Tampereen yliopisto

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# DESIGNING AUGMENTED REALITY FOR PASSENGER CARS

## Literature review

Faculty of Information Technology and Communication Sciences
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# ABSTRACT

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Augmented reality is soon fully enabled in modern passenger cars. This is why it is important to cover the aspects that must be taken into consideration when designing augmented reality for passenger cars. This literature review will take a dive into a world of augmented reality and passenger cars and explores the factors that affect user experience in such a world.

In passenger cars augmented reality can be utilized visually through windshield. Current solutions can display mostly static information on the windshield in the proximity of the driving wheel. This is about to change. In more futuristic approaches larger surface area of the windshield can be utilized which enables more information to be displayed. These approaches are also able to fix information according to the real-world environment which results in true implementation of augmented reality.

This literature review will take a look into what needs to be considered when designing content on the windshield of a passenger car using augmented reality. I will cover how the use of color affects the readability of the content on the windshield and what needs to be considered when designing colors. I will explore how to approach the use of opacity when designing content and functionality on the windshield. Thesis will cover what types of content users desire on the windshield and how it should be located and arranged on the windshield including the depth behind the windshield. In addition, this literature review will take a look how should one approach using augmented reality in automated vehicles. Thesis will also take a look into content size including the minimal size which the content should be displayed and how size of different information categories should be thought on the windshield display. All this will be done in the context of current solutions in utilizing augmented reality, more advanced solutions which are still in development and in the context of manual and automated vehicles.

Regarding colors, it turns out that the use of color is somewhat limited in the content on the windshield display. Varying scenery and lightning behind the windshield make it difficult to adjust colors so that they work in every situation and lighting condition. This limits the available color which perform well with these limitations. It also turns out that use of opacity needs to be carefully implemented. Content types that users desire somewhat include information that is currently located in the head down display and information cluster. In, addition as the surface area grows bigger in the more futuristic approaches the desire for content grows too. In the context of automated vehicles this insight strengthens even more. Use of automated vehicles creates a desire for content that focuses on entertainment and other pleasure activity. The amount of content quantity varies between manual and automated driving. In the context of automated driving the quantity of content increases. Regarding location and arrangement, the most favorable place which should be utilized for the support of primary task, which is driving, is in the proximity of the driving wheel. For secondary tasks, even the periphery of the windshield can be utilized for content. The use of depth is encouraged as it increases the user experience and enables categorization of the information.

As the studies which this literature review will cover are mainly done with prototypes and in laboratory conditions the results might not reflect how they would work in the real-life situation. More studies in real-life conditions are needed to be performed to counter this issue. Future research should be focused in combining the information discoursed in this thesis. For example, the use of opacity as a background to counter the readability problems of certain colors and how minimal size affected in different depth levels behind the windscreen. Also, the categorization of information should be studied. Future research should also focus on diving deeper on what types of content are truly desired and do they benefit from being moved to the windshield.

Key words and terms: Augmented reality, passenger cars, literature review

The originality of this thesis has been checked using the Turnitin OriginalityCheck service.

# Contents

# 1 Introduction

Augmented reality is a concept of mixing digitally produced information into a real-world environment. Therefore, it leaves a lot of room for interpretation of how to define the term augmented reality. Although the opinions of the definition may vary, some aspects of the concept still stay the same. One of the key aspects is that even if you are using augmented reality, you remain in the "real world". This means that the real world is still visible and audible even though augmented reality is superimposed on it. This is the key difference compared to virtual and mixed reality (Craig, 2013). Digitally produced information usually means visual information but for example different types of haptic feedback can be included into the definition of augmented reality (Yu & Wu, n.d.)

The increase in use of augmented reality will continue throughout this decade (Statista, 2023). Augmented reality is already in use at car industry at some degree, and there is a lot of potential to make better use of utilizing augmented reality in passenger cars. Augmented reality can be enabled in multiple ways such as head mounted displays (HMD), type of smart contact lenses, through smartphone or other similar way (Cipresso, 2018). This thesis focuses on how augmented reality is enabled in passenger car visually through a windshield display. Augmented reality has the possibility to further enhance the user experience in passenger cars for its possibility to display more information close to the driver and expand this information with the available space on the windscreen (Gabbard et al., 2014). This is why it is important to study the use of augmented reality in passenger cars.

There have been a lot of studies with different aspects regarding augmented reality and passenger cars and the overall status of the research surrounding the use of augmented reality in passenger cars is wide. Boboc et al. (2020) did a literature review of usage of augmented reality in the car industry in which they wanted to find out where augmented reality is being utilized, in what kind of applications it is used in and how these applications would be characterized and what kind of benefits these solutions bring to the table. Riegler et al. (2022) did a literature review of how augmented reality is being utilized in automated driving and categorized the literature into application areas. Regarding safety and user groups that are considered risk groups, several studies have been conducted. Kim & Dey (2009) studied if augmented reality powered navigation system would help elder drivers with the declining spatial cognition. Wai-Tat et al. (2013) studied if augmented reality could be utilized to prevent collision and other driving hazards for old and young drivers. Augmented reality has been studied also as a way to improve navigation. Regarding navigation, Utsuboya et al. (2013) studied augmented reality powered navigation system in a passenger car. Jose et al. (2016) compared head-up display, head mounted display and heads down display as a way to introduce augmented reality powered navigation cues to the driver. Bark et al. (2014) presented an augmented reality navigational aid and tested a prototype of more advanced solution for depth recognition. User experience benefits from many different aspects have been studied also. Kim & Dey (2016) presented how augmenting human senses with augmented reality and haptic technologies can improve performance of the driver. Carotenuto et al. (2014) presented a system which uses augmented reality through mobile phone to explain dashboard lights. There are a lot of studies regarding situation awareness. Eyraud et al. (2015) conducted a user study in which users watched videos of driving with augmented reality cues attached to general driving task or to an incoming maneuver. Tonnis et al. (2005) compared two solutions in which they informed the driver of dangerous situations. First solution focused on highlighting the danger from drivers frame of reference and the second solution from exocentric frame of reference. Charissis & Naef (2007) conducted a user study to find out the focusability of the information on the head-up display and how it affects the performance of the driver.

This literature review will take a look into how augmented reality is enabled and utilized in passenger cars and what needs to be considered when designing augmented reality on windshield displays to create a good user experience and driving performance. User experience design is meant to deliver meaningful and relevant experiences to user in addition to the ease of use of the product (Interaction Design Foundation, 2023). Another definition for user experience is that it helps users to carry out tasks successfully and effectively which results in users' thoughts about the system (ISO, 2019). I will go through the visual factors that affect user experience moving from individual element properties, such as content color, content size and content types to how this type of information is located and arranged on the windshield. In addition, I will explore the size of the content windows. In addition, we will take a glimpse of how these factors work in applications to improve the functions that automated vehicles bring to the table. This thesis will cover these factors in manual drive perspective, but also through automated vehicles perspective. Automated vehicle means that the vehicle is able to drive by at itself at least for some degree and the driver can therefore focus on other activities (Hummer, 2020). Automation levels are defined by SAE international into 5 levels, in which level 5 means fully automated driving and for example level 3 that the car is not fully capable of independent driving but requires human interceptions, for example take over scenarios

(Synopsys, 2022). When I am talking about automated driving, these are the levels that are taken into consideration.

The goal of this thesis is to explore the world of augmented reality, windshield displays and passenger cars from visual standpoint. There is no clear research question, but the goal is to get a broad view on the subject. I want to how augmented reality is enabled in passenger cars, what needs to be considered when designing augmented reality, what needs to be considered when positioning content on windshield display to achieve the best driving performance and user experience and what implications does automated driving bring to the table. Therefore, there is no hypothesis.

In Chapter 2 I will go over my literature review process and define the different literature review types. In Chapter 3 I will go through how augmented reality is enabled in passenger cars. In chapter 4 I will explore how to design augmented reality for passenger cars and what to consider. In chapter 6 I will reflect my work, discuss my thesis limitations and what should further research focus on. In Chapter 7 I will sum up my findings.

# 2 Literature review

This chapter will define the literature review, the traditional literature review and the methods and steps included to conduct it. I will also explain the steps I took while conducting my traditional literature review.

## 2.1 Definition of literature review

Literature review is a systematic review of academic papers regarding a chosen topic. Literature review is supposed to critically analyze, evaluate and integrate findings in these papers. Literature review also investigates the approaches that the publisher took in his or her research. Literature review's goal is to gather an overall understanding of the chosen topic and the research around it. To achieve that, the conductor of the literature review should compare different studies and theories in order to expose potential gaps in the research and to acknowledge what more could be researched around the topic. Literature review can act as a basis for future research but is not solely aiming to be such. (Efron & Ravid, 2019)

According to Efron & Ravid (2019), literature review process can be divided into six steps. These steps are described in Figure 1. They also describe literature review as a continuous process, so the steps in the process should be viewed with that in mind. (Efron & Ravid, 2019)

Literature reviews can be divided into subsets. These include systematic literature review, traditional - narrative literature review and hermeneutic - phenomenological literature review. Systematic literature review can be described as highly structured, and protocol driven. Unlike other types of literature reviews, systematic literature review usually answers a focused and specific question that is generated before conducting the literature research. Systematic literature review includes comprehensive research of the studies regarding the chosen topic to identify all the possible aspects. The role of the writer is to stay neutral and unbiased during the review. (Efron & Ravid, 2019)

Traditional literature review is the most common one of the literature review subsets. It can be described as a mix of different academic disciplines, and it can include a variety of different research methods. It ties together the main points from a large sum of research and can find new holes in the research and guide the way for future research. The research question might evolve during the traditional literature review process since the review starts with a stated problem or a declared question. The traditional literature review might end up with not answering a specific research question but to offer a comprehensive understanding on chosen topic. Traditional literature review does not try to locate all the literature around the chosen topic and usually for example the search criteria and methods are not included in the review. Therefore, traditional literature has gathered criticism since the process can't be backtracked. (Efron & Ravid, 2019)

Third subset of literature reviews is a hermeneutic-phenomenological literature review. This type of literature review is often used in more philosophical research and the outcome of the review should not be seen as a truth but as a conversation base for the researchers. (Efron & Ravid, 2019)

**1. Choosing a literature review topic**

- Choose a meaningfull topic
- Narrow down or broaden your topic according to limiting factors
- Form research question(s)

**2. Locating literature review sources**

- Identify proper search and keywords
- Plan a search strategy
- Record the sources that you use
- Start your bibliography

**3. Analyzing and evaluating literature review sources**

- Read the research material you gathered
- Decide if the source should be included in your review
- Document the relevant themes and issues
- Evaluate the chosen sources

**4. Organizing and synthesizing the literature and building an argument**

- Assemble the analysis of each individual sources into well structured persuasive and holistic narrative
- Construct logical arguments from your point of view

**5. Developing a writer voice and following writing conventions**

- Decide your writer voice
- Decide citation and reference style
- Keep citation and reference style consistent

**6. Writing, editing, and refining the literature review**

- Write, edit and refine your literature review
- Iterate if needed

Figure 1. Literature review process according to Efron & Ravid (2019)

## 2.2 My literature review

This section will define my personal process when conducting my traditional - narrative literature review. Since this is a traditional - narrative literature review, I do not have a clear hypothesis over anything, but the study is meant to give background information on how augmented reality is utilized in passenger cars. More precisely, how does these applications improve the driving experience and who benefits the most over this new tech.

