much time they spent on a specific activity. This fact is an important factor of the motivation of the thesis. Although it is difficult to avoid this issue it is important to be aware of it and to reduce biases by planning questions, having many interviewees or by combining several data gathering methods. (Preece et al., 1994)

Preece et al. (1994) describe that interviews can be planned for by creating questions, consent forms, structuring the interview guide, organizing times and places and checking the recording tools. The style of the questions can be open for exploratory interviews and closed where the possible answers are identified beforehand. A semi structured interview can contain both open and closed questions. (Preece et al., 1994) Robson (2002) argues that questions should not be compound sentences, since it can be confusing for the interviewee to answer. The questions should be neutral so that the participant can express their real opinions. Furthermore, interviews should not contain jargon or complex languages since it might make the interviewee uncomfortable. (Robson, 2002) A pilot study with peers can be conducted before the main study to quickly test out interview questions and practical matters like recording equipment (Preece et al., 1994).

4.4.2 Focus Groups

Preece et al. (1994) explain that interviews are commonly performed with one interviewee and one interviewer yet conducting interviews in groups is also common. A focus group is a kind of group interview that is common in political campaigning, marketing, and social sciences. Focus groups usually involves three to ten participants and a trained facilitator who steers the conversation. A benefit of the method is that sensitive or diverse issues can be raised. It is the facilitator's role to make sure everyone's opinions are heard regardless of personality traits. The discussion often is recorded so that it can be analyzed afterwards. (Preece et al., 1994)

4.4.3 Observations

According to Preece et al. (1994) observations can be used at any time in the design process. If observation is conducted in the beginning of the design it helps the designers to understand the users' goals, tasks and context. If observation is conducted in the later stages of development, it may be used to evaluate whether the prototype helps the user with her tasks and goals. If the users are observed when they are conducting their activities the observation is direct and if the user is recorded the observation is indirect. Direct observations in the field are good for understanding

the context of the user activity. Observations can also take place in the field or in a controlled environment. It is difficult for interaction designers to get the full picture of what a user is doing without observing the users, since it can be hard for them to explain what they do in an interview. A downside to observing users is that it can result in a lot of data, all of which is not relevant if not planned thoroughly. (Preece et al., 1994)

4.4.4 Questionnaires

Preece et al. (1994) explains that questionnaires are common for gathering demographic data and data of users' opinions. The questions need to be formulated in a way that makes it possible to analyze the answers, which takes skill and effort. However, questionnaires are suitable for getting answers to particular questions from a large set of people and especially if the participants are spread out all over the world and it is difficult to visit each and every one of them. (Preece et al., 1994)

4.5 Analysis Methods

There exist several research methods for analyzing research findings. This section presents some of them that will be used in the thesis.

4.5.1 Affinity Diagramming

Pernice (2018) describes Affinity Diagramming as a suitable method to analyse research findings. The method stems from the KJ diagramming method. Affinity diagramming involves organizing similar facts, such as observations from a research study into groups. The method often is performed in two steps – writing facts on notes and analyzing and structuring the notes. (Pernice, 2018)

4.5.2 User Stories

User stories represent small instances in user's lives and are used in design process by designers to empathize with the users (Interaction Design Foundation, n.d.). User stories should be based of qualitative data from for example interviews and observations (Interaction Design Foundation, n.d.).

4.6 Prototyping Methods

Prototyping will be performed in the thesis. Hartson and Pyla (2012) says that prototyping can be seen as a form of design representation. Prototyping can be used to effectively test ideas and gain knowledge about a concept before it is entirely implemented. Furthermore, prototypes can be low fidelity and high fidelity. Low fidelity prototypes do not have the look and feel and same level of detail as high fidelity prototypes. One example of low fidelity prototyping is sketches on paper. (Hartson and Pyla, 2012) Sketching ideas is helpful in data visualization (Kirk, 2016). Low fidelity prototypes can be used for discussing plans and be used to as a communication tool when understanding stakeholder's expectations of the visualization (Kirk, 2016). Hartson and Pyla (2012) argue that the advantages with low fidelity prototypes are that they are less expensive since they take much less time to create. Low fidelity prototype can be produced and iterated several times in a fraction of the time one high fidelity prototype takes to create. High fidelity prototypes are detailed representations of design which contains look and feel and decision of behavior. High fidelity prototypes are good for evaluating concepts with users. This since the users can get a sense for the

realism of the concept. Even though high fidelity prototypes takes longer time to create than low fidelity prototypes, they are less expensive than programming a full interface. (Hartson and Pyla, 2012)

4.7 Evaluation Methods

Evaluations of the prototypes will be performed to ensure that the dashboard meets the user needs. This section explains some of the existing evaluation methods in interaction design that may be used in the thesis.

4.7.1 Formative and Summative Evaluations

According to Hartson and Pyla (2012) evaluation of interfaces are often referred as user testing. However, they argue that it should be called User Experience (UX) testing. It is a more polite term since it is the interface that is tested, not the user. Evaluations can be either formative or summative and are used for different purposes in the interaction design process. Formative evaluations can be used during the design process to form the design concept and that the type have mostly a diagnostic purpose. Formative evaluations can be used to collect qualitative data from users to locate potential problems that they might have with the design. The summative evaluations can be used to sum up the design and therefore they are performed at the end of the design process. The aim of the summative test is to find the design's level of quality. (Hartson and Pyla, 2012)

4.7.2 Usability Testing

Usability testing as a process in which the test participants represent the target audience (Rubin and Chrisnell, 2008) Landauer and Nielsen (1993) argues that testing with five users results in the finding of 85% of the usability problems, see Figure 4.4. However, the Abras, Maloney-Krichmar and Preece (2004) claims that the number of test participants depends on the tools used and tasks performed during the tests.

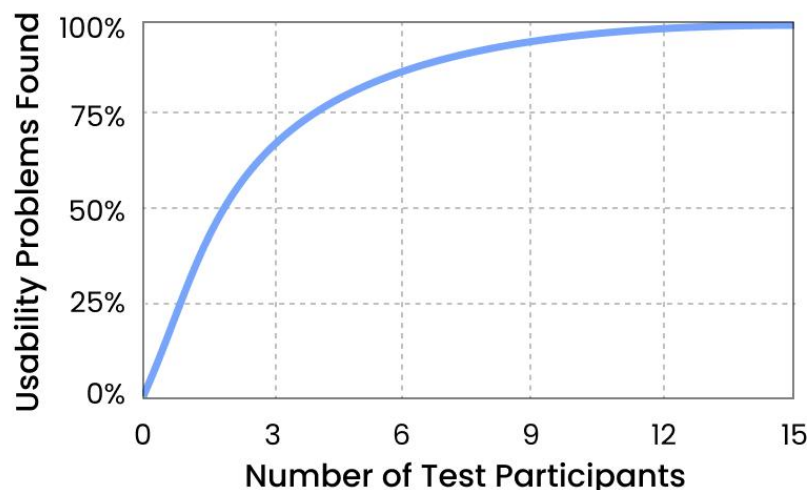


Figure 4.4 Landauer and Nielsen (1993) has created a formula that shows that testing with five users find 85% of the usability problems.

(Adapted from Why You Only Need to Test with 5 Users, Nielsen, 2000, <https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/>)

4.7.3 Thinking Aloud Testing

Nielsen (1993) argues that Thinking Aloud might be the most important usability engineering method. Nielsen (2012) explains Thinking Aloud Testing as asking users to use a system while describing out loud what they are thinking. This should be done while the participants are performing a set of tasks. The method can be used to understand what the users think of the system. Thinking aloud test have several benefits, such as being cheap, robust, flexible, convincing and easy to learn. However, it can be an unnatural situation for the test participants and that the participants might filter what they say. (Nielsen, 2012)

4.7.4 Heuristic Evaluation

The Interaction Design Foundation (n.d.) describe Heuristic Evaluation as a method that can be used to find usability problems of a design. The interface is evaluated against heuristics or usability principles instead of with users. It is recommended that the evaluation is performed by five evaluators. It can be time consuming, yet it helps the evaluators to focus on certain problems. Heuristic Evaluations are adapted from Human Computer Interaction in Information Visualization. However, the method is not well defined for information visualization and the evaluator needs to find heuristics that are suitable for information visualization (Interaction Design Foundation, n.d.) Forsell and Johansson's (2010) has recommended a set of heuristics that can be used for Heuristic Evaluations of Information Visualizations, these can be seen in Appendix C.

5

Planning

This section describes how the work in the project was planned to be conducted. The work should be performed over 20 weeks, consisting of four phases, continuous documentation and a final presentation. The planning consisted of the creation of a Gantt chart, see Table 1, and defining tasks for the different phases. The time plan and phases are described in detail below. Furthermore, the planning consisted of initiating the project at the company and deciding on weekly supervisions with the supervisor at Chalmers and advisor at Volvo. Due to the unforeseen pandemic the plan was revised. The changed plan is presented in the end of this chapter.

5.1 Time Plan

A time plan was created for the thesis, see Table 1. The work was decided to follow an iterative design process consisting of initial planning and research, user research, design and implementation (1st iteration), design and implementation (2nd iteration) and continuous documentation. The phases and their tasks are described in detail in the following sections.

5.2 Planning and Research

The first phase of the project was decided to consist of planning and research. The phases and tasks were defined through the creation of a Gantt chart, see Table 1. The tasks in this initial phase was to initiate the project at Volvo Group Trucks Technology, conduct a literature study, write a planning report and learn the data visualization tool Power BI. The purpose of the planning phase was to assure that the work was performed on a solid theoretical and methodical ground. The literature study involved researching methods and theory for design of data visualizations and trucks. Theories and methods were researched and selected for the project.

5.2.1 Planned Processes

A Research through Design approach was decided to be followed. The approach was chosen to gain knowledge in the aims of answering the research question. The process of the thesis would follow Preece et al. (1994) The Wheel: an iterative UX process lifecycle template, as described in section 4.3.1. Furthermore, the steps in Ware's (2012, p. 4) four feedback loops of visualizing data would be used as guidance since it focuses on creating visualizations that people can understand.

Phase \ Week	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Pre Study																				
Initiate project	█																			
Literature study	█	█	█	█																
Planning report		█	█	█																
Learning Power BI			█	█																
User Research																				
Prepare interviews				█	█															
Interviews designers					█	█														
Focus group						█														
Interviews drivers							█													
Transcribe & analyze							█	█												
Design & Implement I																				
Working with the data								█												
Low-fi sketching								█	█											
Formative evaluation									█	█										
Implementation										█	█									
Formative evaluation											█	█								
Design & Implement II																				
Low-fi sketching												█								
Formative evaluation												█	█							
Implementation																				
Prepare evaluation																				
Summative evaluation																				
Transcribe & analyze																				
Documentation																				
Report	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
Diary																				█
Presentation																				

Table 1 Gantt chart of the project with its different phases; plan and research, user research, design and implement (1st iteration), design and implement (2nd iteration) and documentation.

5.3 User Research

The second phase of the project was planned to consist of user research. The aim was to find user needs for the data visualization dashboard in order to create a useful application. Researchers agree that including users early in the design process results in a better outcome (Chiang, 2009). It was decided to use a combination of data gathering method: interviews, a focus group and further on in the project evaluations with users to overcome the issue that interviewees do not always do as they say, as described by Preece et al. (1994) and Nielsen (2001). As suggested by Preece et al. (1994) a combination of data gathering methods might help solve the problem.

It was planned that the project should include around six exploratory interviews with the end-users of the visualization. The aim of the interviews is to understand the user goals and therefore semi structured interviews would be used. According to Wilson (2013) semi structured interviews are useful for understanding user goals. Furthermore, two semi structured interviews with truck drivers would be performed. Ideally these would include observations with the truck drivers. They would be direct in the field since direct observations are good for understanding the context of the users (Preece et al. 1994). However, because the truck transported dangerous goods this was found not to be possible because of safety. Therefore, pictures of the truck interior was planned to be brought to the interviews. Questionnaires would not be used since the future users of the data visualization was around ten people working at Volvo in Gothenburg and all would be included in the focus group.

The interviews with feature and ergonomics specialists were planned for through booking meeting slots via mail. Preparation of the interviews would consist of creating semi-structured interview guides and consent forms. Furthermore, it was decided how to record the interviews. Which ethical aspects that needs to be considered was also considered, such as GDPR. The interviews with the Volvo employees and truck driver was decided to be audio recorded with a dictaphone. The recordings would be transcribed and analyzed with affinity diagramming.

5.4 Design and Implementation 1st iteration

The fourth phase of the thesis was planned to consist of a first iteration of design and implementation. First, the raw data would be examined and mapped to the right functions as suggested by Kirk (2016). Secondly, several low fidelity sketches of chart ideas and compositions would be created and formatively evaluated with a couple of end-users at Volvo. During the design process guidelines and theory of data visualization would be followed. The formative evaluations would be audio recorded, transcribed and analyzed. Alterations to the design would be made according to potential issues.

After the sketching, the visualization would be implemented with the visualizing software Power BI. The steps in Ware's (2012, p. 4) four feedback loops of visualizing data would be used as guidance during the implementation. However, the first step - to collect and store data was already conducted by Volvo before the thesis started. The company had collected data through logging equipment in a test truck. The second stage to transform the data into a form that is easier to manipulate and change was partly initiated by Volvo. Before the thesis had started Volvo had brainstormed and selected what data that was going to be collected. However, further transformation of this data was planned to be done. A data analyst at Volvo would support the thesis with data cleaning and transforming that needed to be done to the data before visualizing it. The help would enable the thesis to focus on the interaction design aspects of the visualization dashboard. The data analyst would for example remove empty values and sample down the size of the data sets.

Furthermore, the third and fourth stages in Ware's (2012, p.4) four steps of visualizing data would be followed. These are, mapping the data to a visual presentation through the input of users (Ware

2012, p. 4). However, instead of using algorithms to construct the images the visualization tool Power BI was decided to be used. The tool was chosen because it was available at Volvo and can be used for creating interactive data visualization dashboards (Microsoft, n.d.). A data scientist working at Volvo would help clean the data so that it could be presented in Power BI. Lastly, the visualization dashboard was planned to be formatively evaluated with a few users to investigate if the viewer could understand driver behavior better with the help of the visualization. The tests would be recorded, transcribed and analyzed with affinity diagramming.

5.5 Design and Implementation 2nd iteration

The final phase was planned to consist of a second iteration of design and implementation. Many researchers support the idea to perform design iterations. The potential problems found in the formative evaluation of the visualization dashboard would be addressed in this phase. First a low fidelity prototype with alterations and possibly more data visualizations would be created. This prototype would be formatively evaluated with a couple of feature specialists at Volvo. Thereafter, possible alterations would be made to the prototype based on the findings in the formative evaluation. The interactive data visualization created in the first iteration of implementation would be altered and possibly filled with more visualizations. The final step in the process would be a summative evaluation. The summative evaluation should first be prepared for through creating a test guide with tasks that the users should perform. The evaluation should aim to include at least five users, since Nielsen (2002) explains that five users are enough for finding 85 % of usability problems. The users should be asked to think aloud. The think aloud method has benefits of being cheap and gaining knowledge of what the users think of the system (Nielsen, 2002). The tests should be recorded, transcribed and analyzed.

5.6 Revised Plan

Due to the Corona virus pandemic it was not possible to continue as originally planned. The Volvo employees were on a six week short term lay off and were not allowed to work by law. The plan for the final weeks was therefore revised. A high fidelity prototype would be created before implementing what was possible without the help of the data analyst at Volvo. In this way the thesis would not end up without a dashboard design. The high fidelity prototype and implementation would still be tested with users. However, these would not have expert knowledge and the tests would therefore focus mostly on the usability of the dashboard. The last four weeks would be used for finalizing the report and preparing for presentation as originally planned. The revised plan for weeks 14 to 19 is presented in Table 2 below.

Week	Phase	Tasks
14	Design 2nd iteration	Create a high fidelity prototype in Figma from initial sketches and user feedback.
15	Design 2nd iteration	Perform formative evaluation consisting of usability tests and a Heuristic Evaluation. Make changes to the prototype based on found problems. If time over start implementation.
16	Implementation	Change the data to the right form with the use of Python in Jupiter Notebook and Power BI. Implement possible visualizations in Power BI.
17	Implementation	Implement possible visualizations in Power BI.
18	Implementation	Continue to implement possible visualizations in Power BI.
19	Summative evaluation	Prepare for evaluation and conduct summative evaluation with at least five participants through video call. Analyze the results.

Table 2 Due to the Corona virus pandemic the plan was revised. A phase of high fidelity prototyping was added to ensure that a design of a dashboard that focused on interaction design aspects was created.

6

Execution and Process

The process of the thesis consisted of four phases: pre study, user research, design and implementation 1st iteration and design and implementation 2nd iteration. The thesis took a Research through Design approach in the aims of answering the research question. The phases and their tasks are presented in this section.

6.1 Pre Study

A pre study was conducted in the initial stages of the thesis. The study consisted of a literature study and interviews and research regarding the logged truck data. The phases are described below.

6.1.1 Literature Study

To make sure that the thesis was grounded on a solid theoretical and methodical ground a literature study was performed. Furthermore, to assure that the project contributed with new research related work was researched. In addition to finding methods, theory and related work guidelines for how to design data visualizations to facilitate understanding were used. The sources for finding literature were Chalmers Library (<http://www.lib.chalmers.se/>) and Google Scholar (<https://scholar.google.com/>).

Methods and theories for the thesis was found in books and articles that were used in the Interaction Design and Technologies master program at Chalmers, together with complementary research found at Google Scholar and Chalmers Library. To find related work keywords such as data visualization, information visualization, driver behavior and automotive was used in different combinations. Literature from related areas such as web analysis was also researched since there was a gap in the research of using data visualization to facilitate for understanding of driver behavior. References that were of interest in the found literature were further researched.