Because the nature of traditional - narrative literature review, there is no attempt to locate all the relevant sources of the use of augmented reality in passenger cars. The inclusion criteria, exclusion criteria, search strategies or the strategies for data analysis will not be available. Also, there will not be a list of duplicate sources.

### 2.2.1 First round for locating sources

According to David and Ravid (2019) process for conducting literature review step number two includes locating literature review sources. I started my first round of locating sources in the spring of 2021.

First round of locating sources included a bit of background study of what kind of information there is available in the field of use of augmented reality in passenger cars. The result was that there are actual scientific studies that map how some augmented reality application is utilized on the target group. There is a lot of not so scientific papers available also. A lot of newspapers especially in the world of cars have taken an interested in this new technology in the passenger cars and how it affects the user experience of driving a car.

I used the following search services in the first round of locating sources:

**Andor**
Andor is an online search service for the collections of the Tampere University Library. The search service includes multiple different databases. (Tampere University Library, 2022)

- Car AND dashboard AND augmented
    - Results: 3626 pcs.
    - Included: 13 pcs.

- Windshield AND augmented AND reality
  - Results: 3503 pcs.
  - Included: 4 pcs.

- Holographic AND navigation AND system
  - Results: 5184 pcs.
  - Included: 0 pcs.

- Car AND augmented AND reality
  - Results: 59689 pcs.
  - Included: 1 pc.

- Windshield AND augmented AND reality AND hud
  - Results: 1053 pcs.
  - Included: 0

Total included: 18 pcs.

**Google Scholar**
Google Scholar is an online search service for scholarly literature. The service can be used to locate articles, theses, books, abstracts and court opinions which are listed or created by academic publishers, professional societies, online repositories, universities or other web pages. (Google Scholar, n.d.)

Since not all the search words I used in Andor resulted in good sources I did not use them in Google scholar. Search words that I used for locating sources in Google Scholar included the following:

- Car AND dashboard AND augmented
  - Results: 8170 pcs.
  - Included: 1 pcs.

- Windshield AND augmented AND reality
  - Results: 8000 pcs.
  - Included: 3 pcs.

- Car AND augmented AND reality
    - Results: 202 000 pcs.
    - Included: 2 pc.

Additional two sources were located from the reference lists of located sources

Total included: 6 pcs.

The initial idea was to include all the material to cover the whole area of augmented reality and how it is utilized in passenger cars. This resulted in a lot of material which I had no chance to properly go through. These sources included a lot of information from individual design solutions, for example supporting elder driving, to more high-level studies, for example information location and content size.

### 2.2.2 Second round for locating sources

Second round of locating sources focused on including sources that were mentioned in other studies.

- Sources from other studies
    - Included: 6 pc.

### 2.2.3 Writing phase

In writing phase I tuned my inclusion criteria and excluded some of the included studies since they did not fit the angle I was aiming for with my literature review. At writing phase, I decided to focus only these high-level studies which affect the user experience as a whole. This resulted from the fact that I could not have gone through all the matters these studies regarded with the resources I had. Also, some of the studies were dated, which made me focus on more recent studies to make the literature review more relevant.

- Studies excluded while writing
    - Excluded: 17 pc.
- Overal studies included to writing phase
    - Included: 13 pc.

# 3 Augmented reality in passenger cars

Passenger car dashboards have been through a radical change during the last two decades. For most of the time cars' dashboards have been dominated by analog controls and meters. Starting from the seventies when Aston Martin introduced the first digital applications for cars' dashboard have the dashboards became more and more digital. This, and the need for more information and controls have turned a modern passenger cars' dashboard into a tablet that hosts most of the controls and information about the car. (Horrell, 2014)

This information flood and the need to present the data to the driver without losing the focus from driving has brought augmented reality into a modern-day car. Next, I will explain the background of how the augmented reality is enabled in a car.

## 3.1 Head-up displays (HUD)

Head-up displays classification is loose. One description is that Head-up display is a transparent display that can present data. The main advantage and the main point of the classification is that the driver does not have to take his or her eyes off the road to receive the data but is instead displayed at his or her field of view. This data can be for example speed, warning signals or navigation directions. (Wheeler, 2016)

Head-up displays would not fit the description of augmented reality today and it can be seen as a precursor of augmented reality (Martindale, 2019). The same design principles still play a role and are still noteworthy in the more futuristic technical solutions.

Head-up display (HUD) creates a virtual image in front of the driver's field of view on the windshield of the car. Its advantage is that the driver does not have to take his or her eyes off the road and the presented data can be acknowledged without the driver having to turn his or her vision to the traditional head-down display. (Knoll, 2016)

Head-up display casts the data to the windshield of the car. As shown in Figure 2, the HUD unit casts a picture into the combiner which then projected on or in front of the windshield (NS West, 2022). In Figure 3 Mercedes-Benz (2022) pictures its solution for head-up display, how the information is displayed and what it could contain.

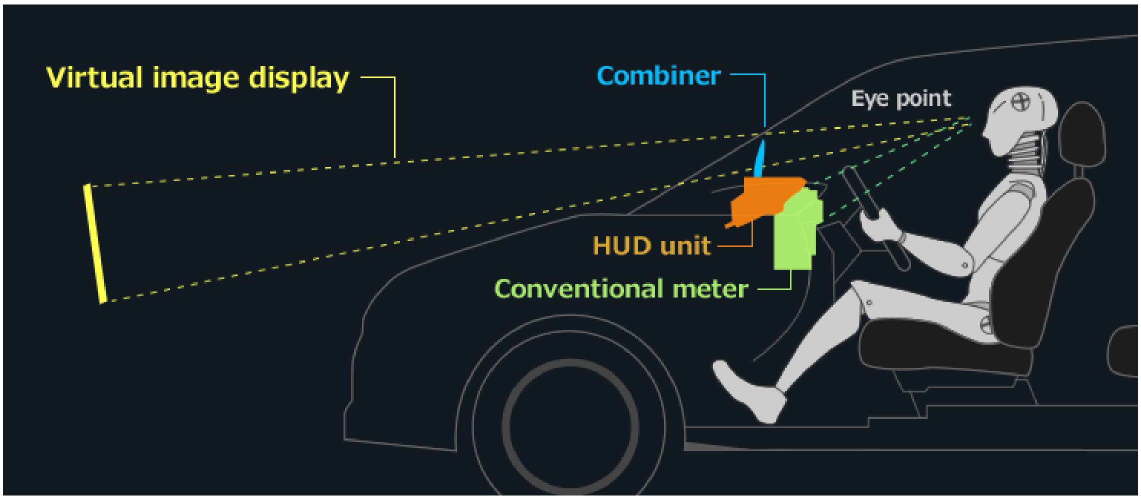


Figure 2. Working principle of a head-up display according to NS West (2022)

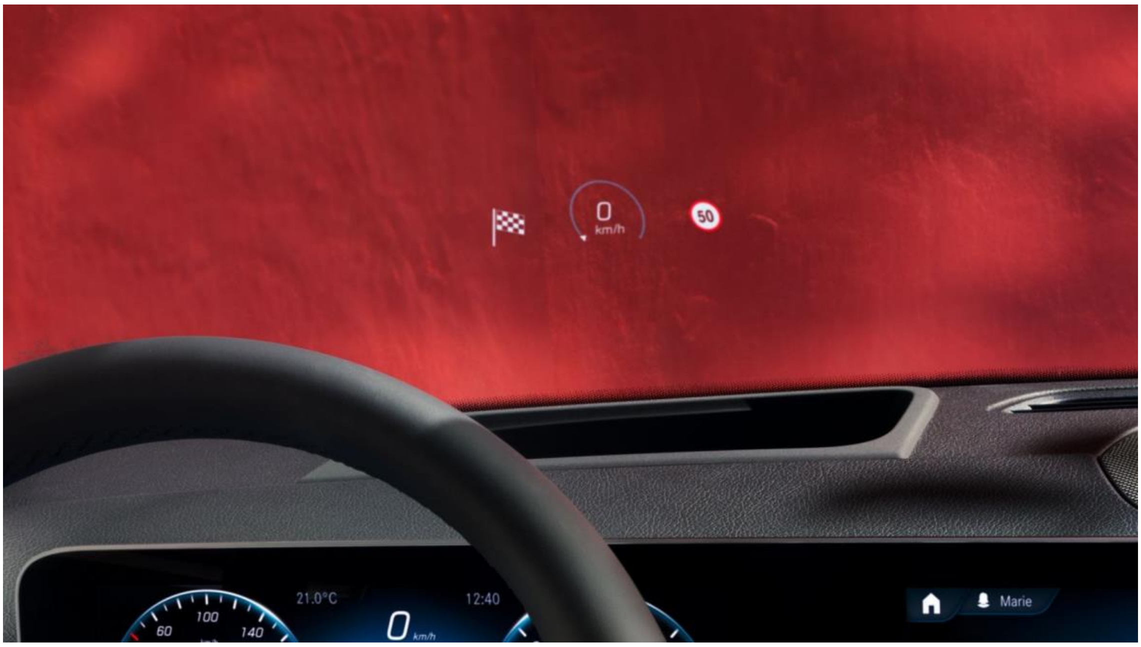

Figure 3. Head-up display by Mercedes-Benz (2022)

### 3.2 Augmented reality head-up displays (ARHUD)

Augmented reality HUD (ARHUD) is the next generation of head-up displays. The main advantage of this new generation is the larger field of view. Larger field of view enables that the information on the windshield can be placed to the same exact location where it is in nature. For example, if the navigation tells you to turn right from the next cross section, the ARHUD can locate the turn sign on the windshield where the cross section is in nature. As you drive closer to the cross section, the turn sign can keep its place in the right place compared to nature. (Knoll, 2016)

A concept of a ARHUD is displayed in Figure 4 in which the 3D elements, for example the navigation cues displayed as arrows, are attached to the natural surroundings. In a live version of this concept the arrows indicating the turn would be placed statically to the placement of the turn and would appear closer and closer when the driver approaches the turn. The concept also includes static information that is attached on the windshield, such as the speed limit and current velocity.


Figure 4. ARHUD concept by Mercedes-Benz (2022)

### 3.3 Windshield displays

The use of term windshield display varies across studies and the timeframe that the study was done in. This is why it is hard to define windshield display as a term. Windshield display (Figure 5) can be defined as a synonym for augmented reality head up display, as a larger version of classic head up display (Takaki et al., 2011). Another definition for a windshield display takes the capabilities of this technology even further. As stated in the previous section, augmented reality head up display still only cover a small area on the windshield and therefore the amount of information that can be comfortably located is limited because classic head up displays and augmented reality head up displays focus only on providing information to the driver's field of view.

More modern definition for windshield display, as the name already implies, is a display which covers the whole of the windshield (Häuslschmid et al., 2015). This enables the information to be placed across the windshield, making it possible to involve information regarding secondary and tertiary tasks. Windshield displays enable more complex information to be placed, for example more world fixed information and points of interested, according to the real-world surroundings (Riegler et al., 2022). Windshield displays by this definition are not production ready and is most commonly associated with automated driving.

So, it could be described that windshield displays possess the properties of head up display but enable these features in more wide and technically advanced way. This is the context that the windshield is addressed in this thesis.

Figure 5. A concept of windshield display showing the capabilities of world fixed information and periphery information (Riegler et al., 2022)

# 4 Augmented reality, windshield displays and user interface design

In this chapter I will go through aspects of user interface design in the context of windshield displays and augmented reality through research done on this part. The chapter will take a look into different type of content that help or supplement the user experience of a windshield display enabled vehicle. We will start with the basics of displaying content on windshield display such as color and opacity theory. I will explore what the size of individual content element should be and what are its minimal size limits. In addition I will explore the desired sizes of content blocks. Trough the context of content, we will also go through how much information should be offered to the user in different driving contexts and what type of information should this be. Later on we explore the research done on content location and arrangement and how depth behind the windscreen affects and dynamic vs static positioning affect this. In the end we will explore couple of use cases from a more futuristic approach mainly focusing on self-driving cars and what implication this creates in the context of user interface design.

## 4.1 Content on windshield display

This chapter explores some of the attributes that affiliate with user interface design of content on windscreen displays through augmented reality. This includes color and opacity theory, and of which size should the individual content element or group of information be. In addition, I will explore the desired content on windshield displays in different driving contexts.

### 4.1.1 Content color and opacity

Color plays an important role in user interface design for its ability to convey visual appeal, data encoding and meaning (Martinson & DeLong, 2012). This importance needs to be especially considered while designing content for windshield displays because of the use context. While driving, the scenery and lightning situation behind the windshield display constantly change, which proposes a threat for content readability. This is why it is important to research color theory on windshield displays. Another thing to consider is opacity. How can opacity levels be utilized while designing content for windshield displays and what opportunities and threats it proposes?

Gabbard et al. (2022) studied color perceiving trough head-up display. Because the outside view through and light conditions vary throughout the journey, they wanted to find out which colors would be most suitable for this type of design scenario and what properties the colors that perform well possess. The way they did this was through a user study in which the users sat in a car which had a head-up display which projected text and symbols onto the windshield. The test was performed in a real-world condition with different “views” from the windshield in varying lighting. There were different backgrounds, brick (red), grass (green) and pavement (grey). Chosen colors for the HUD projection were blue, brown, green, orange, pink, purple, red and yellow. In the study, participants completed two types of visual search tasks. In text search task participants located number of target letters from a set of letters and in symbol task participants located target symbol from a set of symbols. Text size was 1 degree in height and symbols height was set at 0.067 degree to 1.67 degree. In addition, there was a color matching and naming task. In color matching task participants chose a color from a tablet, displaying a predefined set of color map, that they thought matched the color that the HUD was projecting. In color naming task participants had to name the color projected by the HUD. For the visual tasks, response time and error rates were measured. In ambient lighting, there were no significant differences in response time between the chosen colors. As expected, the response time for text task was significantly higher than for symbol task. Also, error rates for text were higher than for symbols. For naming accuracy, it was found out that blue, yellow and green performed best with above 80% accuracy while other colors (brown, green and yellow) only achieved 0-40% accuracy. Analyses of these findings focused on dispersion and color shift. Dispersion resulting from the differences of participants individual sight and shift from resulting from color blending through different backgrounds. It was found out that the lower the shift (Figure 6) and dispersion (Figure 7) results in higher naming accuracy, which also held true in the case of blue, green and yellow. The analyse also reported that high luminance level of the color results on better naming accuracy.

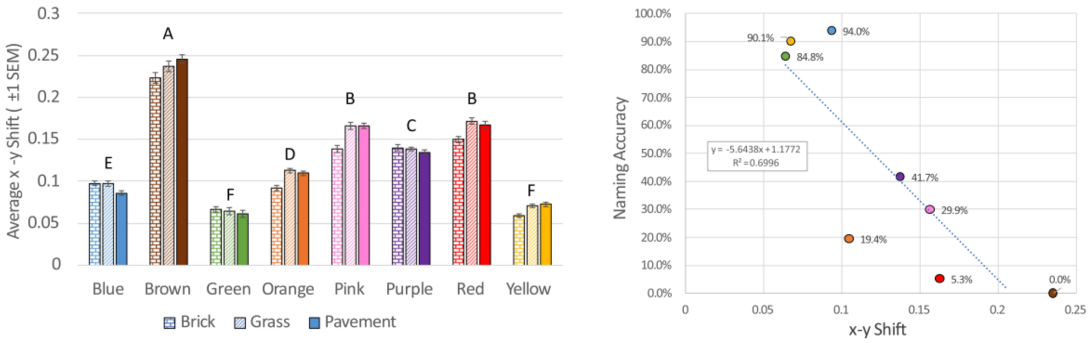


Figure 6. Average shift across backgrounds (left) and shift by naming accuracy (right) (Gabbard et al., 2022)

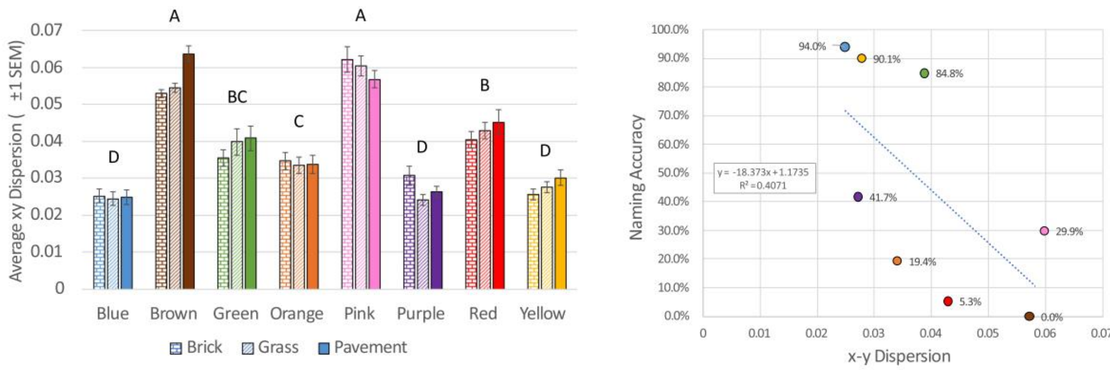


Figure 7. Average dispersion across backgrounds (left) and dispersion by naming accuracy (right) (Gabbard et al., 2022)

As stated in the previous study, designing colors for content on windshield display was proven to be hard. Designing colors that work properly in many lighting situations and changing outside view, in addition to basic color hierarchy, comes with more open questions. The theory presented in the previous study gives us a starting point. Future studies could implement a color system which changes according to the talked attributes. Other improvements might be studying if the usable color scheme can be expanded with the use of high opacity level backgrounds.

van Amersfoorth et al. (2019) studied if drivers' response time and feeling of safety can be improved through making the other traffic on the road translucent, in this case the lead car (Figure 8). Making the other traffic translucent enables the driver to see unexpected objects which would otherwise be blocked by other traffic. This can be enabled through a futuristic approach in which the cars communicate with each other. They tested this with a driving simulator in which the participants drove multiple routes with different amount of translucency in the lead car. Translucency levels tested were 10%, 60% and 100%. Through their drive, they were faced with a situation in which they had to break to prevent a collision. The response time was measured from the point of breaking situation to the breaking action. Feeling of safety was measured in a after study interview. The study found out that there was a slight improvement in response time the lower the luminosity level, but not significant enough to make too many conclusions. Also, the feeling of safety was slightly improved. Only slight improvement of safety might be because the translucency of the lead makes it more focus demanding to acknowledge the movements of the lead car.


Figure 8. Translucent lead vehicle (van Amersfoorth et al., 2019)

What we can learn at using opacity as an attribute on windscreen display is that the situations in which it is acceptable to use opacity need to be carefully thought. Opacity is not an automatic answer to increase the feeling of safety (van Amersfoorth et al., 2019). Using opacity on windshield displays needs more research and some of the open questions include for example if increasing the opacity of other objects in the traffic could be utilized only after there is an imminent threat incoming. Also, opacity could be utilized on information blocks placed on the windshield display. Increasing contents opacity when there is something noteworthy outside might be a good feature to have.

### 4.1.2 Content size

Content size can be thought in two ways. First one being what should be the size of an individual content element be. From individual content element we want know the minimum size of which it can be perceived but also the desired size. Second one being the size of information block. Information blocks contain different types of information, so the desired size is affected by many factors.

Haeuslschmid et al. (2017) studied minimal sizes for windshield display information and how it relates to reaction time. They conducted two studies; second study being used to verify the results of the first one in a darker driving environment. Both studies were conducted with three 32 displays and OpenDS driving simulator. Studies included a lane change task as a primary task and a detection response task as a secondary task. In lane change task the participants had to conduct a lane change and in the detection response task participants had to response to a stimulus, which appeared in a predefined area of 17 possibilities (Figure 9). The stimuluses were shapes and text, shapes being squares, triangles and circles, while text was a three-letter name of either a male or female. In the second study the shapes were limited to squares and circles. Participants had a target stimulus and as it appeared participants reacted to it with a push of a button. Stimuli started as small in size and grew until the button was pushed or the stimuli was left unregistered. Independent variables were driving performance and performance related to detection response task. Their hypothesizes were if reaction times increase when the visual angle to stimulus increases, there are no difference for reaction times for different shapes and that reaction times are higher for text stimuli. In the first study, there was no significant difference in the driving performance. For detection response test, text averaged in highest response time. For shapes, there was no significant difference between square and circle, but significant difference between triangle and square. Thus, hypothesis that there are no differences between shapes is disregarded and that text results in higher response time can be confirmed. For hypothesis that stimuli at the edges of the point of view results in higher response time the first study could not come into conclusion. In the second study, hypothesizes were once again that stimuli angle results in higher response time (Figure 10), response time decreases as the driving condition becomes worse and response time is higher for left-hand driving setup that right-hand. Some adjustments were made for the second study to increase the peripheral workload. Hypothesis that the larger stimulus angle results in worse performance was found true this time. The worse driving condition did not result in poorer response time, so the second hypothesis was disregarded. Also, the hypothesis that left-hand drive performs worse was disregarded.