The data visualization design guidelines were also found at Google Scholar and Chalmers Library. The main sources for guidelines were Information Visualization: Perception for Design by Colin Ware (2012) and Andy Kirk's A handbook for Data Driven Design (2016). Ware (2012) explains the human visual perception which is important to understand in order to facilitate understanding through data visualization and Kirk (2016) provides practical examples of how to use data visualization to facilitate understanding.

6.1.2 Research of the Logged Truck Data

Several unstructured interviews with two data analysts were held to understand the logged truck data. The questions regarded which signals were linked to what physical buttons and truck ECU's. These interviews were vital for understanding what data was available for later implementation. Furthermore, the logged signals of functions and buttons were found in the Volvo FH's Driver book (Volvo Trucks, n.d.) and written down. This phase was also conducted to have an understanding for the truck functions and controls before conducting the interviews. With this knowledge, probing questions could be asked during the interviews instead of questioning statements.

The logged data comes from ECU’s in the truck. The controls that were logged were most of the physical controls in the truck except for the bunker bed control panel and the door control panel. However, all functions that the controls steers were not logged. The available data from functions were from some traction, cruise, safety, climate, lights and audio functions. Situational data such time, GPS and speed were available. Other logged data was brake and gas pedal positions and steering wheel angle.

6.2 User Research

The user research was performed to find user needs for the data visualization dashboard. User research is according to Preece et al. (1994) is vital for user-centered design and important in interaction design. Furthermore, Chiang (2009) argues that in order to create a successful dashboard the users and business analysts should be involved in the beginning of the design process. The user research phase consisted of interviews and a focus group which are described in detail below.

6.2.1 Interviews

Seven semi structured interviews were held, see Table 3. Five of the interviews were with designers at Volvo, or feature specialists as they call themselves, one was with an ergonomic specialist at Volvo and the last interview was conducted with the driver of the logged truck. All interviews were recorded with a dictaphone to enable translation. In this way important details in the conversation were not missed. All interviews followed semi structured interview guides. Probing questions were used to understand the interviewee better. All the interviews were started with an introduction to the project and the purpose of the interview. Thereafter, the interviewee was asked whether they agreed to audio record the interview. Furthermore, they were told that the recordings would only be listened to by the thesis worker and that the data would be anonymized and deleted within two weeks.

Participant	Profession	Interview duration
1	Feature specialist	45 min
2	Feature specialist	40 min
3	Feature specialist	45 min
4	Feature specialist	1 h
5	Feature specialist	1 h 15 min
6	Ergonomics specialist	1 h 5 min
7	Truck driver	1 h 30 min

Table 3 The interviews were conducted with six specialists at Volvo and one truck driver. Each interview lasted around one hour.

6.2.1.1 Volvo Employees Interviews

The goal of the interviews with the specialists was to understand what they needed to know in their daily work to better understand driver behavior. The meetings took place in meeting rooms in Volvo Lundby. The interviews followed the interview guide, see appendix A. The first question was open and regarded what the interviewee works with. It is a fact that they most likely are comfortable with discussing and the aim was to make the participant at ease in the interviewing situation. Thereafter, the participants were asked openly what driver information they felt like they were lacking in their work. Mediating images of the truck interface was not shown until after this question. They were showed after to not steer their answer in to only include the logged gas truck. Since the feature specialists often are responsible for an area of functions, such as the climate panel or the traction functions their answers were often specific to their responsibility areas. However, some interviewees were interested in everything. One participant stated:

"Please just show us frequency and time of use!"

A few of the participants wanted to know what and why the driver behaves the way they did. However, the need of knowing why drivers act in a certain way is difficult to explain with the use of quantitative logged truck data visualization. Several of the participants expressed frustration of not knowing enough about a large set of users. Some examples of quotations showing the need to know what controls and functions the driver uses are:

"If they use the controls as we think that they use them".

One participant explained the motivation for the thesis and need of the data visualization in one sentence:

"We have too vague documentation. We are guessing too much. It is based on what we think."

The ergonomics specialist expressed similar areas of interest. However, the purpose behind the need differed from the feature specialists. One example of such a statement is:

"We want to know how often the driver reaches for different parts of the instrument panel. As an example, if it is important to prioritize that the climate controls or the radio is easily reached."

6.2.1.2 Truck Driver Interview

The purpose of the interview with the truck driver was to understand the context of the data and the driver behavior according to the driver. From the start it was planned to conduct interviews with two drivers. However, one driver was on sick leave, so it was not possible. The interview was held inside the truck that was used for the logging, which was parked in a workshop at Volvo Trucks in Lundby. It was not possible to ride along while the truck driver was driving since the gas that he transported was marked as dangerous goods. The interview was semi structured and followed an interview guide, see appendix B. The questions regarded the truck driver's daily work, habits and behavior. The interview was conducted to enable a reflection of the validity of the logged data and whether the driver's statements of their habits matched the logged data. As many users do not always do as they say (Nielsen, 2001) it would be of interest to compare the drivers answers to the logged data.

The driver estimated that the controls he used the most frequently was Cruise Control, bogie lift, power outlet (PTO) and the stalks behind the steering wheel. He said that he did not use adaptive cruise control, only the standard cruise control. However, the driver explained that he did not use many of the functions in the truck. He stated that many of the functions did not work or he could not trust that they would work. As stated the truck is a field test truck which Volvo uses to test new functionality. Many of the functions does not work correctly because of this fact.

6.2.2 Focus Group

The focus group was prepared for through creating a schedule of activities. The meeting was planned to consist of an introduction of what the project is about, what data is available, a description of the brainstorming session, inspiration, review of their sketches and a final summary. The session took place in a meeting room at Volvo Lundby the 26th of February. It lasted for two and a half hours. The details of the focus group is described below.

6.2.2.1 Participants

The group consisted of eight individuals, six males and two females. Seven of the participants worked as feature specialists at Volvo and one was an intern. Two of the feature specialists had been interviewed before. The participants had varied experience within the truck industry. Furthermore, they worked with different areas of the truck. Seven of the individuals had Industrial Design Engineering background or Ergonomics background. They had experience of sketching from their education. However, in their daily work at Volvo they did not sketch at all. The feature specialists were responsible for different areas of the truck interface, such as the traction, safety and media controls.

6.2.2.2 The Session

A PowerPoint presentation was used to introduce the project and brainstorming session. The facilitator presented, kept time, steered the conversation and took notes of the meeting. First, an agenda was shown and the session's sections was briefly explained. Thereafter, an explanation of the master thesis purpose and deliverables was given. The logged truck was displayed for the participants and they were given a background information about the truck. Thereafter they were shown pictures of the logged truck interface signals and surrounding signals. The pictures were shown to refresh their memories of which functions and buttons the truck contains. Furthermore, the participants were shown inspirational images of a visualization dashboard and diagrams that could be used to show change over time, correlation, categorization and distribution. The charts were shown to enable the participants to focus on what data they were interested in seeing instead of being blocked by not knowing how to visualize it.

The participants were asked to draw diagrams and ideas of what could be of interest to visualize, see Figure 6.1. The group was told that it is not the type of diagram that was used that was of interest. Moreover, what kind of data they were interested in seeing. They were told that it is unimportant that the sketches looked good and if they felt that it was too difficult to draw they could write down their ideas. The statement was made to relieve the participants from some pressure to perform well and make them more comfortable in the situation. For 40 minutes the participants brainstormed and sketched. After the brainstorming session a short break was taken.

After the break, the participants were asked to explain their drawings one by one. The facilitator asked the participants if they agreed to record the discussion and explained that the recordings would be deleted within two weeks. The listening participants were told to pitch in if they had anything to add to the presenter's ideas. The ideas were often tailored to the participant specific working area. One idea was showing different functions in relation to road types in a combination of a matrix and bubble chart. One participant wanted the visualization to show all data that is available from the truck and that the viewer should be able to do the analysis on their own with the use of filtering and queries in the visualization dashboard.

Then the brainstorming was summarized with four questions:

1. What groups of controls or functions are of the most interest?
2. What situations are of the most interest?
3. What data would be interesting to log in the future that is not logged now?

4. What trucks would be of interest to log in the future?

The group's answers were used in the analysis that would result in the user needs.

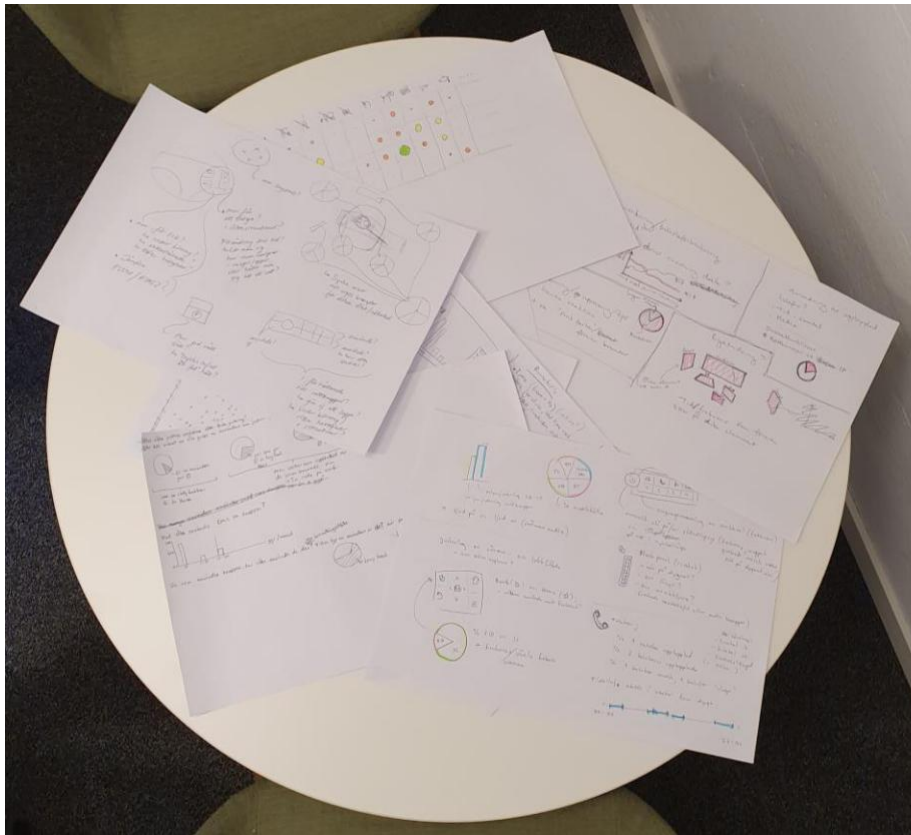


Figure 6.1 The sketches of data visualization that were created by the participants during the focus group's brainstorming session.
(Photo by the author)

6.2.3 Analysis

First, the interviews and focus group were transcribed through listening to the tapes and writing down important quotations. Thereafter, the data was analyzed through creating an Affinity Diagram, user stories and the available data was prioritized. The stages are described in this section.

6.2.3.1 Affinity Diagramming

The quotations of interested were written down in a spread sheet. Groups of similar statements started forming and after time names were given for the groups. The groups were dashboard, steering wheel, stalk, interior and exterior light controls, gears and steering wheel, context, designers' and chauffeurs' lack of knowledge and future logging of trucks and signals. Examples of important quotations are:

"Do they use auto on climate. Manufacturers want their users to use their automatic modes. So that is interesting to know."

“For example, the traction systems that we have. I have ridden along with drivers and the first thing they do is to deactivate the security systems because they do not like the sound of them and get annoyed by them. And when I asked them what they did there they reply: What do you mean? I did not do anything. Because they do it automatically and do not even think about it.”

6.2.3.2 Creating User Stories

The affinity diagram was used to create user stories that represent the user needs and their motivation. The number of participants that had the same need was written in parenthesis in the end of the user story. The numbers were added to make it easier to prioritize which needs should be taken into account first. One example of a user story is:

As a feature/ergonomics specialist I want to know the usage frequency of different controls so that I can create requirements to improve the user experience. (All)

All user needs are described in Appendix F.

A reflection of how well the feature specialist knowledge and opinions of the functions and controls compared to the drivers was made during the analysis. There were some examples of quotations that demonstrated the feature specialist’s needs of knowing more about the driver behavior. As an example, many thought that the logged truck that was driving dangerous gas was driving on small roads with hills. However, when speaking to the chauffeur it was found that trucks that transport dangerous goods are not allowed to drive on those kinds of roads. The interviewees themselves also stated that they lacked knowledge of the driver behavior and usage of controls and functions.

6.2.3.3 Data Prioritization

The available logged truck data was prioritized based on the number of participants that had expressed the same need, the controls that had a critical layout, estimated time for data analysis and what is feasible for logging on a larger scale in the future. The prioritization was done to make sure that the most important needs were accommodated for in the given time frame. The prioritization is described below.

Controls

1. Steering wheel controls
2. Stalks
3. Backlight and black panel
4. Gearbox
5. Infotainment control panel
6. Flexible Switch Panel in the dashboard
7. Climate Panel
8. The controls in the panel above the driver seat
9. The rest of the exterior lights and flexible switches

Although the Flexible Switch Panel in the dashboard was of interest for many of the feature specialists, it was less prioritized because the data analysis of the switches was difficult. The difficulties are due to the switches being flexible and therefore do not send their names as signals but rather “FSP1”.

6.3 Design and Implementation 1st iteration

The first iteration consisted of creating low fidelity sketches, formatively evaluating the sketches, implementation in Power BI and formatively evaluation the implementation. It was decided together with the supervisor and a data analytics employee to start with the data that was easiest to transform and thereafter build on with more data in the second iteration. Therefore, the Flexible Switch Panel was not considered for the controls in the first iteration.

6.3.1 Low Fidelity Sketching

The sketching started off with brainstorming different ideas that would suit the most important user needs while following data visualization guidelines. Furthermore, the limitations of what was possible to implement in Power BI was taken into account. Thereafter, different layout alternatives for the grid layout of the dashboard was quickly sketched. Since Volvo employees have stationary 21-inch computer screens the design was optimized for this screen size.

After the initial brainstorming paper prototypes were created. A blank paper was used as a background and cut out cards of charts were taped on the paper. In this way the cards could be moved around to test different layouts. Paper prototypes were used in aims of making the sketching more efficient. The initial prototype, see Figure 6.2, shows a map, a bar chart of function usage time, a bar chart of amount of used controls, a filtering pane and information about the logged truck. Color coding was used in the charts to distinguish categories in accordance to Material Design guidelines (Google, n.d.). However, the hue, value and saturation of the colors depended on the available pens and would be changed in the implementation. Since the user needs were diverse and many of them specific it was challenging to design a visualization that would fit each user. Although, all interviewees were in need of knowing frequency of clicks on controls and function activation time. Hence, frequency and time of controls and functions were considered the most important need which needed to be accommodated for in the design.

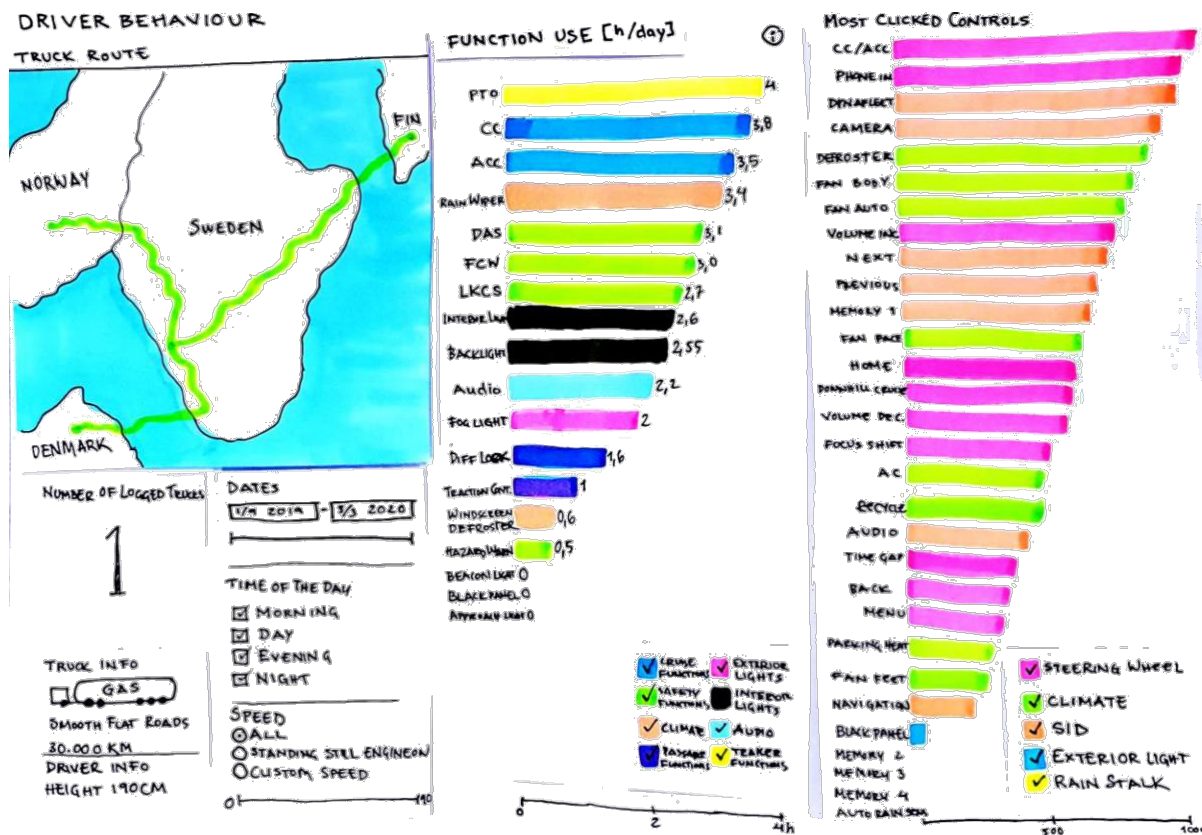
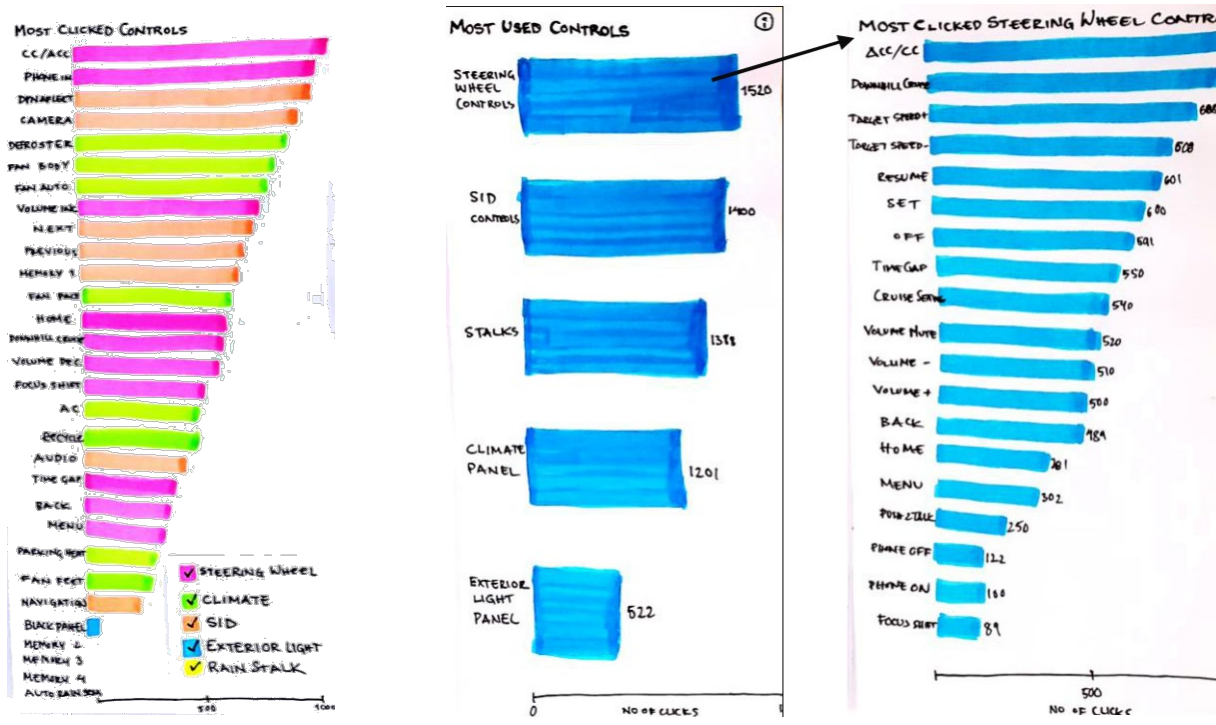