The two study results were combined, and it turned out that for the stimuli sizes on 35° x 15° grid the angular sizes of stimuli range from 0.6° to 0.8°, increasing while moving towards periphery (Figure 11).

Figure 9. Stimuli locations (Haeuslschmid et al., 2017)

mixed pattern of circles & squares (1st study)

| | -10° | -5° | 0° | 5° | 10° | 15° | 20° | 25° |
|---|---|---|---|---|---|---|---|---|
| 7.5° | | | 1730 | | | | | 1303 |
| 5° | | 1818 | 1471 | 1605 | | | | |
| 0° | 1402 | 1309 | 1171 | 1044 | 1345 | | 1185 | 1365 |
| -5° | | 1782 | 1279 | 1035 | | | | |
| -7.5° | | | 1641 | | | | | 1855 |

replication (2nd study)

| | -10° | -5° | 0° | 5° | 10° | 15° | 20° | 25° |
|---|---|---|---|---|---|---|---|---|
| -7.5° | | | 1216 | | | | | 1271 |
| 5° | | 1146 | 1192 | 1197 | | | | |
| 0° | 1409 | 1340 | 1089 | 1151 | 1467 | | 2100 | 2527 |
| -5° | | 1333 | 1376 | 1210 | | | | |
| -7.5° | | | 1527 | | | | | 2344 |

Figure 10. Reaction times for circles and squares according to stimuli position. Upper one being the first study and lower second study (Haeuslschmid et al., 2017)

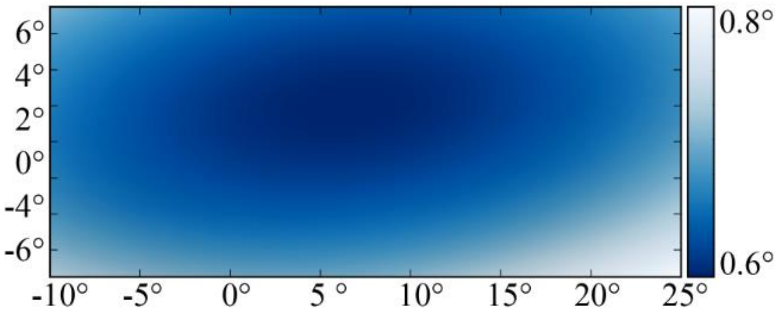


Figure 11. Stimuli angular sizes at the time of registration (Haeuslschmid et al., 2017)

Minimal individual content piece size is important knowledge when there is a need to accommodate a lot of information at same time. Though one could suspect that the minimal size is not the optimal size, minimal size can be utilized for example for information, that starts to grow from a certain point. For example, a dynamically placed navigation sign. It is useful to know when it is expected for the user to notice it. For minimal size, it would be useful to combine the size with other attributes. For example, how color affects the proper minimal size. The fact that text size is harder to decide than symbols come with no surprise. More research needs to be done what is the optimal size for text with color taken into consideration also.

Riegler et al. (2018) wanted to find out how the users prefer the content size, position and type on a windshield display. This study is based on a previous study by Häuslschmid et al. (2015), which is covered also by this thesis, and it differs from it by giving the participants more freedom to express their preferences. In this study, the participants draw rectangles in Adobe Photoshop, which included the boundaries of the windshield display, and decided the size and position. They also decided what content would this rectangle include. The options for the content included warnings, vehicle information, work related information, entertainment, social media and other/custom. Participants did not have to use all the content types and overlapping the rectangles was allowed. They then created heat maps from these designs. The participants did the procedure for two different automated driving concepts. Other one being SEA level 5 automated driving and other one being SEA level 3 automated driving. Level 5 means fully automated driving and level 3 that the car is not fully capable of independent driving but requires human interceptions, for example take over scenarios (Synopsys, 2022). Their research questions were the following; how many areas on the windshield display do users prefer for automated driving and how the level of automated driving influences this, in which size and format are the areas desired and are there any hidden agreements for the location of different areas. Regarding the size, level 5 content windows were nearly twice as large as level 3 content windows (Figure 12). At level 3 warnings and in-vehicle information were most used and took 25.42% and 14.75% of the available content area (Figure 12-a & c). On contrary, at level 5 these content types were not considered to be important and only took 10.59% and 4.79% (Figure 12-b & d). They still were present, but in a smaller windows. The remaining information relative sizes can be seen from Figure 11 and the actual sizes from Figure 12. Overall, the landscape format was preferred by the participants.

| | Content Type | W | V | O | E | S | C |
|---|---|---|---|---|---|---|---|
| Level 3 N=145 | Counts / Percentage | 35 24.13% | 33 22.75% | 26 17.93% | 29 20% | 19 13.10% | 3 2.06% |
| | Share of total size | 25.42% | 14.70% | 18.41% | 24.86% | 14.60% | 1.99% |
| Level 5 N=169 | Counts / Percentage | 26 15.38% | 34 20.11% | 32 18.93% | 36 21.30% | 33 19.52% | 8 4.73% |
| | Share of total size | 10.59% | 4.79% | 24.86% | 34.48% | 22.18% | 3.07% |

Figure 12. Relative sizes of the content windows (Riegler et al., 2018)

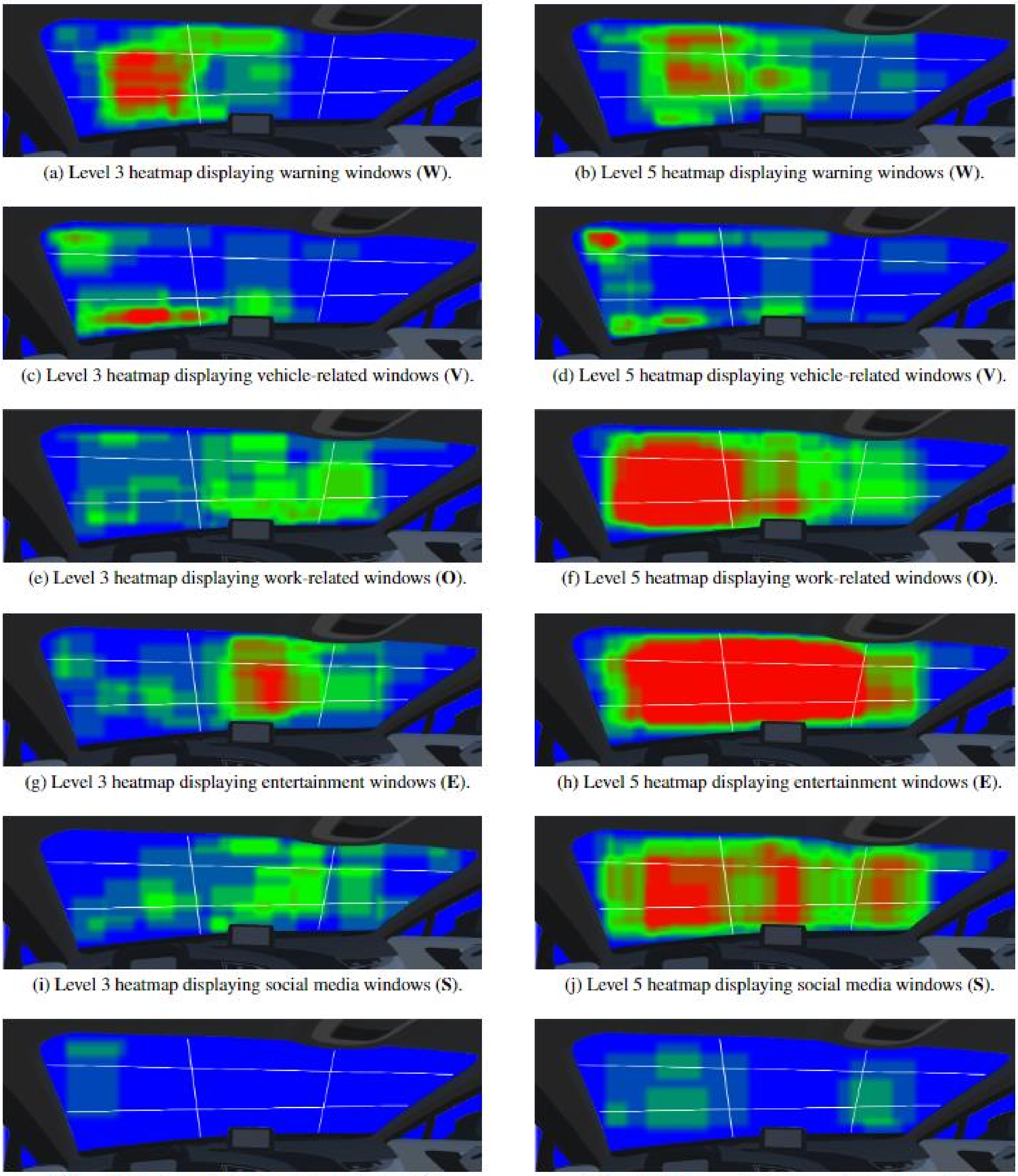


Figure 13. Individual heatmaps of the content windows and their desired locations and sizes (Riegler et al., 2018)

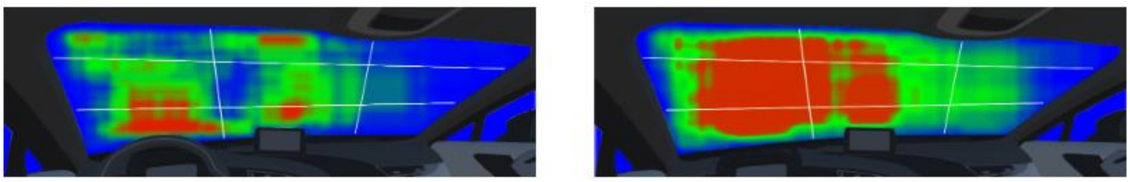

Figure 14. Combined content windows for SEA level 3 (left) and SEA level 5 (right) (Riegler et al., 2018)

From the study above we can learn the effect of fully automated vehicles related to content size. Fully automating the vehicle results in smaller basic information, for example warnings and in-vehicle information, and results in the rise of additional information's size. Still, with fully automated vehicles users seem to want to fill the whole windscreen with content. At lower level of automation, we can see that content is still placed with moderate sizes.