Figure 6.2 Low fidelity prototype of the data visualization dashboard. The prototype contains a map that shows the driver route, information about the logged truck, filtering options, a chart showing function usage per day and control usage all time. (Sketch by the author)

Ordered horizontal bar charts (see Figure 6.3a) were used in accordance with Material Design guidelines. The Material Design guidelines states that horizontal charts can be used since it makes it easier to read the bar labels (Google, n.d). An additional motivation for using bar charts for comparison is Ware's (2012, p. 169) guideline G5.17. G5.17 states that length or height should be used to represent quantity as long as the range of value low. The bars were initially decided to be long and thin to be able to include many controls and functions, see Figure 6.3a. However, since the number of controls were around 60 it was difficult to assess if they would fit in a single bar chart through paper prototyping. Therefore, another alternative containing categories was designed, see Figure 6.3b. The chart in the second alternative first shows the most used controls in categories and the used can interact with the graph through clicking the bars. If the viewer clicks a bar the chart shows detailed data for that specific group of controls, see Figure 6.4. Affordances such as hovering states and pointer cursor would be used to show the available action. Furthermore, a navigation bar was added to the design, see Figure 6.4. The bar was added to explain to the participants that the view was a dashboard overview and more views could be added for the more specific needs if time allows.



(a) The chart shows all controls and can be filtered on steering wheel, climate, exterior lights and rain stalk.

(b) The chart initially showed categories of controls, which is illustrated on the left. If the user clicks a bar the controls in that specific category is shown, which is illustrated to the right above.

Figure 6.3 Alternatives of the most used controls chart. (Sketches by the author)

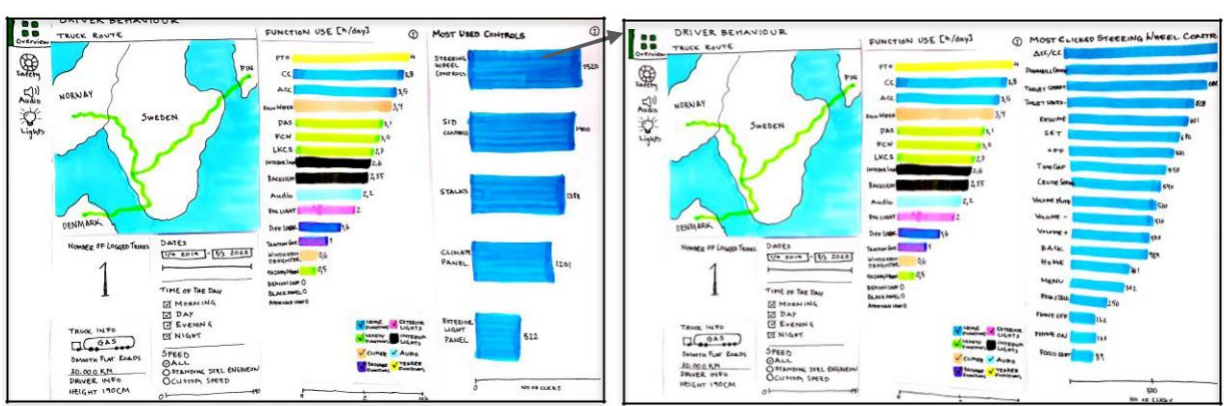
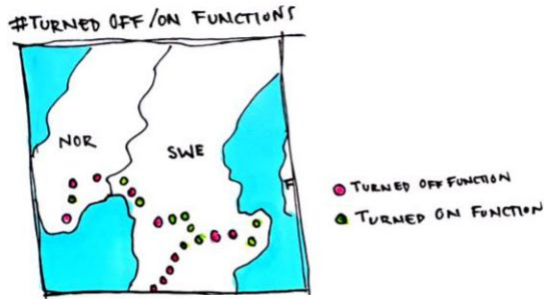


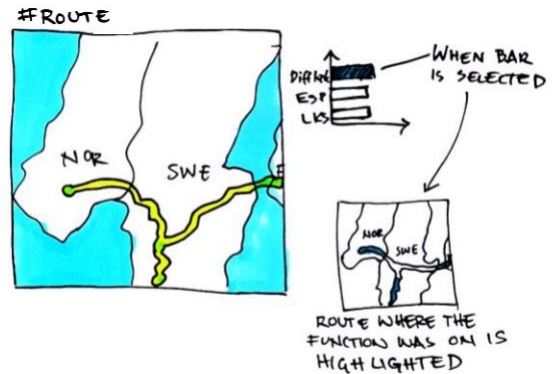
Figure 6.4 The second alternative of the most used controls chart to the right. First the categories are displayed and if a user clicks a bar a more detailed chart is shown. Furthermore, a navigation bar to the far left was added to the design. The navigation bar could in the future iterations contain other dashboards of specific areas. (Sketches by the author)

Many interviewees expressed a need for knowing where different functions were activated and deactivated. Therefore, alternatives of interactive map visualizations were sketched, see Figure 6.5. As the users wanted to know where and when the functions were turned off a map showing this was sketched, see Figure 6.5a. The second map alternative allows the user to see where a

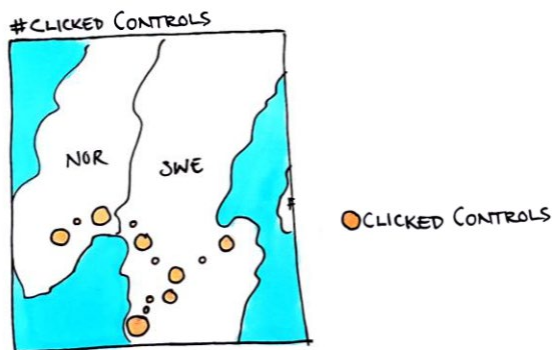
specific function was turned on, see Figure 6.5b. As the specialists wondered in which situations different controls were used two map alternatives that showed amount of used controls were ideated, see Figure 6.5c and Figure 6.5d. The idea was that an area of the map could be selected with the cursor, see Figure 6.6 and the charts would be filtered on that area. The alternatives shows activated and deactivated functions respective clicked controls with the use of circles on maps. However, it was difficult to foresee how the map would look when implementing the visualization with real data.



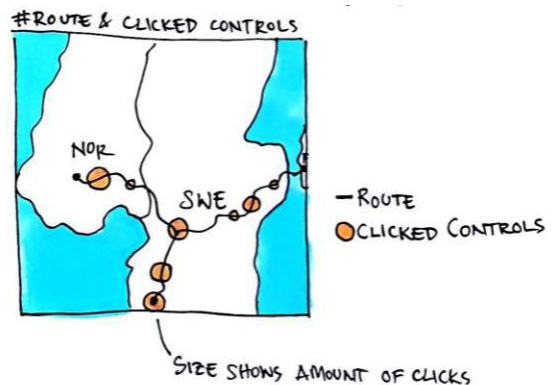
(a) A map alternative where the circles show where the driver has turned on and off functions.



(b) A map alternative where the route is shown as a line. The user select a function to see where it was activated.



(c) A map alternative where amount of clicks on controls are shown as circles.



(d) A map alternative where amount of clicks on controls are shown as circles and route as a line.

Figure 6.5 Different alternatives of maps were ideated that could be used in the dashboard. (Sketches by the author)



Figure 6.6 An example of how an area on a map could be selected to filter the charts showing in the dashboard.
(Sketch by the author)

6.3.2 Formative Evaluation of Low Fidelity Sketches

The initial paper prototypes were shown to two feature specialists and one data analyst at Volvo. Unfortunately, the number of participants in the evaluation was less than initially planned. The participants were less due to the short time lay off caused by the Corona pandemic.

6.3.2.1 Data Analyst Evaluation

To understand what was possible to implement an unstructured evaluation was performed with the data analyst. The data analyst came with an important point that the data needed to be relatable for the viewer. Instead of showing function use and controls clicked all time they could be shown as an average of how many controls were clicked per day. Day averages could be easier to relate to.

6.3.2.2 Feature Specialist Evaluation

The evaluations with the feature specialists were of semi structured characteristics. The aim of the evaluations of the sketches was to understand whether the dashboard showed information that the feature specialists were interested in knowing and if it was a feasible overview. Furthermore, the goal was to understand if the viewer understood the visualizations.

Three questions were asked together with probing questions:

1. Tell me what you see.
2. Is there any information that you are interested in seeing?
3. Is anything unclear?

The participants were first shown the initial prototype containing chart that displays all controls, see Figure 6.2. They were explained that it would difficult to display all controls at once. However, the employees were told that it could be possible to make a scrollable chart. Thereafter they were shown the prototype containing the interactive chart, see Figure 6.4.

Both specialists preferred the first dashboard alternative containing the chart of clicks that shows all controls and ability to filter on categories. They favored that alternative despite the fact that they might not see all bars at the same time. They appreciated the ability to filter the chart on different categories to enable comparison of the categories. They said that it was preferable to be able to choose themselves which controls to compare.

The first employee thought that the two right most charts showing function use and control use should have the same categories. She thought that it created confusion to have different categories and that it was easier to compare the two charts. Furthermore, she stated that the category names should be the same as in the Volvo driver handbook. She thought that the label for the function

use graph should be called “Function active” and that the most clicked controls should be called “Frequency of use”, since it was more used within Volvo.

The first feature specialist did not understand the navigation bar. The specialist thought it was a way of filtering. However, the second participant understood directly that it was a navigation bar. Both participants liked the ability to filter on dates, time of the day and speed. Although, the first specialist were uncertain to if it would affect the entire sketch.

One specialist was uncertain if the ability to select on a map would be of interest for all functions. She said that it was of high interest for traction and retarder functions and possibly cruise control functions. However, they were uncertain if it would bring as much value as time to implement. However, the other employee appreciated the ability to select a specific area on the map to filter. She said that there was a need to be able to select a road and see what functions were used in that specific area. As an example she explained that drivers during interviews had stated that in a specific hill they always use certain functions.

One specialist said that in the future it would be of interest to filter on different types of trucks. The employee said that showing driver height would be difficult because of GDPR. The difficulties to understand certain parts of the interface might be influenced by the fact that the prototype is a sketch.

6.3.3 Implementation in Power BI

After the first iteration of low fidelity sketching and evaluation the first implementation iteration was supposed to be conducted. While the data analyst worked with the data a smaller data set of logged truck data was used to investigate if the design was possible to implement. The possibility to create colored checkboxes was tested. It was found that Power BI did not support colored checkboxes at the time.

Due to the pandemic caused by the Corona virus in spring 2020 the Volvo employees were short term permitted for six weeks. The data analyst who were preparing the data had only prepared the function and GPS data. She was not allowed to work for six weeks and therefore no further help with the data analysis would be given. Therefore, the chart showing the most clicked controls was not possible to implement. Furthermore, the data was not in the correct format. A few days were spent with changing the data in PyCharm with Python. The process was time consuming without the help from the data analyst. When it was realized that it would take a long time it was decided to change strategy. Since the focus of the project is creating a dashboard that accommodates for the found user needs and focuses on interaction aspects the plan was changed. It was decided to create a high fidelity prototype before implementing in Power BI.

6.4 Design 2nd iteration

The second iteration consisted of creating a high fidelity prototype. First, a high fidelity prototype of the overview was created based on the initial sketches and the user feedback. Thereafter a formative evaluation was performed.

6.4.1 High Fidelity Prototyping

A high fidelity prototype of the initial sketches and user feedback was created in Figma. The first step was to decide the target screen size. Since there was a lot of data to show the design was optimized for a 21-inch screen with a resolution of 1920 * 1080. This format was chosen because it is the most common type of screen at Volvo. The dashboard should also be displayed inside Power BI Sharepoint and therefore will lose some screen space to the Power BI navigation. The dashboard was placed inside the Power BI Sharepoint to decide how big it could be, see Figure 6.10.

Thereafter the design was created. The design was created with made up data and for a scenario where more trucks were being logged since the feature specialists were in need of knowing how a larger set of truck drivers behaved in order to draw conclusions. Design decisions were made based on literature and the found user needs. Three alternatives were explored, Figure 6.7, Figure 6.8 and Figure 6.9.

6.4.1.1 Color Selection

Color coding of the function categories was explored. The original idea was to color code each area of controls in the truck interface. The coding resulted in nine categories which were too many. The categories were grouped into bigger categories. The grouping resulted in seven categories which were tested in a prototype, see Figure 6.7. Labels of the color categories was also tested, see Figure 6.9. However, the labels took up unnecessary space. It was also found during the first implementation phase that colored checkboxes was not a supported feature in Power BI. Furthermore, Wilke (2019) suggest that color coding categories works best for around three to five categories. The prototype showed that it was difficult to distinguish the seven categories. Therefore, it was decided to not use color coding as a way to distinguish function categories. With literature supporting the choice and knowledge about limitations in Power BI the alternative with same colored function categories, see Figure 6.7, was chosen to proceed with.

The colors that were chosen were based on knowledge from the literature study. Wilke (2019) states that intense saturated colors can distract the viewer. Therefore, less saturated colors were chosen for the visualizations. Ware (2012) color guidelines G4.2, G4.12 and G4.14, described in section 3.3.3 describe that colors needs to be accessible for color blind persons. To ensure that the colors was distinguishable by color blind persons the color were tested with the Figma plugin Color Blind, see section 2.4. It was found that the initial chosen colors was difficult to see for many types of color blindness's, see Figure 6.11. The bottom-most truck in Figure 6.11 was changed to a red shade, see Figure 6.12. The test showed that the red color was easier for color blind persons to distinguish. Thereafter the colors were tested against the map background, see Figure 6.13. The test revealed that many of the persons affected by color blindness would be able to distinguish the colors. However, the red color stood out among the other blue scale colors and might be interpreted as a highlighting method. The fact would be tested in the summative evaluation.