### 4.1.3 Content types and quantity

Things to consider while doing user interface design for windshield displays is the content that should be displayed for the user. This chapter explores the desired content on windshield display in different driving situations. In addition, I will explore how much content should these situations include.

Park & Im (2020) studied how the number of information, arrangement of the information and the area of the head-up display affect the driver's performance. The study was done in a driving simulator composed of three 43-inch monitors, tablet computer and wheel, breaks etc. To measure the degree of information access effort and to make the experiment visually more challenging the area of the head-up display was defined into three different places. One area being left hand side, second right hand side and the third in the centre. Areas were 20cm apart. Information regarding urgency were placed vertically left and the information regarding general driver information (GDI) and in-vehicle infotainment system (IVIS) either vertically or horizontally. Response time was measured by the time that the participant took from recognizing the information to verbally speaking it aloud. Subjective workload was measured with tuned Cooper-Harper rating scale, which is normally used to evaluate handling of an aircraft during a secondary task. Regarding the information types, they did a pre-study literature study from which they chose 44 types of information from which the participants chose the pieces that they would like to see on the windscreen. After participants were done, a total of 24 information types we selected. These information types we divided into three categories, which included urgency matters, GDR and in IVIS. The selected information types can be seen from Figure 15. Importance level for these information types were measured. In every category, information related to safety was measured with highest importance score. Regarding quantity of information, the experiment included three levels of information quantity. Level one included one type of information from every category, level two included two types and level three types. In other words, level one had the total information of three types, level two total of six types and level three total of nine types. The study found out that the more information is offered to the driver the slower the response time becomes, and the subjective workload increases. The quantity of information also had the greatest effect on driving performance. Overall, there should be maximum of six pieces of information offered to the driver.

| | Categorization of factors | | |
|---|---|---|---|
| **No.** | **Urgency** | **GDI (General Driver Information)** | **IVIS (In-Vehicle Information System)** |
| 1 | Low window washer fluid | Speedometer | Excessive speed status |
| 2 | Low fuel level | Trip computer | Lane change help |
| 3 | Engine stall | Outside temperature | Road image at night or poor weather conditions |
| 4 | Oil pressure | Cruise control | External speed control |
| 5 | Anti-lock braking system (ABS) failure | Multimedia | Road hinders image |
| 6 | Low tire pressure | Phone | Navigator |
| 7 | Door is ajar | Buckle seatbelt reminder | Video of passengers |
| 8 | Malfunctioning light bulb | Which door is ajar | Status of driver |

Figure 15. Selected information types per category (Park & Im, 2020)

Lindemann et al. (2018) conducted a user study how one could support driver's situation awareness during automated driving. They specifically focused on urban driving which proposes significantly more situations which may lead to an unexpected breaking or steering and is more demanding for the driver to keep up situation awareness. They had a simulator which took place in a city and included a simulated windshield display in which they projected fixed information and "real world" augmentations. Information chosen for the concept was selected by interviewing the participants about which content would increase their feeling of safety. Fixed information included automation confidence bar, destination and time panel, driving panel (current speed, breaking and acceleration indicator), navigation panel (upcoming turns and such), traffic light panel (remaining time for traffic lights) and traffic regulations panel (traffic rules and environment variables). All but driving panel and destination panel appeared dynamically when needed. Dynamic panels either turned up their brightness or blinked if the situation was more dire. "Real world" augmentations included threat and warning markers (a blockade on the road for example) in which potential threats were colored yellow and imminent threats red. If the threat status was red, other elements of the windshield display were hidden. Oncoming traffic indicators were projected on the road and included red arrows in direction that traffic is detected. The number of arrow heads correlated with the distance of the traffic element.

Break and stopping bar were projected on the ground in case of unexpected situation where the car had to break. It indicated where the car is going to be at full stop. Rotating object markers were placed on top of the other traffic, and it indicated by color if the behaviour of that traffic element is going to propose a threat. Markings with green color indicated traffic that moved as supposed and red if the traffic element differs from expected behaviour. Simulation contained hazards familiar to urban settings such as children or a dog crossing road unexpectedly, debris on the road, unexpected behaviour from proceeding car, obscured view and rule ignoring behaviour. Simulation was run in four different pretermitted routes with additional user interface effects turned on or off and with high and low visibility. Situation awareness was measured creating four situation awareness tests for each route. Each test included 10-13 questions customized to each route. Questions were divided to perception (recognized elements on road), comprehension (understanding situation going on) and projection (how the situation is going to evolve from here). Situation awareness was then evaluated with situation awareness global assessment technique. In addition, participants fulfilled a questionnaire after the drive including drivers' own evaluation. Study found out that there is a significant difference in situation awareness between additional windshield elements turned on. Effect was even larger in low visibility setting.

Seems so that users want to move the basic information types that are normally present in instrument panel and in infotainment system on the windshield display (Park & Im, 2020 & Lindemann et al., 2018). These are for example the speedometer, fuel level and engine status from instrument panel and for example navigation cues and multimedia from infotainment system. Future research subjects could include if this is truly the desired way, which could lead to removing the whole of classic instrument panel. Even though large, the windshield display size is limited and research on prioritizing the information is needed. That said if for example the engine status is the desired content on the windshield display, one should research if the information should be copied from the instrument panel or improvised with the capabilities of the extra size.

Automation of the vehicle brings other desired content types. Users seem to want to see "status" of the automation with different types of information, for example the confidence bar and acceleration and breaking indicators (Lindemann et al., 2018). Future studies could focus on the matter of what other content types should be included in the context of automated vehicles.

In a study presented in chapter 4.1.2 Riegler et al. (2018) also studied the preferred amount of information windows in automated driving. Their research question was “how many areas on the windshield display do users prefer for automated driving and how the level of automated driving influences this”. Level of automated driving being SEA level 3 and 5. They found out that at SEA level 3 scenario participants placed average of 4.26 information windows on the windshield display. At SEA level 5 participants placed average of 4.97 information windows across windshield.

What we can learn from the study above, is that even with fully automated vehicles the number of desired content windows is still limited. Noone probably expects that all the information desired is shown at same time. Another research matter is grouping the information so that the user can toggle between the information blocks in the windshield display.

## 4.2 Content positioning on windshield display

This chapter explores the attributes that must be taken into consideration when placing content on windshield display. This includes the location of information on windshield display and the depth of which the information is shown. In addition, it is possible to locate information dynamically and statically, which will be taken into consideration in this chapter.

### 4.2.1 Location and arrangement on windshield

Location of the information on windshield display plays large role in how it can be utilized. Because the nature of windshield display, there is a lot of room to accommodate the information across the windshield. Most important information must be available with ease for it might have impact on driving. It is important to locate the areas which are best liked by the users, and which offer most in terms of safety, response times and other primary task related features.

Topliss et al. (2019) conducted an experiment where they tested different positioning for head-up displays output on passenger cars’ windshield. The experiment included a passenger car which was hooked up to a simulator which projected a road which the participant had to drive. During the experiment participants had to follow a lead car which at time to time slowed its speed when the participants had to react to that and adjust their own speed. This means that the participant had to maintain awareness during the drive. During the experiment participants were exposed to a visually demanding secondary task which appeared on different positions on the windshield projected by the head-up display. During the drive several attributes where measured. These included lane positioning, driving velocity, distance to the lead car in different parts of the experiment, minimum time to collision and steering wheel reversal rate. These attributes were measured to determine how different positioning affects the overall driving which is the primary task. In the end, participants chose the position they preferred for the head-up displays projected information. The study found out that the most preferred locations for projected information for a right-hand driven vehicles include positions that are close to the natural view of the road center (Figure 16). In addition, the higher the projected information was, the lower was the lane deviation. Overall, the study found out that display position can have a big impact on driving performance. Limitations of the study include the factor that the study only took into consideration secondary tasks that. This means that if the information is meant to assist in the primary task, which is driving, the results may not be valid. Other limitations were that the study did not take into consideration larger eccentricities and the fact that secondary task was considered visually demanding, probably more than an average information or task would actually be.

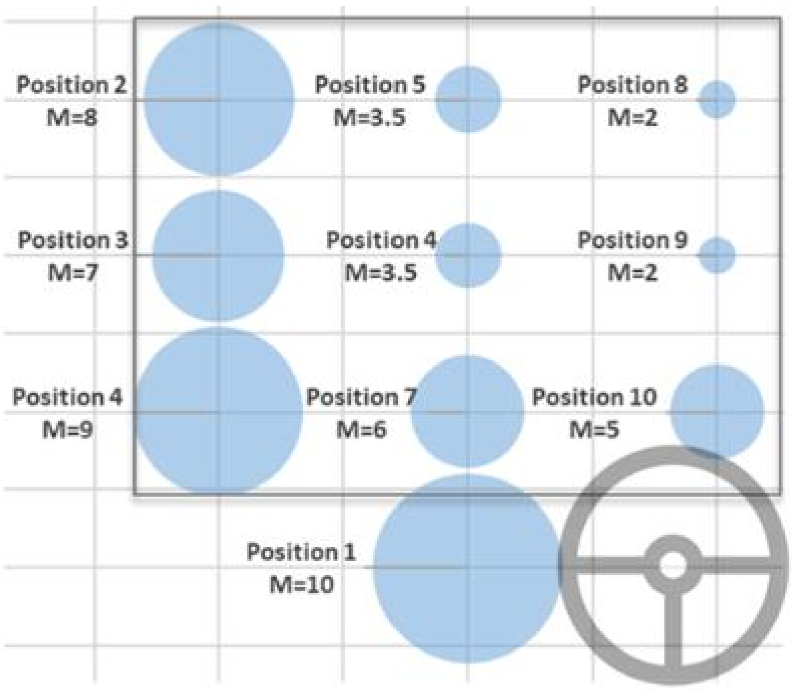


Figure 16. Most preferred positions for display locations (1 being most preferred and 10 least preferred) (Topliss et al., 2019)

In a study presented in chapter 4.1.3, Park & Im (2020) studied the arrangement of information and information areas on a windshield display. To measure this, the simulation included information on three different areas on the screen. These areas included left side of the screen, middle of the screen and right side of the screen (Figure 17). Arrangements included vertical and horizontal alignments in either two or three rows. It was found out that vertical alignment leads to a better response time (Figure 19) and a lower subjective workload (Figure 21), and it feels more intuitive for the user. Also, information should be placed on one row rather than two. They found out that middle area of the screen had the fastest response time (Figure 18) and lowest subjective workload (Figure 20). The response time and subjective workload for the side areas were about the same. According to the results, if the amount of information pieces is less than three, the information should be offered in the middle section. Equally, if the number of information is more than three but less than six, main information should be offered in the middle section of the screen and the rest on either side. Other conclusions include that the number of information has a higher effect on performance than the placement or the arrangement of the head-up display.