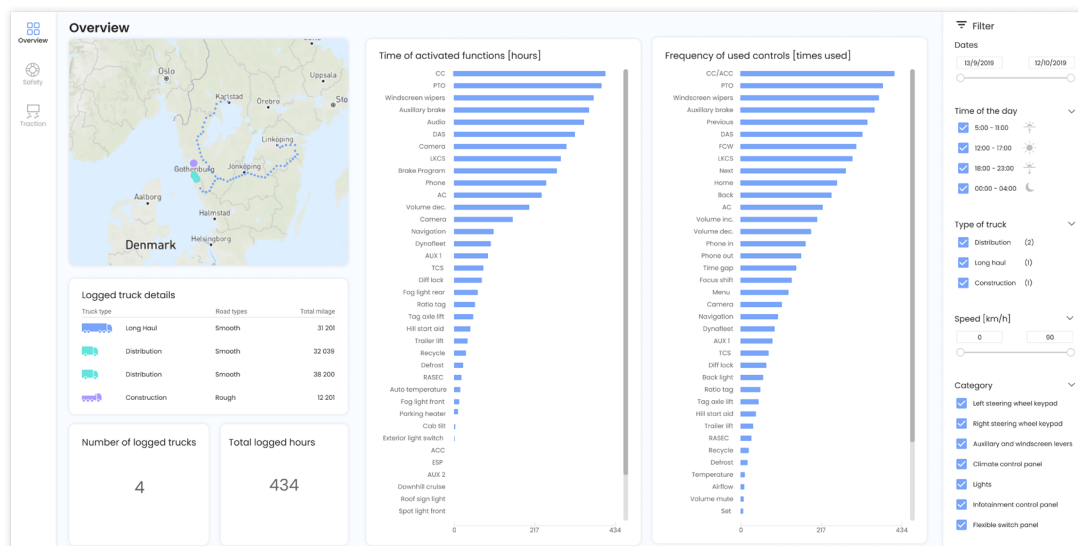


Figure 6.7 The overview dashboard without color coded function and control categories. (Image by the author)

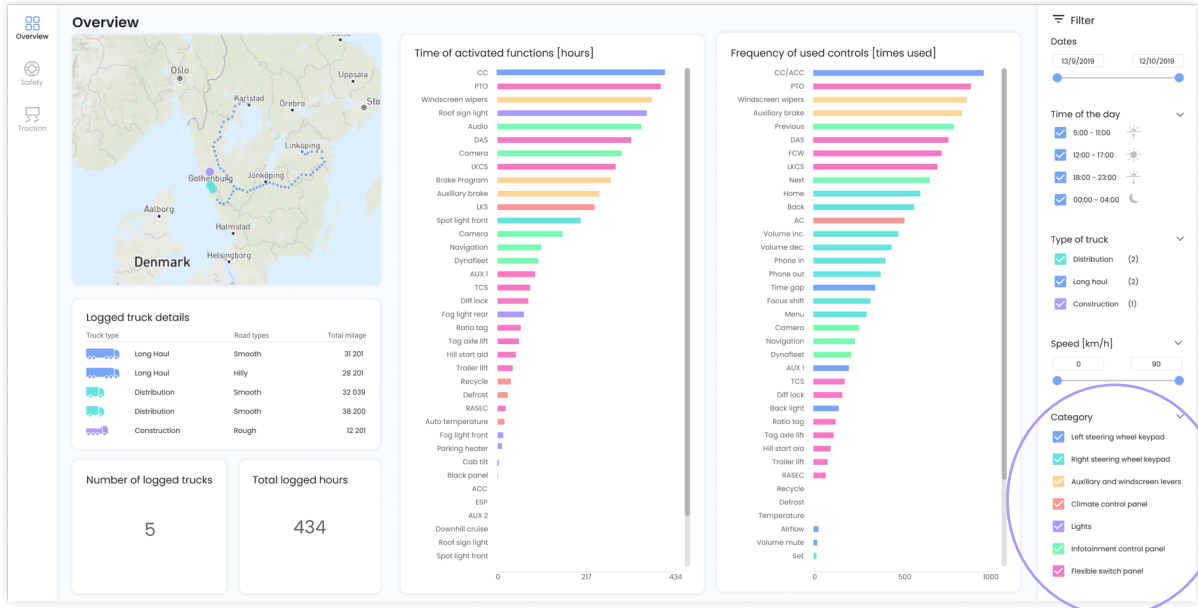


Figure 6.8 The overview dashboard with color coded function and control categories and checkboxes showing category names (marked in purple). (Image by the author)

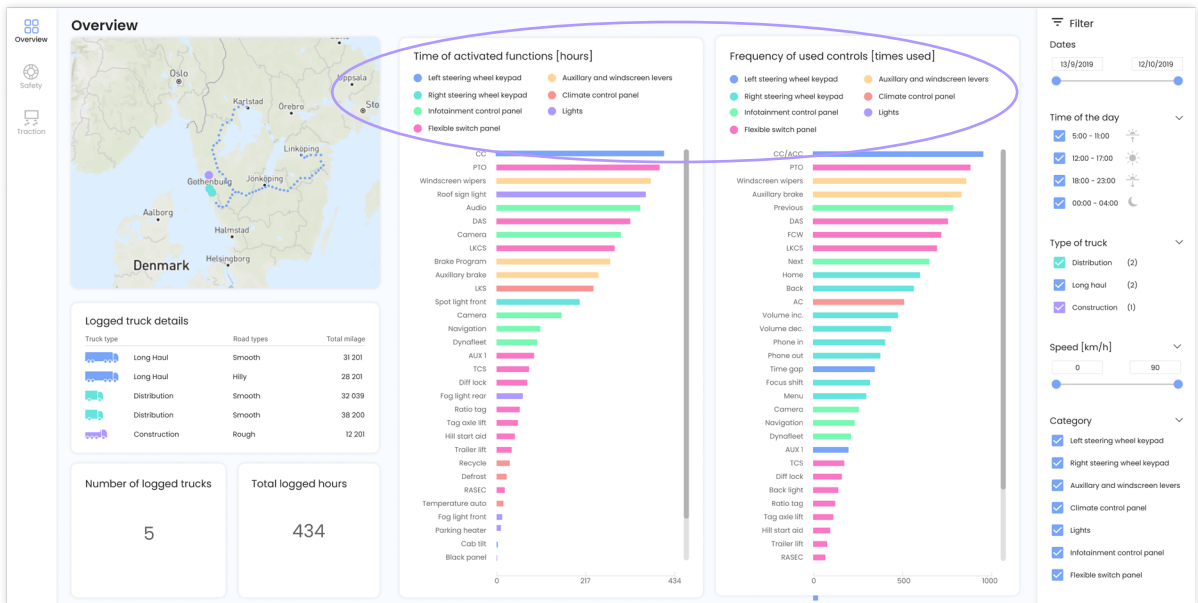


Figure 6.9 The overview dashboard with color coded function and control categories and labels (marked in purple) showing category names. (Image by the author)

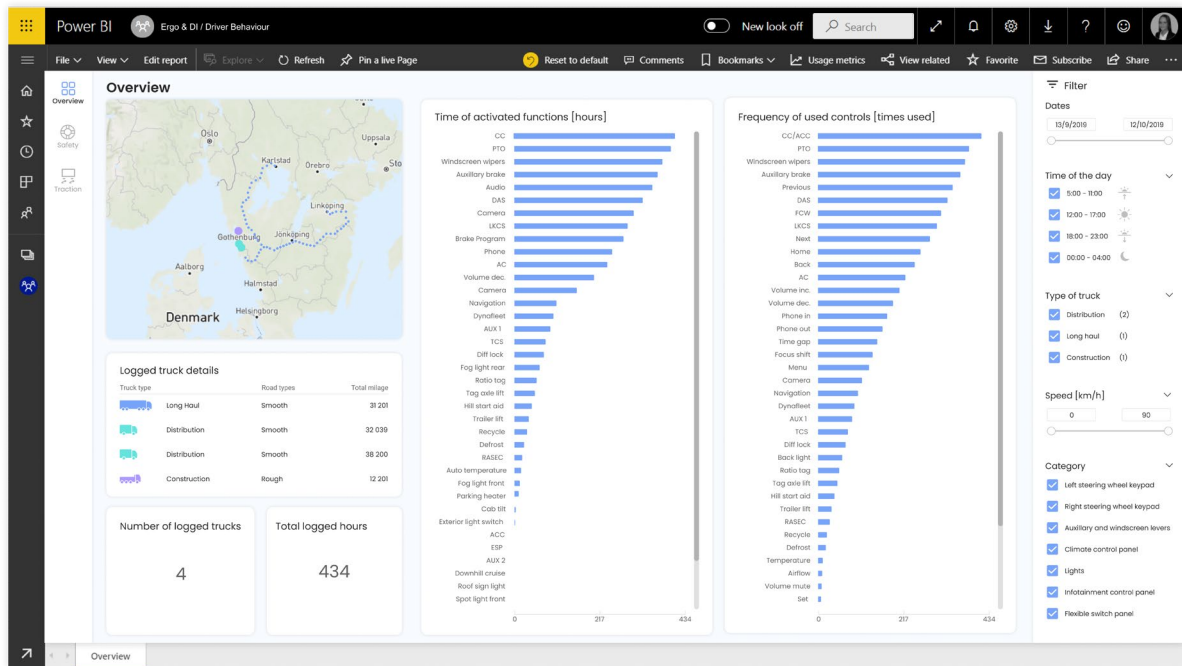


Figure 6.10 The dashboard inside the Power BI Sharepoint view. (Image by the author)

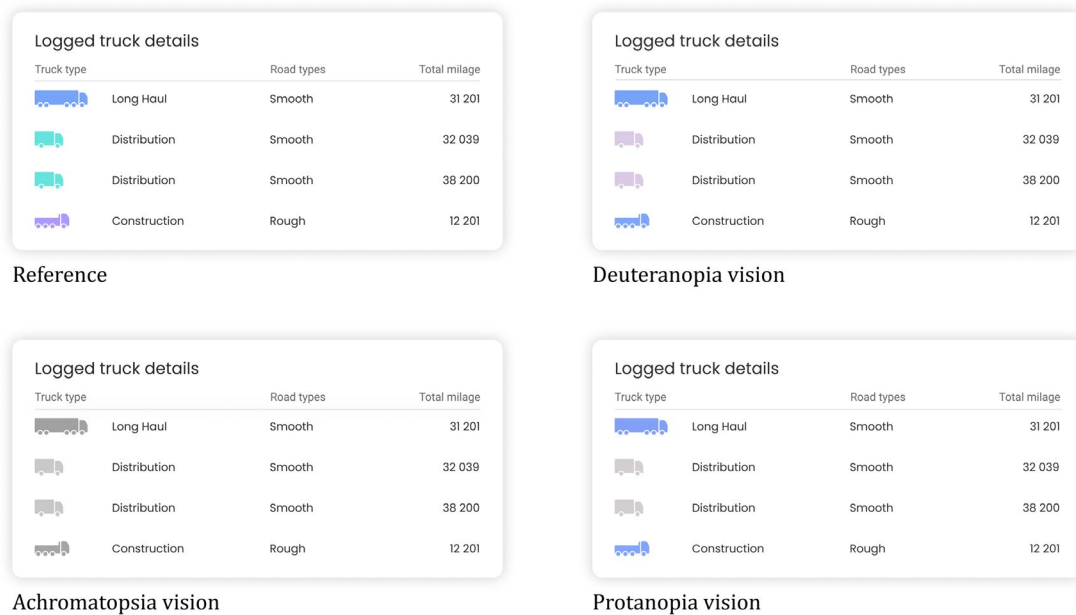


Figure 6.11 The colors of the trucks were tested with a Figma plugin to test how they were perceived by persons affected by different color blindness disabilities. The reference card shows how individuals with normal trichromacy vision sees the colors. The test revealed that people affected with different types of color blindness would have difficulties with distinguishing the color of the top-most and the bottom-most truck. (Image by the author)

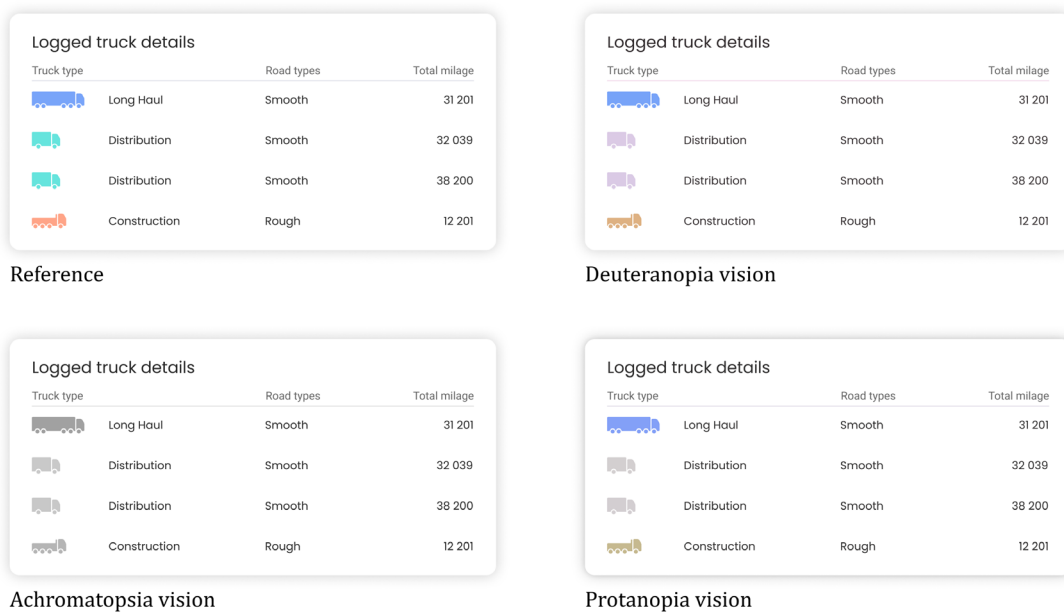


Figure 6.12 A test of the changed colors revealed that persons affected by color blindness would be able to distinguish the colors of the trucks better when the bottom-most truck was changed to a red shade. (Image by the author)



Figure 6.13 The colored circles against the map background was tested with the Figma color blindness plugin. The reference map shows how persons with normal trichromacy vision sees the colors against the map. The other maps shows a selection of how individuals affected by different types of color blindness sees the colors against the map. (Image by the author)

6.4.1.2 Map and Layout

The initial ideas of having a map that shows the number of times a control has been used or when a function has been turned on and off were abandoned. The idea was abandoned since it was found to not work well with the diagram showing function usage time. Instead a design for a scenario where more trucks were logged was created. The cars could then be color coded to distinguish which routes different truck types had taken. The feature specialists were interested in different trucks and in this way the user can select the truck type that they are working with and see where they have driven. The gestalt law closeness was used to make the viewer aware of that the colored trucks were color coded to their routes in the map. The principle was applied by moving the card “Logged truck details” beneath the map, instead of at the bottom of the page as initially placed.

6.4.1.3 Filter Pane

It was decided to move the filter pane from below the map to the far right. It was moved since the right side of the screen is a common standard to place a filter pane on. Furthermore, the participants in the summative test of the low fidelity sketches had difficulties with understanding if the filter pane would affect the entire dashboard. With this placement it could be clearer for the user that the selection affects the whole view. An additional filtering option was added for choosing what type of truck to display. This option was added to accommodate for the feature specialists need of seeing how drivers of different truck types use the controls and functions.

6.4.1.4 Interactivity

Interactive elements were built into the prototype to enable test participants to interact with the prototype during the evaluation. These were hovering over bars to show the exact amount of the bar, selecting checkboxes in the filter pane and seeing the charts change, selecting an area on the map (see Figure 6.14) and dragging the slider to apply filtering on speed.



Figure 6.14 The map in the high fidelity prototype was possible to interact with. To select an area on the map to filter and zoom into the user should click and drag. (Image by the author)

6.4.2 Formative Evaluation of High Fidelity Prototype

Since the Volvo employees were on short term layoff due to the pandemic, the available participants for tests consisted of friends and family. Because a summative evaluation would be

performed at the end of the thesis and the amount of participants was limited it was decided to combine user feedback with a Heuristic Evaluation for the summative evaluation. The parts of the formative evaluation are described below.

6.4.2.1 Heuristic Evaluation

First it was decided to use Forsell and Johansson's (2010) selection of heuristics for visual analytics. Thereafter, the visualization dashboard was evaluated against the heuristics. The aspects that supported or violated each heuristic and the placement of the matter in the interface were written down. The found problems were:

High data density

The dashboard has high data density. Data density means that a large amount of data elements is displayed. High data density can make it difficult for the viewer to distinguish the relevant data.

Multiple navigation options

The navigation ways are multiple. The Power BI Sharepoint has a navigation bar and navigation tabs in the bottom of the dashboard and the data visualization dashboard has a navigation bar.

Hidden information

The bottom bars in the ordered bar chart are hidden. The user needs scroll down to find the least used functions and controls. It can be difficult to locate unused functions and controls.

Unnecessary attention

The red colored truck can draw unnecessary attention and seen as a highlight due to its color standing out from the rest of the colors. The truck icons can also be seen as drawing unnecessary attention.

Memorizing information

If users want to compare which ones of all controls or functions are being used most often or least often, they need to scroll up and down in the bar chart and memorize which function or control it was. Furthermore, to see the exact amount of a bar chart the user needs to hover above the bar. Therefore, they need to memorize that specific number if they want to compare several bars by exact amount.

Ineffective filtering checkboxes

Filtering on one category can result in many clicks. If the user wants to see only one category of controls or functions they need to uncheck all the other ones, in this case six clicks. However, if radio buttons would be used they would only be able to filter on all or one set of controls.

The complete Heuristic Evaluation is found in Appendix C.

6.4.2.2 User Evaluation

The formative evaluation was conducted with three participants. The participants were in ages 30 to 60 years old. Since the participants were not truck experts the tests focused on the usability of the dashboard. The tests followed an evaluation guide with tasks and interview questions, see Appendix D. Each session took around 30 minutes. The session started with a short explanation of the master thesis and how their participation would help in the design of the dashboard. They were told a short scenario that was that they were Volvo designers who wanted to know more about how their users used the truck interface. Thereafter, they were given some tasks to perform while talking out loud. The tasks were for example finding out what function were being used the most at speeds up to 45 km per hour and finding what control was being used the most by long haul trucks.

The tests were performed online via video call services. The participants got a link to the Figma prototype and were asked to share their screen. The screen and sound were recorded. Thereafter, the recordings were transcribed and problems were listed. The found problems were:

Map missing affordances to click and drag

As described in Figure 6.14 an area of the map could be selected by clicking and dragging. None of the participants found the click and drag function. They tried to click on the map to select a city. The map does not show any affordances that it can be clicked and dragged to select an area. They thought it was more intuitive to click or double click to zoom.

Comparing bar length instead of hovering to see exact amount

One participant did not find that she could hover on a bar to show the exact amount of a bar. She compared the bars length against the bottom scale with the help of the cursor and estimated the amount. Only one bar in the prototype was possible to hover on to see the amount and this fact might contribute to the problem.

Understanding the unit of the “Total Mileage” column

One participant pointed out that it was difficult to understand what unit the “Total Mileage” column was in, since it did not say.

Truck information cards taking unnecessary space

One participant pointed out that she thought that the truck information cards “Number of logged trucks” and “Total logged hours” took up unnecessary screen space. She thought that it would be easier to see the map if it was made bigger instead.

Understanding the colors of the trucks

One of the participants did not understand that the truck types were color coded to the map. She instead thought that the color was saying something about the truck type and the kind of roads it drove on. She thought that the construction truck was red since it can be dangerous and red means warning. The long haul was blue since it is calm to drive on smooth roads.

Understanding the truck’s routes on the map

One participant thought that the small blue circles on the map each represented one truck. She did not interpret them as locations of where the trucks had been.

Too long bar chart titles

Two of the participants pointed out that they thought that the bar chart titles “Time of activated functions per truck [hours]” and “Frequency of used controls per truck [times used]” were too long. They had to read it each time they wanted to know what the chart was displaying and it was annoying.

The participants also expressed positive opinions about the dashboard. Some of these were that they were not overwhelmed by the information in the dashboard, they thought the layout was logical (starting from left to right) and that the filtering options were useful and intuitively placed. They had no problems with scrolling in the bar charts to see more bars.

6.4.3 Design Changes

The insights from the formative evaluation was used to make some design changes. Some changes were made to the dashboard according to the analysis of the formative evaluation, see Figure 6.15. The changes of the map card was adding an affordance of the click and drag functionality, adding a labels that describes the color coding and making the map size bigger. The truck information cards “Total logged trucks” and “Logged hours” were made smaller to give more screen space to the map. The title of the bar chart to the right-most was changed from “Frequency of used controls [times used]” to “Amount of control usages per truck [times used]”. The change was made to try to better describe the content of the chart. However, it was difficult to make the titles shorter without losing meaning. The unit of the total mileage column was added.

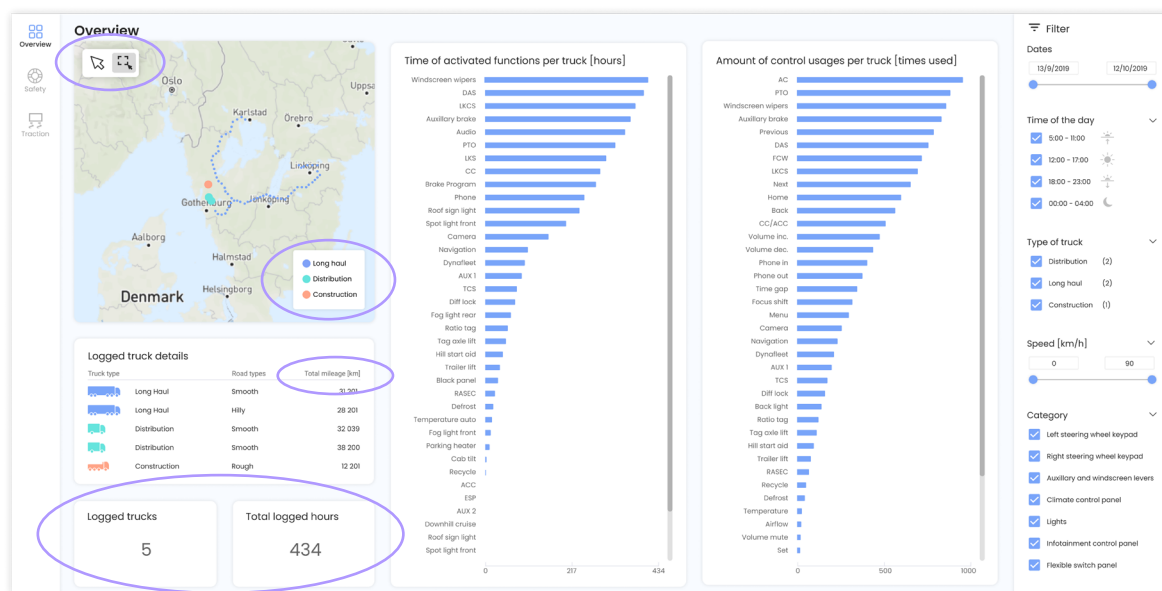


Figure 6.15 A few design changes (marked in purple) were made to the dashboard after the formative evaluation. The selection of an area versus a single point and the labels of the color coding appears when the user hovers on the map. (Image by the author)

6.5 Implementation

The available data that the data analyst had started working with was transformed with Python and implemented in Power BI by the author. The data analyst had not prepared the amount of clicks on the controls, so the right most chart was not implemented by the author.

6.5.1 Data Preparation

The data was further transformed into the right form with the help of Python and PyCharm. The form prepared by the data analyst was dates and times and what modes the different functions had at the specific time, such as on, off or error. For the “Time of Activated functions [hours]” chart the amount of time a function was on needed to be summarized. Since the file size was large it was decided to remove some of the data. Thereafter, a column of the duration of time was created by subtracting each rows date by the previous date. The data for each function consists of numbers that represent different modes. The modes that the numbers represented was provided by Volvo, see Figure 6.17 for an example of the values and corresponding modes. A conditional statement was created for each function depending on their values, see Figure 6.16. The statement changed the column modes to the duration of time if the mode was on.

The changed data was imported into Power BI. The types of the function columns were changed from text to decimal numbers so that they would be summarized. To show the duration of activated function time measures were created in Power BI for each function, see Figure 6.18 for an example of a measure. Since the Power BI map was limited to ten thousand points the some GPS coordinates were removed in Excel.

```

data.py x
1 import pandas as pd
2 import datetime
3 from datetime import timedelta
4 from pandas import DateOffset
5
6 df = pd.DataFrame(pd.read_csv('func_cc_defrost_rear_traction.csv', sep=","))
7
8 # remove column
9 # pd.drop(axis=1, )
10
11 # remove first rows
12 # pd.tail()
13
14 counter = 0
15
16 for index, row in df.iterrows():
17
18     if df['fcw_status'][index] == 1.0:
19         counter = counter + 1
20
21         if counter == 1:
22             df['fcw_status'][index] = 0
23
24         if counter > 2:
25             print(counter)
26             df['fcw_status'][index] = df['TimeDuration'][index]
27     else:
28         df['fcw_status'][index] = 0
29         counter = 0
30
31
32 # read to new file
33 df.to_csv('func_cc_defrost_rear_traction_fcw.csv', index=False)

```

Figure 6.16 An example of how a conditional statement was written for the Forward Collision Warning (FCW) function with Python in PyCharm. (Image by the author)

```

3 "DisableEnable_NotAvailable"
2 "DisableEnable_Error"
1 "DisableEnable_Enable"
0 "DisableEnable_Disable" ;

```

Figure 6.17 An example of the different modes that the FCW has. The mode in quotation corresponds to the number in front of it, which is shown in the data. (Image by the author)

```

CC = SUM(func_cc_traction_rear_fcw_defrost[ccactive])/3600

```

Figure 6.18 An example of how a measure of the Cruise Control can be created to show the sum of the hours activated. (Image by the author)

6.5.2 Data Presentation

After the data preparation in PyCharm and Power BI the data was presented in Power BI, see Figure 6.19. First the ordered bar chart was filled with the created measures which were described above. However, the function titles of the bars did not show. Therefore, a switch consisting of conditional statements and a table of the function names was created in Power BI. The switch and table enabled the titles to be shown on the axis. A measure was also created to order the bar chart. Thereafter the map was filled with the GPS coordinates. The truck information was filled into text fields. Sliders were created for dates and speed. A conditional statement was created for the “Time of day” filtering. The icons next to the “Time of day” filtering, see Figure 6.15 was removed because it is not possible to change the distance between the check boxes in Power BI. They are close together and the icons would then need to be very small to not overlap and therefore difficult to distinguish, see Figure 6.20.

The data analyst had not had time to prepare the data for the “Amount of Control Usages per Truck [times]” before the short term layoff. Therefore, the chart could not be created. The high fidelity prototype “Time of Activated Functions [hours]” chart contained more bars. The logged data did not contain all functions and therefore the implementation consists of less function bars. The Category filtering was not implemented because of time limitations and the fact that there were such few functions. Furthermore, it was not possible to filter the map through selecting bars in the chart or selecting an area on the map, see Figure 6.14. This could be due to the GPS data being removed, because of the limitation of ten thousand data points.

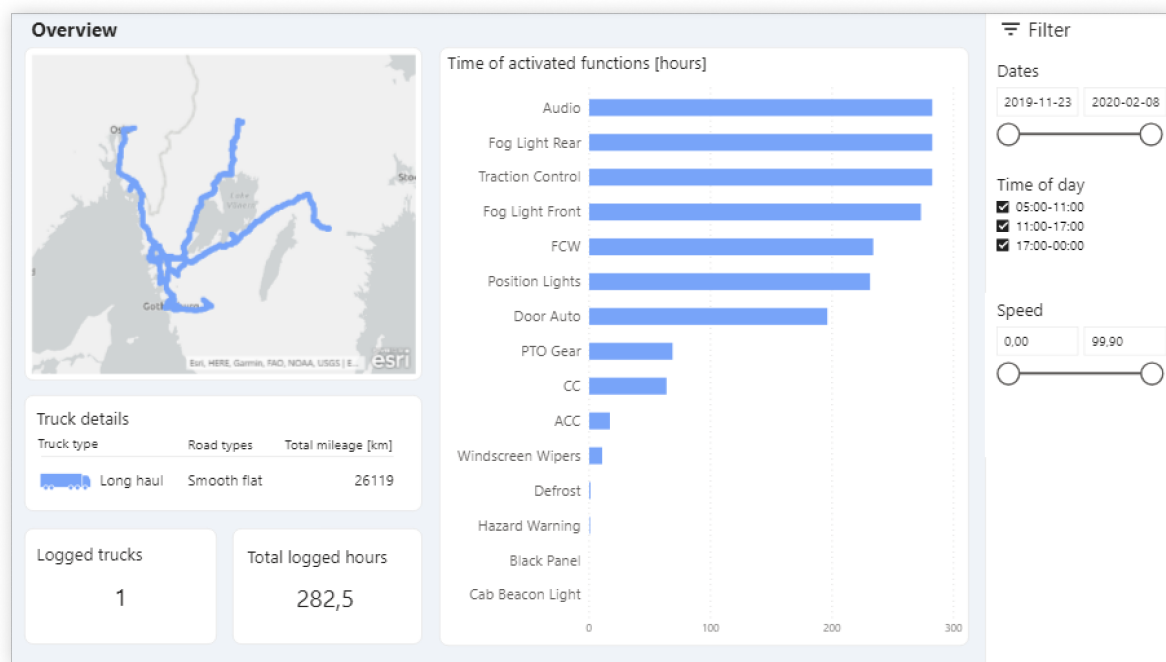


Figure 6.19 The Power BI implemented prototype with logged data from one truck. (Image by the author)



Figure 6.20 The icons next to the "Time of Day" filtering was too small in Power BI due to limitations in the program.
(Image by the author)

6.6 Summative Evaluation

A summative test was held to evaluate the usability of the dashboard. The original goal of the summative evaluation was to see whether the dashboard accommodated for the target user's needs. However, it was not possible to perform the evaluation with the Volvo employees were prohibited by law to not work during the short term layoff. Therefore, the test focused on finding usability issues.

6.6.1 Participants

The summative evaluation was held with five participants. During the Corona pandemic social distancing was encouraged. Due to the secrecy reasons the tests had to be done in person, which limited the number of participants to five. The participants were in ages 18 to 55 years old. Since the participants were not truck experts the tests focused on the usability of the dashboard. The participants considered themselves to have different levels of technology experience. Two of the participants were female and three males. Three of the participants had a driver's license, which might affect their ability to understand the content of the dashboard.

6.6.2 The process

The tests followed an evaluation guide with tasks and interview questions, see Appendix E. Each session took around 30 minutes. The tests were recorded with video. The session started with a short explanation of the master thesis and how their participation would help in the design of the dashboard. The testers were told a short scenario that was that they were Volvo designers who wanted to know more about how their users used the truck interface. Thereafter, they were given some tasks to perform while they were asked to talk out loud. The tasks were for example telling how much the windscreen wipers were activated in the end of November or which function were used the most at high speeds. Notes of observations were written down. After the test an interview was performed. The questions were about what information they perceived as the most important and whether they had any problems with the dashboard.

6.6.3 Analysis

The recordings were transcribed together with the observation notes. Thereafter, affinity diagramming was used to analyze and group similar quotes. Issues and positive aspects were written down. Many of the participants had the same issues and after the fifth participant no new issues were found. The issues and positive feedback are presented below. The most occurring usability issues are described below.

6.6.3.1 Bar Chart Issues

Only two of the five test participants found the exact amount of the function by hovering above the bar. The others estimated the length of the bar against the bottom scale. Furthermore, they said that hovering over a small bar such as Hazard Warning was difficult, see Figure 6.21. They thought that the tool tip appeared to slow while hovering above the bar. One alternative to fix the problem would be always display the bar values, see Figure 6.22. Since the majority of participants experienced this issue and Kirk (2016) argues that the values always should be displayed it was decided to implement the change.

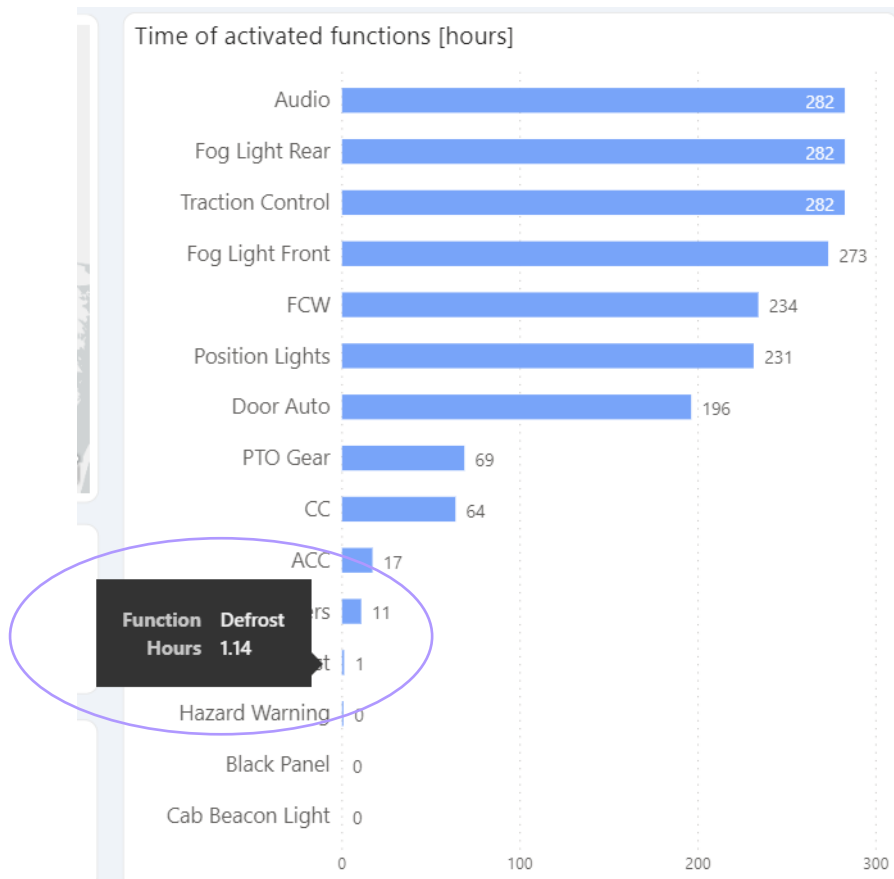


Figure 6.21 Hovering over bars to show the exact amount of hours of a function (marked in purple) was perceived as difficult by several of the participants. (Image by the author)

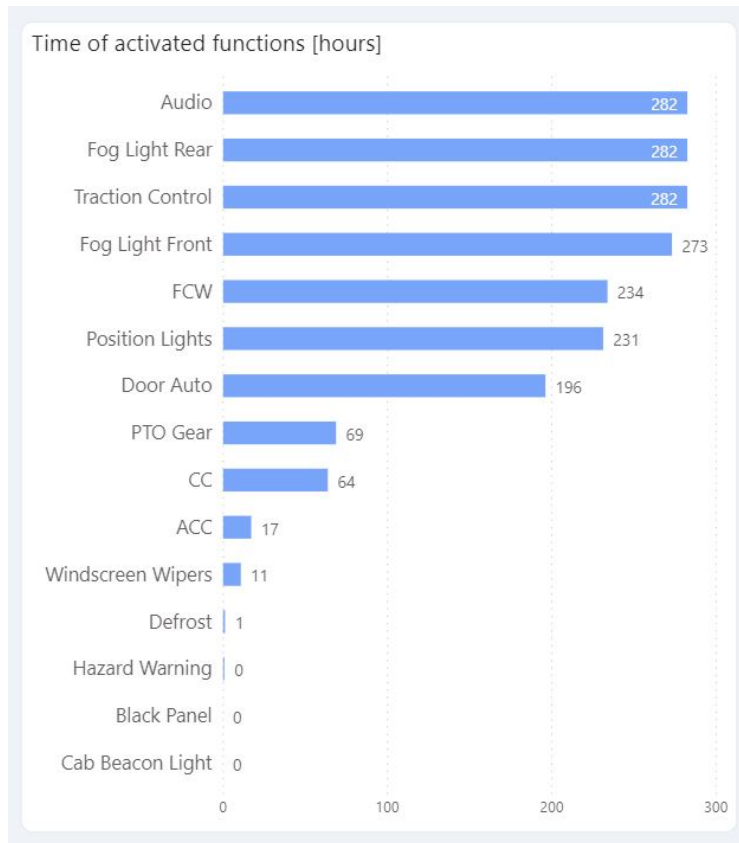


Figure 6.22 An alternative bar chart where the bar values always are displayed. (Image by the author)

6.6.3.2 Map Issues

Three of the participants thought that the zooming on the map was difficult. They expressed that it was difficult due to too high speed. Three of the participants also thought that latitude and longitude that appeared on the map when hovering was not helpful, see Figure 6.23. They wanted to see the city name instead.



Figure 6.23 When hovering over a location a tool tip displays the GPS latitude and longitude.
(Image by the author)

6.6.3.3 Sliders

All of the participants had difficulties with using the sliders for date and speed filtering. One participant said that he appreciated the sliders because they were easy to use. However, it was observed that he and all other participants had difficulties with selecting an exact amount on the slider. It took long time and they adjusted it several times to perform a task. The values of the speed slider had two decimals which made it difficult to select a specific integer, see Figure 6.24. Therefore the values were changed to integers instead, see Figure 6.25. The participants also had difficulties with understanding which dates the date slider was showing. Power BI shows the date in American format (month/date/year) instead of the Swedish format (date/month/year). The format made the participants confused to as if the first or the second number was the date.