Figure 17. Information areas used in the experiment (Park & Im, 2020)

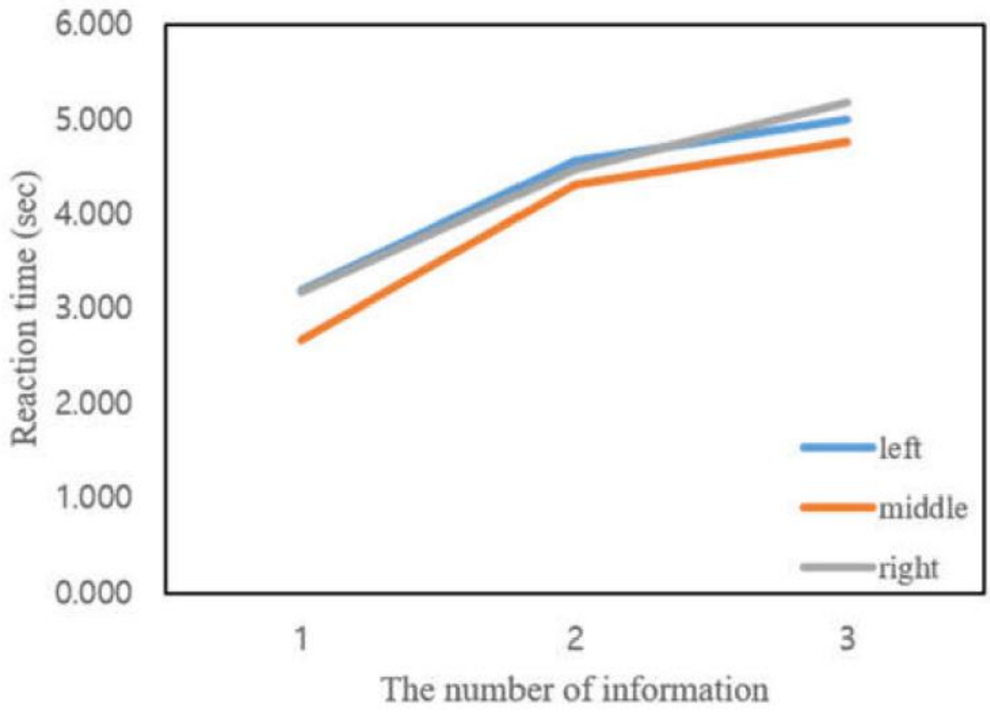


Figure 18. Response time related to the amount of information on different areas (Park & Im, 2020)

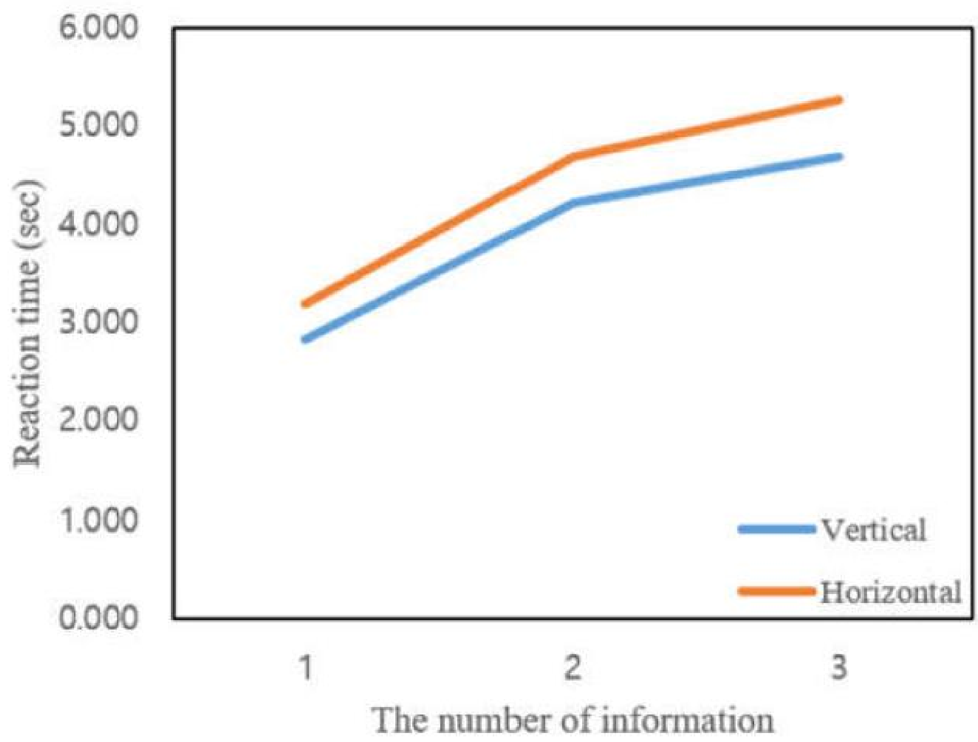


Figure 19. Response time related to the amount of information on different alignments (Park & Im, 2020)

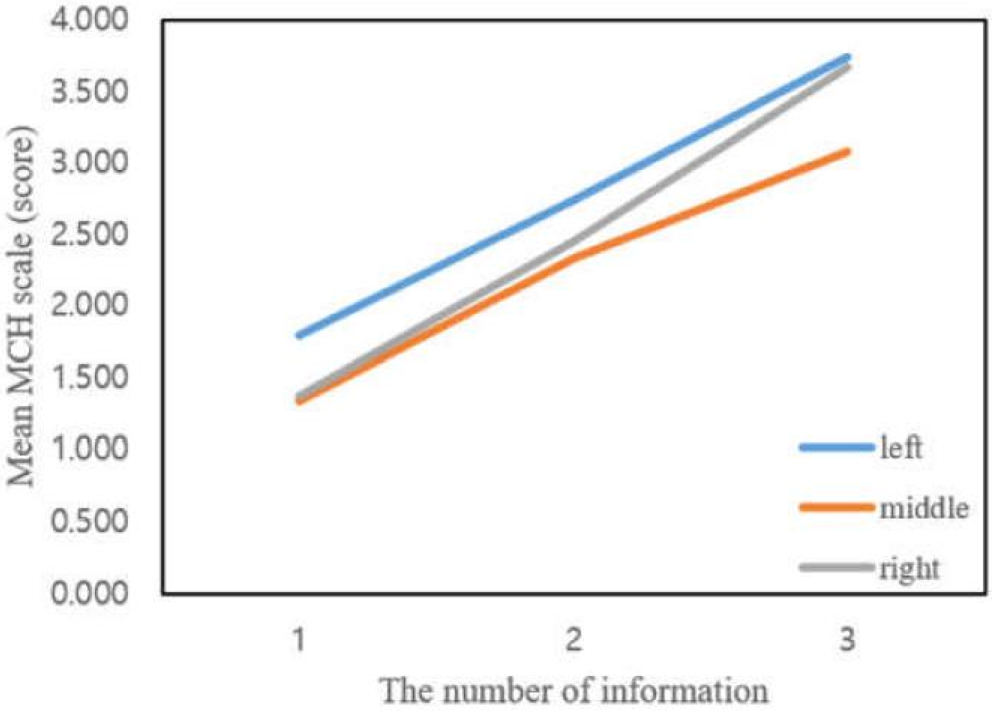


Figure 20. Subjective workload related to the amount of information on different areas (Park & Im, 2020)

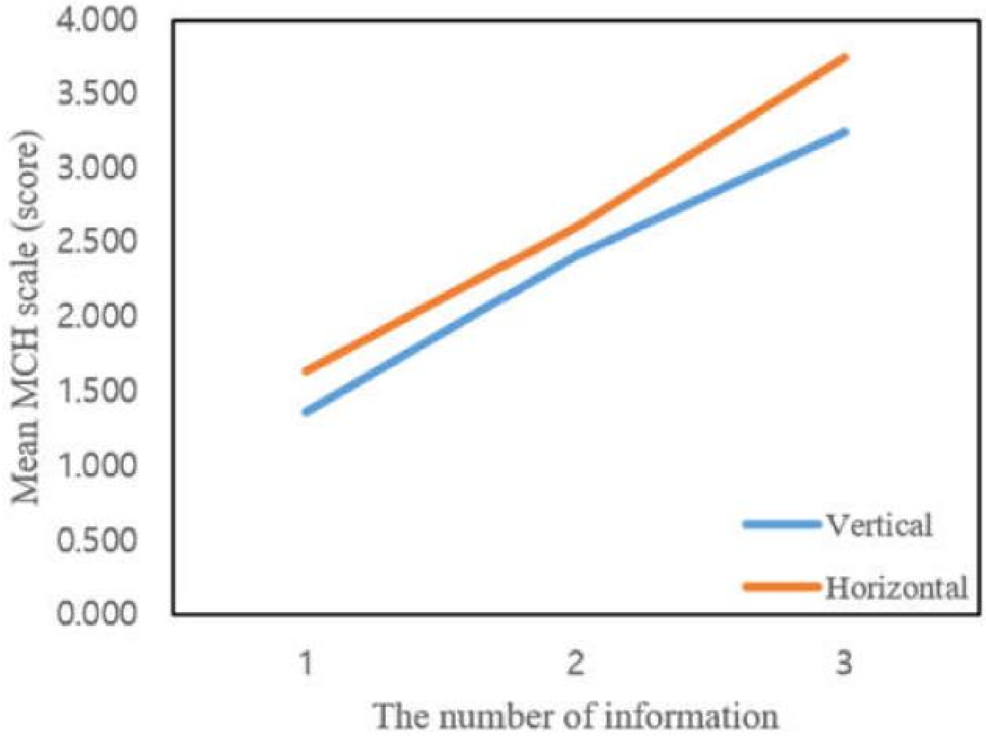


Figure 21. Subjective workload related to the amount of information on different alignments (Park & Im, 2020)

Both of the studies above focus on a small part of the windscreen and come to same conclusion approximately. The best and most liked position of the information is located somewhat middle of the windshield. This also results on best driving performance. This should be the first location of choice for information if there is not much of it. Also, this location probably is most suitable for most critical information since it has the lowest response time. Side area performed well in both studies also. In the study by Topliss et al. (2019) left hand side was preferred for right hand driven vehicles. Park & Im (2020) found out that both side locations perform the same, but they did not take the participants preferences into consideration. We can deduce that these side locations offer the next best location for information. Future studies could study the matter if this true for left hand driven vehicles or does the preferred position change to right side. Regarding the layout, Park & Im (2020) found out that two rows of information performs better than three rows. This study only used simple symbols to imply the information. More high-fidelity approaches might include more than symbols; therefore, this two-row preference should be investigated with more complex information blocks. Same thing goes for the left alignment. Also, both factors should also be studied in the context of automated vehicles.