Figure 6.24 The speed filtering text field showed decimal numbers.
(Image by the author)



Figure 6.25 The speed filtering text fields were changed to integers for easier selection and manipulation.
(Image by the author)

6.6.3.4 Checkboxes

Although all of the participants understood how to use checkboxes, two of the participants had difficulties with clicking in the area of the checkbox. The issues could be due to the small size of the checkboxes and the close proximity of them.

6.6.3.5 Attention

Three of the participants stated that the color scale was calm and easy to look at. One participant however thought that it was too little colors. The differences shows that colors are individual preferences. Two of the participants thought that the icon of the truck was helpful for understanding that it was a long truck that was being logged. One participant thought that the display showed too much information. He was overwhelmed and did not know what to focus on. The participants said that the bar chart brought their attention and the truck detail cards. One participant said that the truck detail cards caught his attentions because the font size and padding was bigger related to other cards.

The final result of the high fidelity prototype and implementation is presented in Chapter 7.

7

Results

A Research through Design approach was used to answer the research questions of the thesis. The process consisted of a literature study, user studies consisting of interviews and a focus group and iterations of design, implementation and evaluation. The steps were conducted with the aim of finding the answers to the research questions, which is:

What should be considered when visualizing logged truck data to facilitate designers' understanding of driver behavior?

And sub question:

What are the user needs of the visualization to further understand truck driver behavior?

The answer to the first question is an annotated design of the data visualization dashboard with the working name Volvo Driver Information Dashboard (VDID). A list of what should be considered when visualizing logged truck data further answers the research question. VDID is based on user needs found during the user research phase, see Appendix F for all user needs. The user needs are the answer to the sub question. The user needs, the high fidelity and implemented version of VDID and the key consideration areas are described in this chapter.

7.1 User Needs

During the user research many different needs of the data visualization was found. The most important needs and some examples that shows the underlying motivation for the needs are presented below. The importance of the needs was decided by the number of participants that expressed a similar need, if the need expressed the underlying user motivation and if the design of the mentioned control in the need was critical. The needs were used as a foundation for the design of the dashboard. A list of all found needs are presented in Appendix F. The needs are expressed as user stories that starts with: "As a feature/ergonomics specialist... ". The numbers in parenthesis after each user story represents the number of users in the interviews that expressed the same need.

7.1.1 General Driver Interaction

Some needs were general and applied to all functions and controls. These were:

...I want to know the usage frequency of different controls so that I can create requirements to improve the user experience. (All)

...I want to the duration of activation of different functions so that I can create requirements to improve the user experience. (All)

...I want to know which buttons are used in sequence so that I can understand which buttons should be placed next to each other. (All)

...I want to know which functions are used in combination so that I can create requirements to improve the user experience. (All)

7.1.2 Controls

Some needs were specific to the controls. Examples of these are:

...I want to know how often the driver uses the controls in the dashboard, so that I can prioritize which buttons should be close to the driver. (All)

.....I want to know how often and when all flexible switches are used so that I can prioritize which functions should be placed where. (5)

...I want to know if the climate panel is used during stand still or while driving so that I can decide if the functions should be placed on physical buttons or in displays. (4)

...I want to know if the change-song-buttons are used so that I can decide if the placement should be on the steering wheel or on the infotainment panel. (4)

...I want to know if the navigation, Dynafleet and camera buttons are used so that I can understand if they can be moved to the side panel. (2)

...I want to know what buttons on the steering wheel are the most used and if any are not used, so that I can prioritize which functions should be on the steering wheel. (3)

...I want to know how often and when the levers are used so that I can create requirements to improve or possibly remove the levers. (3)

...I want to know if the driver uses the brake program button, so that I can understand if they find it. (2)

7.1.3 Unused functions and controls

The function specialists wanted to know which functions and controls that were unused so that they could possibly remove or change these functions and controls. Some example of these needs are:

...I want to see if any of the duplicate controls are redundant so that they can be replaced or removed to improve the user experience. For example, steering wheel controls in relation to the dashboard controls. (3)

...I want to know which of the functions that have automatic modes that are in manual mode and when so that I can understand if the automatic functions are good enough. (5)

...I want to know which functions the driver turns off so that I can understand which they are and when they are not working, so that I can create requirements to improve these functions. (4)

7.1.4 Context

The feature specialists were in need of knowing the context of use to better understand the driver behavior and improve the user experience depending on the situation. Some examples of needs related to the context of use were:

...I want to know which controls are being used during drive or standing still, so that I can understand which functions needs to be on physical controls or if it is acceptable to have them in a display. (3)

...I want to know which controls are being used during different times of the day such as morning, day, evening and night, so that I can optimize the controls and functions for these times. (6)

...I want to know how the infotainment controls are being used during driving, certain speeds and situations in relation to the steering wheel buttons so that I can prioritize which functions should be placed where. (3)

...I want to know which controls the driver uses when he starts or ends his shift so that I can improve the user experience. (3)

...I want to know which functions and controls are used on different road types so that I can improve the requirements of these functions. (4)

...I want to know which functions and controls the drivers use during different speeds. (4)

7.1.5 Future logging

The participants expressed many needs that related to data that was not logged and expressed a need for knowing how a large amount of truck drivers behaved. A few examples of these needs are:

...I want to know how a greater scale of drivers interact with the truck interface, so that I can with certainty make data driven decisions to improve the user experience of the truck. (All)

...I want to log on a wide range of trucks in the different sections – long-haul, distribution and construction. (All)

...I want to know how the driver uses the displays in the truck so that I can prioritize the views and controls in them. (4)

7.2 The Data Visualization Dashboard

The final result of the prototyping consisted of a high fidelity prototype consisting of made up data and an implemented dashboard with real data. The high fidelity prototype is based on user needs and in a scenario where more data is available from more trucks. The implemented version is done with logged data from one truck.

7.2.1 High Fidelity Prototype

This section describes the high fidelity prototype that was created in the thesis. The prototype shows which aspects needs to be considered when designing a dashboard that should enable users to better understand driver behavior.

7.2.1.1 Dashboard Overview

VDD consists of a map, truck information cards, bar charts, a filter pane and a navigation bar, see Figure 7.1.

- 1. Map**

The map shows the truck routes. Each circle is one GPS location and the colors corresponds to the different truck types.

- 2. Truck Information Cards**

The truck information cards give the user a context of logged trucks characteristics.

- 3. Function Bar Chart**

The function bar chart shows the function usage times from most used to least used.

- 4. Controls Bar Chart**

The function bar chart shows the control amount of usages from most used to least used.

5. Filter Pane

The filter pane can be used to filter on dates, times, truck types, speed and categories. The filter pane was added to accommodate for the different needs of the users.

6. Navigation Bar

The navigation bar can be used to navigate to different views. The navigation bar was included since the users had different specific needs that was not possible to fit in one dashboard. However, partly due to the Corona pandemic no further screens were implemented as more interviews were needed.

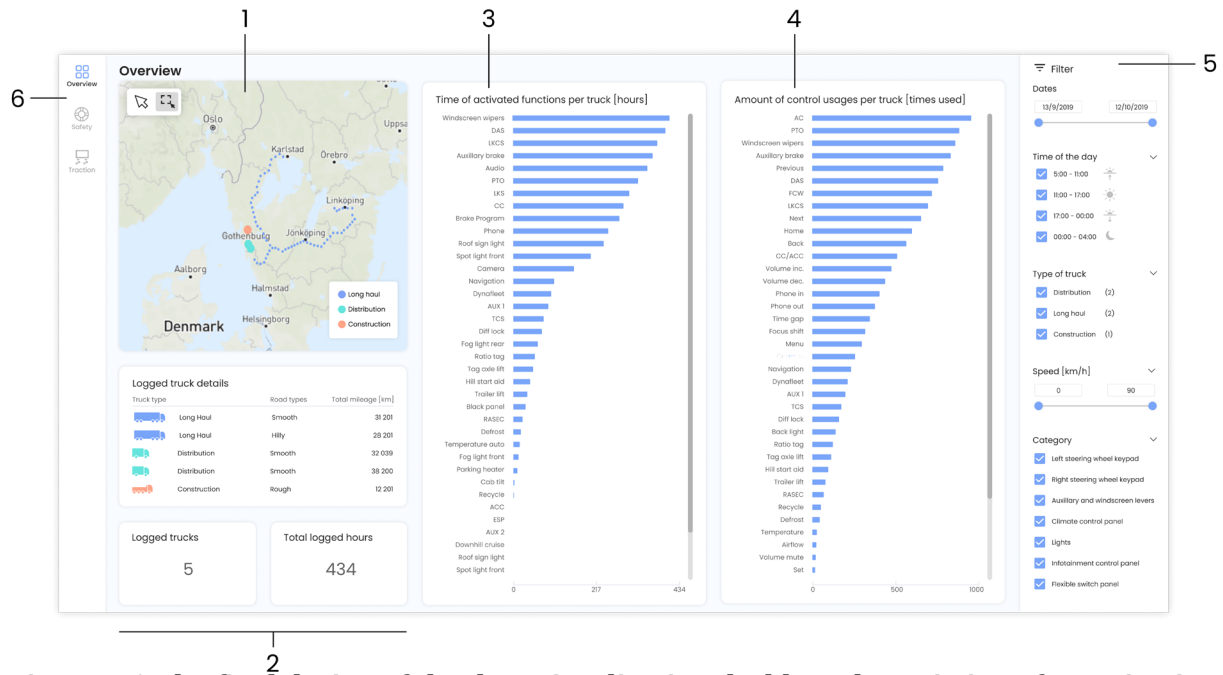


Figure 7.1 The final design of the data visualization dashboard consisting of a navigation bar, a map, truck information cards, two bar charts and a filter pane. (Image by the author)

7.2.1.2 Color Choices

The colors in the dashboard are optimized for being differentiable by many individuals. The dashboard's accessibility is largely affected by the color selection. The colors are less saturated as Wilke (2019) states that saturated colors can distract viewers. The color palette is shown in Figure 7.2 below.



Figure 7.2 The color selection for the dashboard and their HEX values. (Image by the author)

7.2.1.3 Map

Many feature specialists were interested in knowing what types of roads the truck drivers were driving on when using different controls and functions. Since it is not possible to log the road type from the GPS at the time writing, a map was instead added in the design. The map shows the

logged truck's routes as circles. The circles represent positions of where the truck has driven during a specific period of time. The colors of the circles are coded to the truck type. Wilke (2019) recommends color coding for up to five categories. Hence, color coding will only be useful for a small number of trucks. If the user hovers over the map an additional label card is displayed. The label card explains the colors meanings.

The user can select one GPS location by clicking a circle to filter the dashboard. When the user hovers over the map a control is shown in the top left corner. If the user selects the pointer with a dashed square they can select an area on the map to filter on. In this way the user can manually look at a road type at a time, if they are for instance is interested in forest roads.

7.2.1.4 Truck Information Cards

Truck information cards were included in the dashboard. They were added since the feature specialists expressed a need for knowing what type of truck the data belonged to and were interested in different types of trucks. Many feature specialists expressed that more trucks needed to be logged in order to draw certain conclusions from the data. They could not draw conclusions based on a small set of users. Therefore, a large card displays how many trucks the data comes from. The total amount of logged hours is also displayed to make the viewer aware of the amount of data that had been collected. The intention is that the viewer can decide whether enough data has been collected for them to trust that their insights gained from the data visualization.

7.2.1.5 Bar Charts

The target users of VDID expressed a need of knowing which functions and controls were being used the most and the least often. Therefore, two ordered bar charts showing function usage time and controls usage frequency were included in the prototype. The human perception needs to be considered when facilitating understanding through data visualization (Kirk, 2016). Therefore ordered bar charts were selected to enable comparison of the bars. Kirk's (2016) guidelines that suggests that length should be used for representing quantity was also followed. Furthermore, Material Design guidelines suggest that ordered bar charts enables comparison of bars. If the user hovers over a bar the exact amount of that bar is displayed.

7.2.1.6 Filter Pane

It was found that diverse needs of users should be considered when designing a data visualization dashboard that should facilitate understanding of user behavior. The intended users of the data visualization dashboard had diverse needs to their specific working area of the truck interface. Therefore, a filter pane was included in the design. The users can filter on dates, times, truck types, speed and categories. The gestalt law proximity was used to group the different filtering options together. With the filter options the user can hide information that is not of interest for them and focus on the data of interest.

For the date filtering text fields and a slider was used since it is what is possible to implement in Power BI. A slider was also used for the speed range filtering. The slider was used since it enables the user to choose speed range themselves. They are not be forced to choose a specific range as with for example radio buttons. For the time, truck type and category filtering checkboxes were used. The checkboxes also enable the user to freely select options. Whereas radio buttons would force the user to look at only one selection at a time. By using the checkboxes the user can look at two categories at a time. Looking at several categories at a time could be useful for the feature specialist that are working with several categories of truck interface controls and functions.

7.2.2 Implemented Prototype

This section describes the implemented prototype. The prototype was implemented in Power BI with logged data from one truck, see Figure 7.3.

7.2.2.1 Differences from High Fidelity Prototype

The differences from the high fidelity prototype is that the implemented prototype does not contain the “Amount of Control Usages per Truck [times]” chart, the categories filtering, the navigation bar, some icons and uses a different font. The functions in the filter pane is fully functional. However, it is not possible to select an area on the map, as described in section 7.3.1.3 above. The colors of the map are not the same as in the prototype either. They are different since it was not possible to select the exact colors. The checkboxes were and slider handles were not either possible to choose color of. The bar chart shows the values of the bars instead of the hovering function. The values are permanently displayed because the majority of the users did not understand that they could hover to show the exact amount.

7.2.2.2 Usability

The summative test showed that users could achieve their goals with the help of the data visualization. The tests showed that the dashboard had high usability. Users stated that the colors were easy to the eye. The users were satisfied with the filtering as they expressed that the filtering was easy to use. However, the final prototype had some usability issues. Some of these were that the speed of the zooming in the map was too high, see Figure 7.4. Furthermore, the date format was difficult to understand.

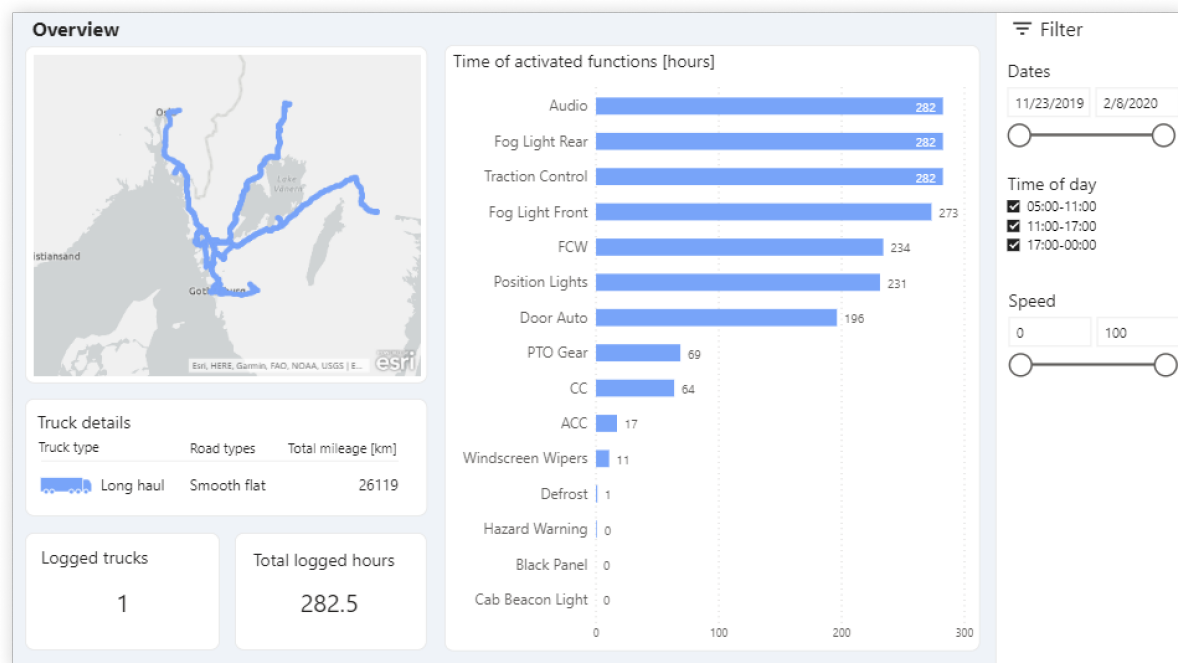


Figure 7.3 The prototype was implemented in Power BI with logged data from one truck. (Image by the author)

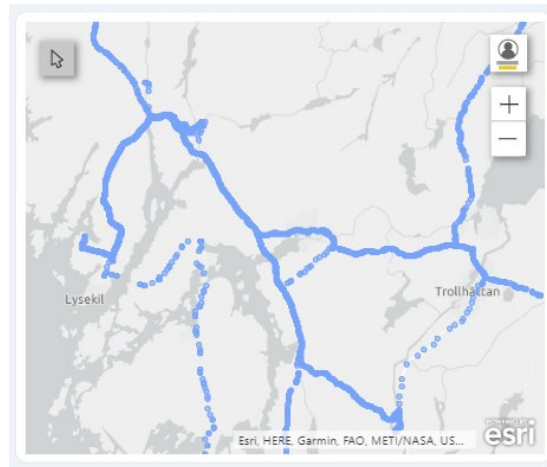


Figure 7.4 The map is interactive and possible to zoom into with the use of the mouse of the plus and minus buttons that appear on hover. (Image by the author)

7.2.3 Key Considerations

As the thesis followed a Research through Design approach the prototype resulted in knowledge of what needs to be considered when designing a dashboard of logged truck data visualizations. The main factors that was found to be important to consider when designing a data visualization dashboard to facilitate understanding in the truck industry was:

- 1. User needs**

According to Chiang (2009) users should be included early in the design phase in order to create a successful dashboard. It was found that the intended user group had diverse needs that could be accommodated for by providing filtering options.