Haeuslschmid et al. (2016) studied users preferences locating different type of information across a windshield display including the depth of the information. They did a preliminary study of information placing theory and past studies of how different type of information is placed on head-up displays. They created a concept from this information which included different depth zones for different type of information areas. This chapter explores the location of the information while the depth aspect can be found in next chapter. Information areas included notification area, reading area, personal area, ambient area, vehicular area and environment area (Figure 22). Notification area included urgent warnings or secondary tasks. Reading area included information such as emails and text messages, information that includes continuous text. Personal area included entertainment and messages and other things that might need interaction by the driver. Ambient area included not particularly interesting information such as the weather. Vehicular area included information about the vehicle, such as the fuel consumption. These areas were then tested in a formative study. This study included 21 participants and a google cardboard paired with a tablet computer. With google cardboard and the tablet they were able to create a 3D virtual reality headset that displayed the windshield. While users wore the "headset" the concept corresponding information was displayed multiple times in sets of information with different distributions. User then answered in a questionnaire in which area they would accommodate the information. The results of the participants preferences on information areas can be found in Figure 23. The participants did not want to place information directly into the driver's field of view and many of them used the sides of the windshield. Notification information, vehicular information and textual information were placed mostly like in the concept. Personal and ambient information locations included most variations in area across participants. Textual area was placed slightly below the proposed area.

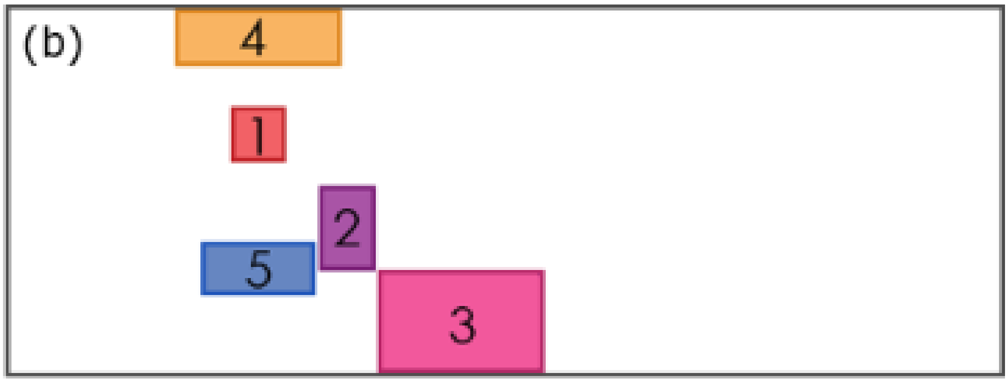


Figure 22. Proposed information areas. 1. Notification area, 2. Reading area, 3. Personal area, 4. Ambient area, 5. Vehicular area (Haeuslschmid et al., 2016)

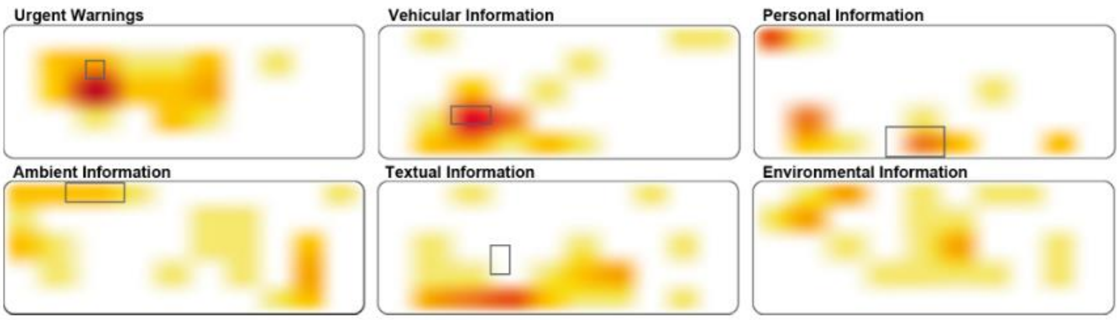


Figure 23. Heatmap results of participants preferred information areas. Square implicates the proposed area (Haeuslschmid et al., 2016)

Haeuslschmid et al. (2016) created their concept focusing on a small proportion of the windshield. Once again, we can see that the preliminary study and the participants' preferences shift into middle section of the windscreen. From the heatmaps, we can see that some of the participants placed some information on the left-hand side of the windshield. This happened with information that was considered less important and therefore complies with the previous studies. Even though the initial concept located information on small portion, the middle section, of the windshield, we can see that some of the participants placed information also on the periphery of the windshield. This implies that at least for some portion of user the periphery can be utilized even in manual driving. If there is a need to utilize the periphery of the windshield, future studies should focus on how this affects the manual driving performance.

In a study presented in chapter 4.1.2, Riegler et al. (2018) also studied the location of which participants preferred information located at in a context of semi-automated and automated driving. The information types included warnings, vehicle information, work related information, entertainment, social media and other/custom. In both SEA 3 and 5 scenario participants preferred placing warnings directly into the drivers' field of view (Figure 13-a). For vehicle related information in SEA 3 scenario participants preferred the lower part of the windscreen directly in drivers' field of view (Figure 13-c) and top left corner in SEA 5 scenario (Figure 13-d). Work related information in SEA 3 scenario was placed on the right side of the windscreen (Figure 13-e) and in SEA 5 scenario right into the driver's field of view (Figure 13-f). Entertainment information was placed middle of the windscreen in SEA 3 scenario (Figure 13-g) and on the whole width and height of the windscreen in SEA 5 scenario (Figure 13-h). Social media information was placed steadily in different positions across the windshield rather than one clear area (Figure 13-i). In SEA 5 scenario the whole width and height of the windscreen was utilized for social media information (Figure 13-j).

Coming into automated vehicles we can see the utilization of periphery of the windshield. After enabling entertainment, work related and social media information blocks, we can see that the accepted locations increase towards the periphery. The most important information is still prioritized above the entertainment, work and social media and are placed similarly to the other studies. Entertainment, work related information and social media, which can be considered secondary to the driving task, are placed on the periphery. With fully automated vehicles the whole of the windscreen is utilized for information. The information related to driving is still present on the approximately same areas as in other studies, but users want to include these additional information blocks, so they are placed on the periphery.

### 4.2.2 Depth behind the windshield

Location of information on windshield display can be separated into two aspects. Actual location on 2D space but also taking into consideration the depth making it a 3D space. Depth can be utilized in grouping and empathizing the information. Depth aspect is also necessary when highlighting information that is in relation with the actual world and when we want to enable a dynamic position of information.

Häuslschmid et al. (2015) compared two solutions in which the information is displayed either on the windscreen or in front of it. They also compared how these solutions affect the memorability, safety risks and driving performance not only for information in the driver's field of view but also on the information displayed on the periphery of the windshield. The study also included a comparison regarding user experience. This experiment had two different setups which included a real car windshield attached to a wooden frame, a real car seat and a gaming steering wheel. First approach included a projector that projected a virtual image directly into the windshield. The second approach included a three 32-inch displays that were placed under the windshield which then projected the image in front of the windshield. First approach will be referred as "projector-based" and the second as "screen-based". These setups were hooked into a simulator that projected the road. As a driving performance indicator lane change task was used. In lane change task, the participant had to change lanes every 150 meters. As a baseline for driving performance, participants drove the setup without anything projected on the windshield or in front of it. Lane change task measurement included reaction speed measurement, mean deviation from optimal lane and number of successful changes. The study included two widget boards which were displayed in different places. First widget board included information that is not usually offered such as weather and social media posts and was placed on the right periphery of the windshield. Second widget included information such as time and date and was placed directly on the driver's field of view on the bottom middle. Some of the information did dynamically change to increase the distraction of the information. Memorability was then measured with a recall questionnaire after the drive. User experience comparison was done with a questionnaire since both test groups drove both setups. The driving performance comparison found out that other than reaction time the measurements were about same. Driving performance was a bit worse compared to the drive without displayed information but did not result into safety risks. Reaction time was significantly better on the projector-based approach (Figure 24). This means that considering reaction time, information in front of the windscreen results in better driving performance. Considering the reaction time, it can be argued that increasing the distance between information and the driver thus decreasing the distance between drive scene and the information would lead to a better reaction time for screen-based approach. The memorability comparison resulted in almost matching results. Participants were successfully able to recall the information that was displayed by the widget boards whether it was displayed on the field of view or periphery of the windshield. This means that the approach method does not affect the memorability and the participants were able to recognize the information in the periphery of the windscreen. User experience comparison resulted in a minor lead for the screen-based approach (Figure 25). Screen-based approach did not outperform projector-based approach in every aspect. Generally, participants found graphics to be easier to recognize when it is presented in front of the screen.

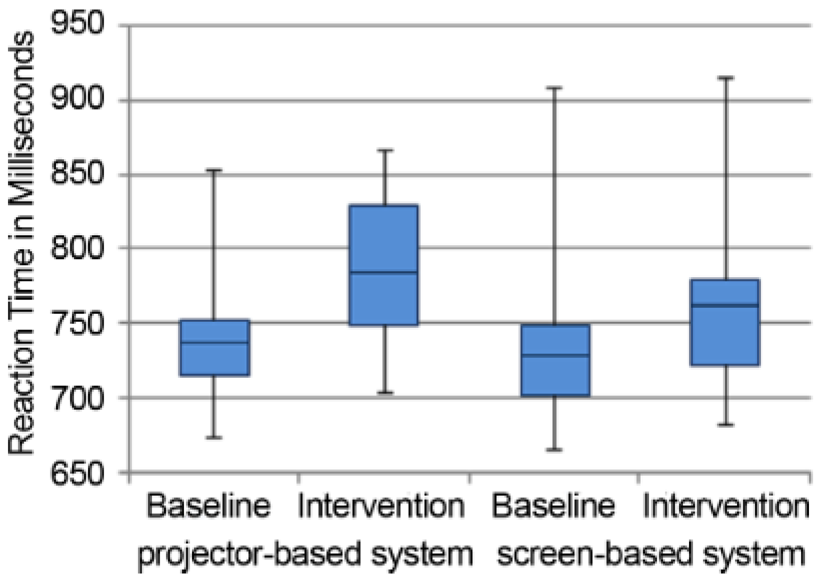


Figure 24. Reaction time was significantly better when the information was projected infront of the windshield (Häuslschmid et al., 2015)