- 2. The human visual perception**

It was found in the literature study that the human visual perception is important to consider when creating data visualizations (Kirk, 2016). One example of this in the thesis is the usage of ordered bar charts to enable participants to see which function was being used the most.

- 3. Colors**

As suggested by previous research colors are important to consider when designing useful data visualizations (Cooper, Reimann and Dubberly, 2013 and Wilke, 2019). The user evaluations in the thesis found that some participants interpreted meaning of colors. Many users appreciated calm color palettes.

- 4. Number of logged trucks**

The user research showed that the users were in need of knowing how a large number of drivers behaved in order to draw certain conclusions.

8

Discussion

This chapter reflects over the work that has been performed in the thesis. Questions arise whether the time it takes to create the visualizations outweigh the benefits of viewing it. Several unfavorable aspects of creating data visualizations of logged truck data were found during the thesis. These matters were specific to Volvo Trucks and might not apply to all truck producers. The truck is complex and comes with various functions and controls which often can be adapted and personalized by the buyer. Although the adaptability might improve the user experience of the truck it makes the data visualization process more difficult. The flexible switches would be time consuming to analyze and was due to the Corona pandemic and Volvo's short term layoff not finalized in this thesis.

Furthermore, the functions in the truck each have different modes that takes time to look up when performing the data transformation. Some function modes had the value one when they were activated and some others had the value zero. Also specific to Volvo is the way the database of the logged data is set up. The data analyst had to manually download the data to import it to Power BI. Therefore, automatic continuous updating of the data is not possible. The manual updating makes the process even more time consuming.

The prototypes were not evaluated with the feature specialists at Volvo because of the short term layoff. Therefore, it is difficult to draw a certain conclusion about whether the benefits outweigh the time it takes to create the data visualization. However, it was found that improvements could be made in the future to make the data visualization process easier. The results, methods and theory, ethical considerations and future work is further discussed in this chapter.

8.1 Results

The results consisted of a data visualization dashboard and user needs. The results were the intended deliverables. Therefore, the thesis can be seen as successful and contributing to the gap in the research of using data analytics to understand driver behavior. The results were expected. A dashboard based on user needs that could be used to achieve goals was created. However, parts of the interface that was intended to be implemented was not due to the pandemic. Furthermore, the prototype was not evaluated with the target users and therefore work remains to fully answer the research question. In this section the final result is reflected over and discussed.

8.1.1 Advantages

The usability of the dashboard was evaluated. The participants in the evaluations of the dashboard expressed that the dashboard was easy to use. They were able to complete the tasks they were given during the tests. These tasks were for example finding how long the windscreen wipers were used at a certain week or which function was being used the most at high speeds. The fact that the users could complete tasks might indicate that the dashboard enables users to make conclusions of driver behavior. However, more tests with the target users are needed.

The users in the summative evaluations stated that the color palette was easy for the eye. These statements might indicate that the colors did not distract them and that they were able to focus on the information that they were interested in. The dashboard shows the user background information about the logged trucks and how many trucks that have been logged. The number off logged trucks

was shown to improve the users trust in the data visualization. Furthermore, contextual information such as place, speed and dates are shown to enable analysis of behavior in certain situations.

The data visualization is based on the identified user needs. However, several needs were not accommodated for. The filtering pane might accommodate for the diverse needs of its users. With the use of the filtering the user can chose to temporarily remove data that is not of interest for them. Although the dashboard was evaluated with non-expert users some of them could draw conclusions about the driver behavior. However, since the dashboard was not evaluated with the target group it is not possible to draw a certain conclusion to if the dashboard accommodated for the user needs.

8.1.2 Disadvantages

During the focus group discussion some participants insisted that a set data visualization would be inflexible and not accommodate for all of the viewers questions. The participant suggested that a more flexible system was created where the user could formulate queries and get answers in form of a visualization. There were some options that could make this possible in Power BI. However, they were difficult to use. Yet, no thorough investigation of the functionality was conducted. Some users might therefore feel unsatisfied with the dashboard. VDID can be seen as being inflexible in this aspect and there is room for improvement in this area.

Furthermore, the feature specialists were in need of knowing why the drivers behave the way they do. However, it is not possible to understand this with the help of the data visualization. The visualization can show indications of behaviors. Yet, complementing qualitative interviews are needed to understand the underlying motivation for the driver actions.

Some functions are always activated until the driver deactivates them. Traction control is one such function. As seen in the data visualization this is one of the functions that is activated the most amount of time which can be misleading. Another type of visualization that shows which functions were being turned off the most often could be more useful. FCW is another function that is activated in the standard mode. However, it can be seen that FCW is not activated all of the time from the data visualization. This fact can give an indication that the driver might turn off the function. This matter was also experienced by the specialists during observations. They thought that the drivers turned off the function due to annoying sounds and warnings. This is an example of how an insight of behavior can be achieved from the visualization and complementing interviews could be conducted to find out why the driver behaved in this way.

8.1.3 Error Sources

It is important to note that the implemented dashboard's data might contain errors. The data set has been changed and made smaller through deletion of data. The data analyst had removed some of the data to make the file size smaller. For example, she removed data from when the motor was off. However, due to the short term layoff collaboration with the data analyst was not allowed by law. Therefore, it is uncertain what the data analyst did with the data before the thesis continued working with the data. This fact might lead to errors in the data. Furthermore, when translating the modes from the functions lack of electronics knowledge might lead to more errors.

Additional to the mentioned error sources many of the logged trucks functions did not work as expected. The functions were dysfunctional since the logged data came from a prototype truck under continuous development. The audio system and many lights were partly functional which could explain they appear to be activated the entire time in the bar chart. In the future the logged trucks should be fully functional so that the users can trust their insights from the visualizations. According to the driver he used PTO, CC and the windscreen wipers the most. If the always activated functions and partly functional functions are removed from the chart PTO, CC and

windscreen wipers are some of the most used functions. It can be an indication that the data visualization matches the reality.

8.1.4 Contribution to Research

Previous research has used data analytics to categorize and detect different types of driving behavior. However, it was identified that there is a gap in the research of using data analytics to enable a better understanding of driver behavior. The thesis sought to contribute to research through a Research through Design approach. Prototypes were created and learnings from the process can be seen as research.

Questions arise to if the thesis did contribute with research that is applicable for other actors in the truck industry. Some of the data was faulty due to functions miss functioning. Furthermore, Power BI had many design limitations that affected the result. The Corona pandemic also affected the thesis in determining if the dashboard was useful by the target users. It is problematic that evaluations with the target users could not be made. More studies are needed of using data analytics so understand driver behavior in order to make certain conclusions to as if the research is applicable for other companies. The automotive industry is moving towards implementing digital displays instead of physical controls. Analyzing user behavior of displays could potentially be more alike web analytics. This thesis did not include the digital displays. Therefore, there is still a gap in research of using data from displays to better understand driver behavior.

8.2 Methods

The thesis took a Research through Design approach in the aim of finding the answer to the research question. If alternative methods and theories would be followed the result might have been different. This section discusses the methods that have been used in the thesis.

8.2.1 High Fidelity Prototyping

The original plan was to not perform high fidelity prototyping since Power BI restricts many design alternatives. Due to the Covid-19 pandemic the plan was changed. The data analyst was on short term layoff and no further help would be given with the data transformation. Therefore, the bar chart showing control interactions would not be possible to implement in the given time frame. Hence, it was decided to create a high fidelity prototype that included all parts of the low fidelity prototype. This change could have had a positive impact on the interaction design of the prototype since the interactive prototype could be better evaluated with users. The formative evaluation showed for example that the truck detail cards took up too much screen space which could be used for the map instead. However, it might also be time consuming as many design aspects were not possible to implement in Power BI due to design constraints.

8.2.2 Implemented Prototype

As Kirk (2016) explain what kind of tool is selected for visualizing the data affects the result of the data visualization. The implemented prototype was created in Power BI. Power BI might speed up the process of creating the dashboard with its ready to use charts rather than creating it from scratch. However, it also limited the design that could be made with the use of it. Some examples of limitations were that colors of objects could not always be adapted and controls such as sliders were often predefined. Furthermore, the map could only consist of ten thousand data points. Some data also needed to be deleted since the program was too slow for the amount of data. It is important to note

that by using another tool or implementing from scratch the dashboard might look and work differently.

8.2.3 Formative Evaluations

The formative evaluations were conducted with few participants partly due to the Corona pandemic. As seen in Figure 4.4 85 % of the usability issues can be found with five participants. However, in the formative evaluations only three users were included. Therefore, only around 60 % of the usability problems were found during the tests. If more participants conducted the tests the dashboard could show fewer usability issues.

To make up for the fact that the tests were conducted with few participants a Hierarchical Evaluation was performed. However, Hierarchical Evaluations should be conducted by several evaluators. Since the thesis is conducted by one person this was not possible. Therefore, the outcome of the evaluation could be seen as subjective and not true to reality.

8.3 Process

The processes that were followed were iterative design, one example is the Wheel by (Hartson and Pyla, 2012), and Ware's (2012) four feedback loops of information visualization. The processes were followed to ensure the best possible outcome through using knowledge by previous researchers. As the thesis is within interaction design and the dashboard is interactive it was important to follow an iterative design process. The four feedback loops of information visualization were guiding in the data visualization process. However, it can be complicated to focus on the two aspects at the same time. A process for creating interactive data visualizations would be preferable.

The Corona pandemic affected the process of the thesis. The process of the thesis consisted of a user research phase and two design and implementation phases. The process was the intended process of the thesis. However, the first implementation phase consisted more of learning Power BI and testing different design solutions. The original plan was to create an implemented prototype that could be formatively evaluated with users. A high fidelity prototype was created which was not originally intended. The additional prototype might improve the usability and interaction design of the dashboard. However, two iterations of implementation were therefore not conducted. Fewer implementations might have led the dashboard to consist of less elements.

The Corona pandemic also took time from the thesis since planning needed to be done twice. Furthermore, several additional meetings with Volvo and the supervisor was needed. Perhaps better planning for unforeseen events such as the pandemic would have led to a better outcome. The thesis plan might have been overly optimistic.

8.4 Ethical Considerations

During the thesis questions arose to as whether it is ethical to collect data from drivers and display it in a visualization. Some of the logged data are of sensitive characteristics. Examples of these are speed, location and safety functions. Some of the participants in the interviews expressed that they knew that some drivers turned off specific safety functions because they were annoyed by the sound and warnings. Is the viewer obligated to report a crime that is displayed in the data visualization such as speeding? However, this fact is not specific to analyzing behavior through data analytics. Observing and interviewing drivers might also bring up topics that creates questions about ethics. Interviewees could for example notice that a driver is not wearing his driver seat belt.

Furthermore, although the driver is informed that his truck is being logged, it is not always his

decision. It might be his employer's wish in order to get a cheaper truck. The driver can also be subjected to other pressures such as delivering goods in time and forced to drive faster than they are comfortable with. These are all areas that needs to be considered when creating a data visualization of logged truck data. Furthermore, at the time, only one truck was logged. Hence, it could be possible to identify the driver of the logged data. If more trucks would be logged in the future this possibly unethical fact would be lessened.

One might think that observing where the drivers go and which functions they use is an intrusion on the driver's integrity. On the other hand, it is a unique opportunity to improve the user experience of the truck interface. The interviewees expressed several times that they were not interested in what the drivers did wrong. However, in the wrong hands a data visualization can be used for the wrong reasons, such as controlling drivers.

Ethical issues were considered in the thesis. One example is that the specialists were interested in the anthropologies of the driver to improve the ergonomics of the truck. The height of the drivers was therefore included in the first sketches of the dashboard. The height could not be logged yet included through interviews with the drivers. However, including anthropologies was found to be a GDPR issue and was therefore not included in the dashboard. In future work ethics should be an important consideration.

8.5 Future work

Due to time constraints and the Corona pandemic work remains to be done to fully answer the research question. This section suggests some areas of future work.

8.5.1 Including Controls Usage

Due to the Corona pandemic the right most bar chart in the high fidelity prototype showing interactions with the controls in the truck was not implemented. Partly because the data analyst that would help with the data transformation was not allowed to work. Interactions with the controls such as buttons, wheels and levers are an important part of understanding how the driver behaves in the truck.

The interviewees were interested in knowing more about the flexible switch control usage. However, the flexible switches were difficult to work with during the data analysis. It could be investigated in future work if the control usage chart were worth the time it took to implement.

8.5.2 Using Artificial Intelligence

The thesis did not use artificial intelligence (AI) to create the data visualizations. Many of the found needs were almost impossible to accommodate for without the use of AI. Some examples of needs that were difficult to base the dashboard on was how the controls are being used in a sequence and which controls are being used in a combination. To create data visualizations that answers these needs is difficult because humans have difficulties with understanding large amounts of tabular data. Finding trends in data consisting of two million rows of data manually was not possible.

AI could be used to accommodate for more needs. Furthermore, AI could possibly answer questions that the users did not even know they had and facilitate for insights that are difficult for humans to make without it. The thesis worker did not have knowledge within AI. A cross-functional approach might have been more beneficial for the thesis. AI could be useful in the future.

8.5.3 Creating More Views

Numerous user needs were found in the user studies. The most important needs were selected. An overview for these needs were created. A navigation bar was included in the prototype that could be used to navigate to other views. However, no other views were designed. More detailed views could be created to accommodate for more of the found needs as many of the users had specific questions in their working area. To create these views more user studies might be needed. Furthermore, user evaluations should be performed to test that the views accommodate for the user needs.

The feature specialists also expressed a wish for being able to formulate queries and getting answers in form of visualizations from the dashboard. This feature could also be created and tested with users to accommodate for more user needs. As the expert users knows best which questions they want answers to, this solution could accommodate for a diverse set of user needs.

8.5.4 Correcting Usability Issues

Several usability issues were identified in the formative and summative evaluations. These were for example too small size of checkboxes, too high speed of zooming in the map and seeing latitude and longitude instead of cities on the map. Future work would be to improve these issues. Although, several problems were due to limitations in Power BI, the program is continuously updated and it might be possible to change for example checkbox size and distance in the future. Furthermore, evaluations with the target group might find more issues. A dashboard with higher usability would make it easier for the users to achieve their goals.

8.5.5 Evaluating with the Target Group

As explained the last prototypes were not evaluated with the target group, due to the short term layoff caused by the Corona pandemic. The prototypes were evaluated with persons without expert knowledge in the truck industry. The usability of the dashboard was evaluated. Some of the participants had driver's license and could somewhat understand the content of the dashboard. However, the expert users at Volvo have a specific expertise. Only they will be able to explain how their needs could be accommodated for through the use of the dashboard.

To investigate whether the visualization enabled the feature specialists at Volvo to better understand driver behavior the dashboard needs to be evaluated with the target users. The expert users will be able to evaluate whether the dashboard accommodates for their needs and if they can achieve their goals with the help of it. An important step would therefore be to test the visualization with the target users. The tests would show how the dashboard could be improved to facilitate data driven design decisions.

9

Conclusion

The aim of this master thesis was to answer the following research question:

What should be considered when visualizing logged truck data to facilitate designers' understanding of driver behavior?

A sub question was answered to support the research question:

What are the user needs of the visualization to further understand truck driver behavior?

To answer the research question the thesis used Research through Design approach. An annotated design of a dashboard of visualizations of logged truck data was created, see Figure 7.3, which partly answers the research question, which Gaver (2012) suggests. During the process the sub question was answered. A set of diverse and specific user needs, see Appendix F, was identified. These needs are based on interview and focus group material from eight feature and ergonomics specialists at Volvo. The most important user needs were knowing which functions that was activated the longest duration of time and the frequency of used controls. The user needs were used as a basis for the data visualization dashboard called VDID.

Research suggest design activities contribute to a knowledge-generating process (Stappers and Giaccardi, 2017). The prototyping in the thesis of led to knowledge which were summarized as four key consideration areas. These considerations further answer the research question. The first consideration is to include users early in the design process, as recommended by previous research (Chiang, 2009). Users should be included early to ensure that diverse needs are found so that the needs can be accommodated for. The second and third consideration areas are that learnings from the human visual perception should be used and that colors should be carefully selected. These areas should be considered to facilitate understanding. The last area of consideration, specific for the truck industry, is that the number of logged trucks affect the viewer's trust of the insights they get from the data visualization.

The thesis concluded that the dashboard had high usability since goals could be achieved with the use of the prototype. However, due to the Corona pandemic evaluations were not performed with the target group. More tests with the target users are needed to make a certain conclusion. There is a gap in the research of using data analytics to enable understanding driver behavior in the truck industry. The thesis succeeded in contributing to filling the gap. The contribution was made by providing an example of what should be considered when designing a dashboard of logged truck data visualizations.

Conclusion

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Appendix A

Interview Guide Volvo Employees

Participant No ____

Number of years working as a feature/ergonomics specialist:

1-2 years

3-5 years

6+ years

1. What do you work with?

2. Is there any information that you feel that you are lacking about the truck driver behavior in your daily work? What? When?

3. Is there any information that you get from drivers under e that you are wondering if it is really true when the driver is out and driving in real life?

4. What functions/controls in the truck are you interested in getting more information about how the drivers use them?
 - a.ACC/CC? Time gap?
 - b.Traction functions?
 - c.Diff lock?
 - d.Climate functions?
 - e.Alarm?
 - f. Light?

5. *Show image of the trucks interface*. It is signals from these controls and functions that we are logging among others. It is signals from physical buttons and controls and ECU's in the truck.
 - a. Is there any of these controls or functions that you are extra interested in? Why? Under which circumstances?
 - b. Are there any functions or controls that you are interested in that are not in this truck?

6. Is there any special time of the day that you are wondering what the driver is doing? Why?

7. Is there any special situation that you are most interested in knowing what the driver does? Why?
8. Can you think of any special combination of functions or controls that you are interested in knowing?
9. Is there any special context that you are interested in? For example weather, road type.
10. Are you the most interested in the automatic functions or the functions that the driver turns on themselves? Why?
11. Is there any functions that are extra important to know more about how the drivers use them because of safety?
12. Right now, only one truck is logged. What types of trucks would you like to know more about if we were to log more trucks in the future? Why?

Thank you! Is there anything you would like to add about better understanding the drivers through data logging that we have not talked about?

Appendix B

Interview Guide Driver

How long have you been working as a truck driver?

1-2 years

3-5 years

6+ years

WORK DAY

1. What kind of goods do you drive?
 - a. How many deliveries per day?

2. About how far do you drive per day? (km)

3. What does your work day look like?
 - a. Driving, in that case how much?
 - b. Loading and unloading of goods, in that case how much?
 - c. Work outside of the cab (for example changing trailer), in that case how much?
 - d. Paper work, in that case how much?
 - e. Sleeping in the truck, in that case how much?
 - f. Waiting time, in that case how much?

4. What kind of roads do you drive on?

FUNCTIONS

5. What functions do you think you use the most in your work?

6. What controls/buttons do you think you use most often?

7. Do you have any problems with the functions? Why?

8. *Go through all functions and describe how you use them. When? How many hours per day?*

Flexible switches:

- What are on AUX 1 and AUX 2?

- How do you use RASEC?

Climate panel:

- Do you change the temperature or do you use the automatic mode?

Infotainment panel:

- Do you use the change song buttons?

Left of the steering wheel:

- Do you ever adjust the back light? When?
- Have you ever used black panel? When?

Steering wheel controls:

- Do you use ACC or CC? In what situations do you switch between them?
- Do you use Cruise Control to adjust idle running when you are standing still?
- Do you use downhill cruise? Together with Cruise Control?
- Do you use touch on the display or the steering wheel controls?

Levers:

- Do you drive on automatic of manual mode on the retarder? In which situations do you use manual mode?
- Do you use the brake program? When?

Panel above the driver seat:

9. Is there anything you use often here? Do you have any problems with anything?

Gears:

10. Do you drive on automatic of manual mode?

11. Do you use the display in the bunker? For what? To turn on lights?

Short break...

12. Do you have the engine on when the car is standing still? What are you doing then? Unloading?
13. Is there anything you change from the standard settings?
14. What functions do you usually turn on or off when you are starting your day?
15. Is there any functions that you use in a sequence? Which?
16. Is there any functions that you use in a combination? Which?
17. Is there any functions that you use on specific road types? Which?
18. Is there any functions that you use in any specific weather? For example rain or snow.
19. Is there any functions that you only use a specific time of the day? Which?
20. Is there any automatic functions that you turn off? When? Why?

Thank you! Is there anything that you would like to add?

Appendix C

Heuristic Evaluation

Heuristic	Dashboard violating or supporting	Placement
<p><i>“Information coding.</i> Perception of information is directly dependent on the mapping of data elements to visual objects. This should be enhanced by using realistic characteristics/techniques or the use of additional symbols.” (Forsell and Johansson, 2010, p. 203).</p>	<p>The ordered bar charts have high data density, meaning that they display many data elements for the user. This can make it difficult for the viewer to distinguish the relevant data.</p>	<p>Ordered bar charts.</p>
<p><i>“Minimal actions.</i> Concerns workload with respect to the number of actions necessary to accomplish a goal or a task.” (Forsell and Johansson, 2010, p. 203).</p>	<p>Filtering on the checkboxes can result in many actions. If the user wants to see only one category of controls or functions they need to uncheck all the other ones, in this case six clicks. However, if radio buttons would be used they would only be able to filter on all or one set of controls.</p>	<p>Checkboxes in filter pane.</p>
<p><i>“Flexibility.</i> Flexibility is reflected in the number of possible ways of achieving a given goal. It refers to the means available to customization in order to take into account working strategies, habits and task requirements.” (Forsell and Johansson, 2010, p. 203).</p>	<p>The filter pane provides customization in order to achieve different goals. The map can also be used to filter on an area. The bars can be clicked to filter on a specific function.</p>	<p>Entire dashboard.</p>
<p><i>“Orientation and help.</i> Functions like support to control levels of details, redo/undo of actions and representing additional information.” (Forsell and Johansson, 2010, p. 203).</p>	<p>The filter pane enables the user to control the level of details. The navigation bar shows which tab the user is at. However, the multiple navigation elements in the Power BI Sharepoint and the dashboard can become confusing for the user. Redo and undo is not supported.</p>	<p>Filter pane.</p>
<p><i>“Spatial organization.</i> Concerns users’ orientation in the information space, the distribution of elements</p>	<p>The elements are not occluded by each other. However some information elements in the ordered bar charts are hidden and need to be scrolled down to</p>	<p>Ordered bar charts.</p>

<p>in the layout, precision and legibility, efficiency in space usage and distortion of visual elements.” (Forsell and Johansson, 2010, p. 203).</p>	<p>be displayed. This makes it harder to locate unused functions and controls.</p>	
<p>“<i>Consistency.</i> Refers to the way design choices are maintained in similar contexts, and are different when applied to different contexts.” (Forsell and Johansson, 2010, p. 203).</p>	<p>All cards are labeled except for the map card, which is an inconsistency. The sliders and checkboxes are consistent and their design is maintained. Since the design consists of only one view this heuristic is difficult to assess.</p>	<p>Entire dashboard</p>
<p>“<i>Recognition rather than recall.</i> The user should not have to memorize a lot of information to carry out tasks.” (Forsell and Johansson, 2010, p. 203).</p>	<p>Since the data for all controls and functions are displayed the user does not need to toggle between different groups of controls. Instead they can select the area of controls that they are interested in in the filter pane. In this way they do not need to memorize information. However, if they are comparing which of all controls or functions are being used most often or least often they need to scroll up and down in the bar chart and remember which function or control it was. Furthermore, to see the exact amount of a bar chart the user needs to hover above the bar. Therefore they need to memorize that specific number if they want to compare several bars by exact amount.</p>	<p>Ordered bar charts.</p>
<p>“<i>Prompting.</i> Refers to all means that help to know all alternatives when several actions are possible depending on the contexts” (Forsell and Johansson, 2010, p. 203).</p>	<p>The filter pane is always open and reveals all available actions.</p>	<p>Filter pane.</p>
<p>“<i>Remove the extraneous.</i> Concerns whether any extra information can be a distraction and take the eye away from seeing the data or making comparisons.” (Forsell and Johansson, 2010, p. 203).</p>	<p>The red colored truck can draw unnecessary attention and seen as a high light. This since its color stands out from the rest of the colors. The truck icons can also be seen as drawing unnecessary attention.</p>	<p>Truck details card.</p>
<p>“<i>Data set reduction.</i> Concerns provided features</p>	<p>The filtering options is a way of reducing the data set. However, their efficiency</p>	<p>Filtering pane.</p>

for reducing a data set, their efficiency and ease of use.” (Forsell and Johansson, 2010, p. 203).	cannot be evaluated with the high fidelity prototype. The ease of use is best evaluated through a usability test.	
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Appendix D

Formative Evaluation Guide

Participant no ___

My master thesis is about visualizing logged truck data to better understand driver behavior. I designed a dashboard that shows the logged data. This is a prototype, and everything is not working as it should. Some elements are clickable. I am going to give you some tasks to perform. Please talk out loud and tell me what you are doing or if you have any opinions when you are completing the tasks. It is not you that I am testing, it is the design. The test is anonymous.

You are working as a designer of the truck interface at Volvo. You are interested in knowing more about how the drivers uses the truck.

Tasks:

1. Look at the dashboard and go through what you are seeing.
2. Which function is being used the most?
3. Which control is being used the least often?
4. Locate the windscreen wiper function and tell me exactly how many hours it has been used.
5. Which controls are being used the most often at 45 km/h?
6. Which function is being used the most often by long haul trucks?
7. Which controls are being used the most in the Gothenburg area?
8. Between what dates have the trucks been logged?
9. How many trucks have been logged?
10. What is the middle bar chart displaying?
11. What is the right-most bar chart displaying?

Interview:

12. Did you have any problems while using the dashboard?
13. What was good with the dashboard?
14. What was bad with the dashboard?
15. What did the colors of the trucks mean?

Appendix E

Summative Evaluation Guide

Participant no ___

Intro

My master thesis is about visualizing logged truck data to better understand truck driver behavior. I designed a dashboard that shows the logged data. Please talk out loud and tell me what you are doing or if you have any opinions when you are completing the tasks. It is not you that I am testing, it is the design. The test is anonymous.

You are working as a designer of the truck interface at Volvo. You are interested in knowing more about how the drivers uses the truck in order to improve the truck interface.

Tasks

1. You want to know the details of the logged truck. What type of truck is being logged?
2. You are wondering which function the driver uses the most. Which function is being used the most?
 - How many hours has that function been used?
3. You are wondering if there are any functions that the driver never uses. Which functions are being used the least?
4. You want to know which function the driver uses the most in the evenings. Which function is being used the most between five o'clock until mid-night?
5. You want to know which light is being used the most at high speeds. Which light is being used the most between 80 and 90 km/h?
 - How many hours has it been on at high speeds?
6. You know that it was very rainy in the end of November and want to know how much the driver used the windscreen wipers that time. How many hours was the windscreen wipers used in November?
 - Where did the truck driver drive that week?

Interview after test

1. What conclusions could you make from the visualization?
2. What did you perceive as the most important information in the dashboard? *Why?*
3. What was good with the dashboard? *Why?*
4. What was bad with the dashboard? *Why?*
5. Did you have any problems with the dashboard? *Why?*

Appendix F

User Needs

As a feature/ergonomics specialist...

General driver interaction

...I want to know which buttons are used in sequence so that I can understand which buttons should be placed next to each other. (All)

...I want to know which functions are used in combination so that I can create requirements to improve the user experience. (All)

...I want to know the usage frequency of different controls so that I can create requirements to improve the user experience. (All)

...I want to the duration of activation of different functions so that I can create requirements to improve the user experience. (All)

Unused functions

...I want to see if any of the duplicate controls are redundant so that they can be replaced or removed to improve the user experience. For example, steering wheel controls in relation to the dashboard controls. (3)

...I want to know which of the functions that have automatic modes that are in manual mode and when so that I can understand if the automatic functions are good enough. (5)

...I want to know which functions the driver turns off so that I can understand which they are and when they are not working, so that I can create requirements to improve these functions. (4)

Dashboard Controls

...I want to know how often the driver uses the controls in the dashboard, so that I can prioritize which buttons should be close to the driver. (All)

Flexible Switch Panel in Dashboard

.....I want to know how often and when all flexible switches are used so that I can prioritize which functions should be placed where. (5)

...I want to know how much the traction functions are used since there is an indication showing when they are on. (3)

...I want to know when RASEC is used since I do not know how the drivers use it. (2)

...I want to know if and how hill start aid is used so that I can improve the function requirements. (2)

...I want to know how often ESP is turned off so that I can create requirements to improve these functions.

...I want to know if the driver uses AUX so that I can prioritize what functions should be placed where. (2)

...I want to know how often the safety functions (LKCS, DAS, FCW and LCS) are used so that I can improve the requirements for the functions. (3)

...I want to know if, how often and when the safety functions (LKCS, DAS, FCW and LCS) are turned off so that I can understand how to make requirements to improve them. (2)

...I want to know when PTO is used so that I can prioritize what functions should be placed where. (2)

...I want to know when the bogie lift is used so that I can understand what the user uses it for. (2)

Climate Panel

...I want to know if the climate panel is used during stand still or while driving so that I can decide if the functions should be placed on physical buttons or in displays. (4)

...I want to know if they use the automatic mode or the manual of the climate controls so that I can understand if they are content with the automatic mode. (2)

...I want to know how often the drivers use defroster so that I can improve the requirements of the function.

Infotainment Panel

...I want to know if the change-song-buttons are used so that I can decide if the placement should be on the steering wheel or on the SID panel. (4)

...I want to know if the navigation, Dynafleet and camera buttons are used so that I can understand if they can be moved to the SID. (2)

...I want to know if the drivers use the 1-4 buttons, so that I can decide if they can be replaced with other functions. (2)

...I want to know how much drivers use audio, so that I can understand if it is a common secondary task while driving. (2)

Emergency brake

...I want to know how the driver uses the emergency brake so that I know if they know how to use it.

Steering wheel keypads

...I want to know what buttons are the most used and if any is not used, so that I can prioritize which functions should be on the steering wheel. (3)

...I want to know if, when and under which circumstances the user switches between ACC and CC, so that I can understand if CC needs to be kept as a button. (5)

...I want to know if the driver changes the time gap and over speed of the cruise control and when, so that I can prioritize the placement of the button. (2)

...I want to know when the driver uses downhill cruise in relation to ACC/CC, so that I can prioritize which functions that should be placed on the steering wheel.

...I want to know how long the driver is in the menu, so that I can improve the user experience of the SID.

...I want to know if and how often the drivers use the focus shift button, so that I can decide if it needs to be changed, kept or removed. (3)

...I want to know how long the driver is in the instrument cluster in relation to the SID, so that I can create requirements to improve the user experience.

...I want to know if back or home is used the most, so that I can create requirements to improve the user experience. (3)

Levers

...I want to know if the rain sensor button is used and when so that I can understand if the driver uses it to improve the user experience. (3)

...I want to know how often and when the stalks are used so that I can create requirements to improve or possibly remove the stalks. (3)

...I want to know whether the drivers are using the automatic or manual mode on the rain stalk, so that I can create requirements to improve the automatic mode or possibly remove the manual mode. (2)

...I want to know if the driver changes the retarder manually or has it in automatic, so that I can create requirements to improve or possibly remove the stalk. (4)

...I want to know if the driver uses the brake program button, so that I can understand if they find it. (2)

Exterior and Interior Lights

...I want to know if the drivers use Black Panel, so that I can understand if they find it. (4)

...I want to know how much the exterior light controls such as Back Light are used, so that I can understand if they can be moved to a display. (3)

...I want to know if and in which situation the drivers use the automatic mode or manually adjusts the lights, so that I can understand if the drivers are content with the automatic mode.

...I want to know how often and when different interior light modes are used, so that I can improve the layout of the buttons. (3)

Gears, brake & Steering wheel

...I want to know which gear modes (A/N/R/M) the driver uses, so that I can create requirements to improve the gear box. (2)

...I want to know how much the driver drives in manual gear mode and in which situations, so that I can understand when they are not content with the automatic mode. (2)

...I want to know how much the driver turns the wheel, so that I can improve the ergonomics of it.

...I want to know how often and how much the driver uses the brakes so that I can improve the ergonomics of the brakes.

...I want to know frequency of use and amplitude of the gas pedal for different transport segments, so that I can create requirements to improve it.

Context

...I want to know which controls are being used during drive or standing still, so that I can understand which functions need to be on physical controls or if it is acceptable to have them in a display. (3)

...I want to know which controls are being used during different times of the day such as morning, day, evening and night, so that I can optimize the controls and functions for these times. (6)

...I want to know how the drivers use ESP and traction control on roads with hills, so that I can improve the requirements for these functions.

...I want to know how the SID controls are being used during driving, certain speeds and situations in relation to the steering wheel buttons so that I can prioritize which functions should be placed where. (3)

...I want to know in which situations and locations the driver uses the retarder stalk, so that I can understand how to improve it. (3)

...I want to know if diff lock is turned off in hills or curves so that I can create requirements to improve the functions.

...I want to know if the security or traction functions are turned off in hills so that I can create requirements to improve the functions. (2)

...I want to know which functions the user uses in slippery weather conditions such as rain or snow and around zero degrees so that I can create requirements to improve the functions. (2)

...I want to know which controls the driver uses when he starts or ends his shift so that I can improve the user experience. (3)

...I want to know which functions and controls are used on different road types so that I can improve the requirements of these functions. (4)

...I want to know which functions and controls the driver uses during different feature modes so that I can understand how the driver behaves in different times of the day. (2)

...I want to know which functions and controls the drivers use during different speeds. (4)

...I want to know if diff-lock is turned off in curves or hills so that I can understand when the function is not working in order to improve it.

Future logging

...I want to know how a greater scale of drivers interact with the truck interface, so that I can with certainty make data driven decisions to improve the user experience of the truck. (All)

...I want to log on a wide range of trucks in the different sections – long-haul, distribution and construction. (All)

...I want to understand in which situations the driver gets warnings from the safety systems, so that I can understand if it is too many. (2)

...I want to know which media source is being used the most (FM, AM TV, USB or Bluetooth) so that I can improve the user experience in the display.

...I want to know if the driver lets the warnings and notifications stay in the instrument cluster or if they press ok/esc to get rid of them, so that I can improve the user experience of the instrument cluster. (2)

...I want to know how heavy the truck is loaded when turning off automatic passable functions, so that I can create requirements to improve the automatic functions.

...I want to know how the driver uses the displays in the truck so that I can prioritize the views and controls in them. (4)

...I want to know how the drivers use the door panel controls, so that I can improve the layout and the functions. (2)

...I want to know the driver's seating and steering wheel preferences, so that I can improve the ergonomics of them.

...I want to know which functions the driver uses when entering and exiting the truck and frequency of enter and exit, so that I can improve these functions.

...I want to know the frequency and time of use of the different kitchen supplies that the driver uses while living in the truck, so that I can decide when they should be on and off.

...I want to know how often the driver charges electrical devices, so that I can prioritize the charging ability.

...I want to know how often the drivers use wireless remote controls to raise or lower the truck while loading and unloading so that I can prioritize if they are needed. (2)

...I want to know where the driver looks while driving, so that I can improve the security of the truck. (2)

...I want to be able to see individual behavior, so that I can improve the user experience for different individuals. (2)

Trust

...I want to know how the data has been manipulated so that I can trust the insights I make from it.