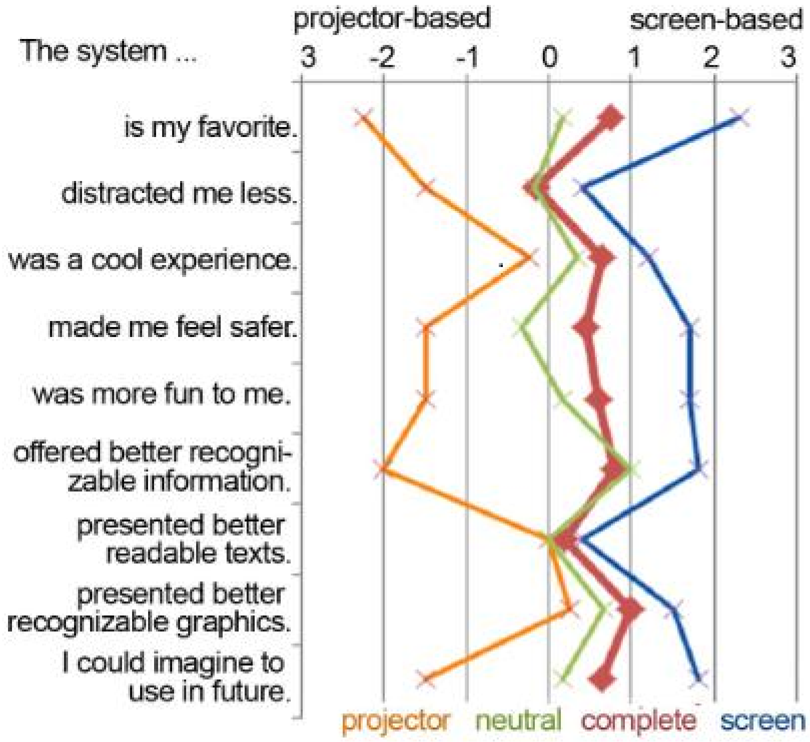


Figure 25. Participants found screen-based approach more favorable (Häuslschmid et al., 2015)

In a study presented in chapter 4.2.1 by Haeuslschmid et al. (2016) research angle included the depth of the information behind the windscreen. Same participants, preliminary study and test setup was used. The depth behind the windscreen was divided into different information zones. The zones included personal zone, vehicular zone and environment zone (Figure 26 and 27). These zones correspond to different depths from the windshield into the field of view. The difference between environment zone and other zones is that information on environment zone is world fixed. World fixed means that the information is displayed fixed in the real world, for example a navigation sign on the road. Personal zone ranges from 0 to 50 centimetres, vehicular zone from 50 to 290 centimetres and environment zone from 290 centimetres to infinity. These zones are related to Hall's theory of proxemics. All information areas, presented in previous chapter, except vehicular area and environment area were placed in the personal zone. Vehicular and environment areas were placed on the corresponding zones. Study results indicated mixed feelings in the use of depth. One third of the participants restricted the depth to 5 or 10 meters behind the windscreen and almost half of the participants restricted the number of depth zones. The preferred depths can be seen from Figure 28. Depths for notification area, vehicular area, reading area and environment area was placed matched that what the concept proposed. Personal area and ambient area were placed much further away from the windscreen compared to the concept.

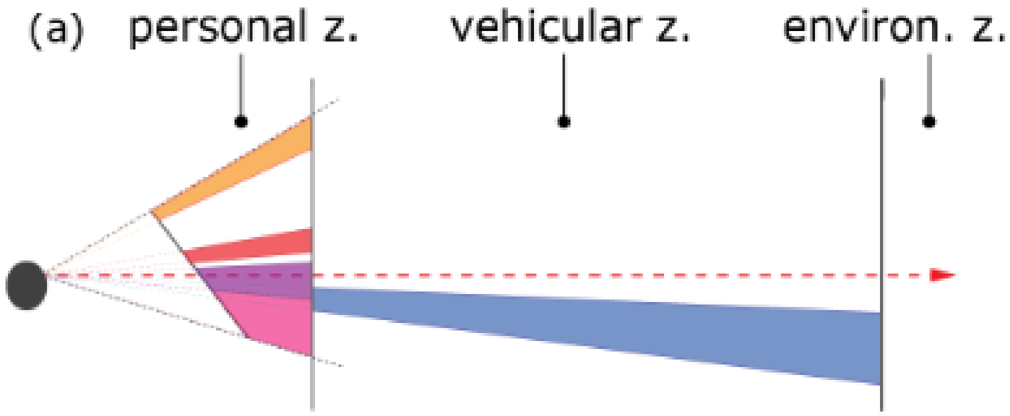


Figure 26. Proposed depth zones for information areas (Haeuslschmid et al., 2016)

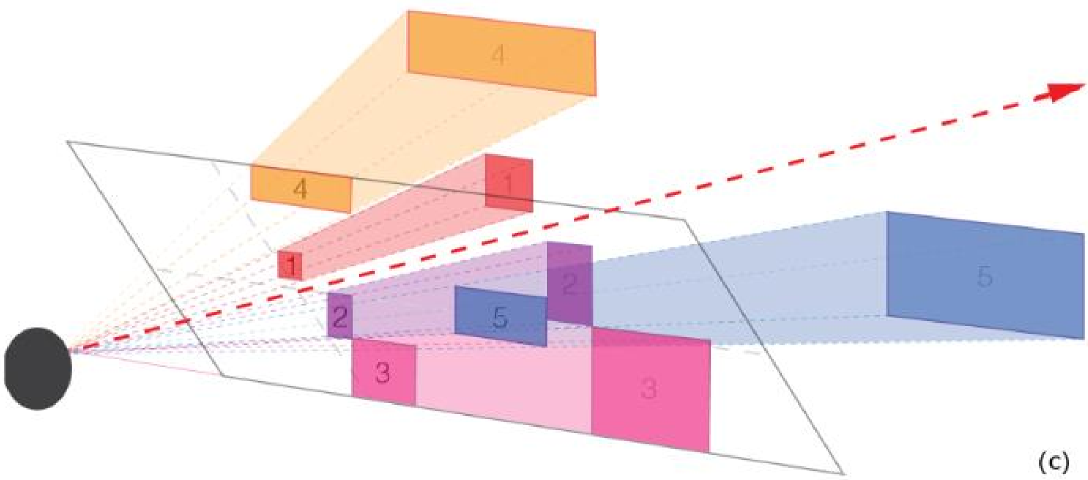


Figure 27. Proposed depth zones and information areas combined throughout their ranges (Haeuslschmid et al., 2016)

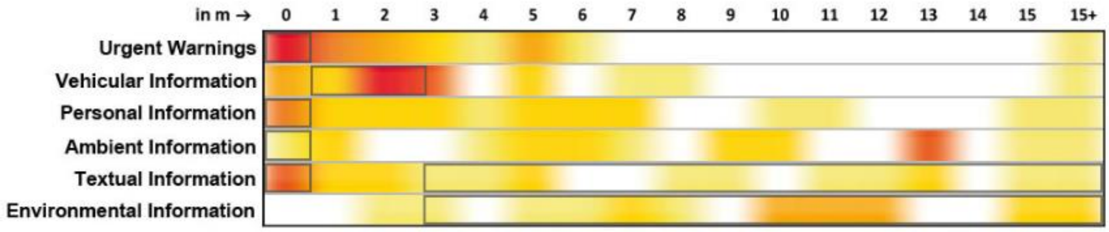


Figure 28. Heatmap of preferred depths for different information (Haeuslschmid et al., 2016)

What we can learn from these studies is that we probably want to include information both on the windscreen and behind the windscreen. There are no significant driving performance differences between the two alternatives (Häuslschmid et al., 2015). Noting this, it comes down to the user preferences. The study of user preferences on information on windscreen versus behind the windscreen resulted in somewhat mixed results involving some of the user experience aspects being better while the information is shown on the windscreen and vice versa (Häuslschmid et al., 2015). This user experience difference comes down to the content types presented. Seems that users prefer for example urgent warnings and textual information close to the windscreen, while information that includes more graphics or information which is dynamically placed further away from the windscreen (Haeuslschmid et al., 2016). More research is needed to confirm which content types should be placed further away from the windscreen and which on it and what are the deciding factors. Also, how for example color, location on the windscreen and content size affect this preference.

### 4.2.3 Dynamic vs static positioning of content

Location of the information can also be separated into dynamic and static positioning. Dynamic position enables information to for example be positioned in relation with real world. Static information stays still on the windscreen.

Riegler et al. (2019) also studied positioning text on a windshield display. In their study they compared statically positioned text (Figure 29) to dynamically positioned text (Figure 30) across windshield display. The study was done in virtual reality that simulated a SEA level 3 automated vehicle. SEA level 3 means that the car can make simple decisions regarding driving task, for example accelerate past a slower object, but on harder tasks human interference is required (Synopsys, 2022). Research question that they had asked that if dynamic contend positioning on the windshield display can have positive effect secondary task performance and if take over times can be reduced with dynamic content positioning. The participants were asked if the shown sentence is semantically correct. Participants answered either “yes” or “no”. If the answer took more than 10 seconds, it was considered as incorrect answer. Regarding second research question the participants were shown a text stating that they had to grab the wheel and take over the driving. The time to react was measured and compared between the two alternatives. The study found out that error rates regarding “yes” and “no” answers to if the sentence is semantically correct and the time that the participant took before giving the answer were significantly better on dynamically positioned text. Also, the take over time was better on dynamically positioned text, but the difference was not significant.


Figure 29. Statically positioned text (Riegler et al., 2019)


Figure 30. Dynamically positioned text (Riegler et al., 2019)

Dynamically positioned information definitely has its place on windshield displays for example, the basic implementation style of navigation cues with augmented reality on windshield display includes a dynamic position. Seems so that other information could be placed dynamically also to increase the driving performance and user experience (Riegler et al., 2019). What are these content types that would benefit from dynamic position needs more research. Also, how dynamically positioned graphics would behave. This is also interesting from the context of color, since the surroundings of the graphics might change within the dynamic position. Changing the graphics color when the dynamic position changes is a thing that needs more research. When placing information dynamically, the minimal size comes into play. When displaying information further away the minimal recognizable size somewhat determines the proper starting point of the projecting.

### 4.3 Future implications and requirements for UI design

This chapter explores user interface design propositions and challenges what we might face in the future as automated vehicles become established on the roads. The challenges with this change include for example the trust and acceptance towards automated vehicles, which we might be able to counter with good design. Other challenge for example includes the situations in which the driver must take over the driving. With proper design this can be also done with better results.

### 4.3.1 Implicit and explicit communication system

Trust is a critical component in acceptance of automated vehicles and automation as a whole (Ghazizadeh et al., 2012). This is why it is important to explore the possibilities of user interface design on windshield displays in automated vehicles to increase the trust of the driver. This chapter explores two different mindsets on how one can support drivers' trust in an automated vehicle.

Wintersberger et al. (2018) studied if user trust and acceptance towards automated vehicles can be improved with augmented reality. They tested this with two separate user studies. For the first study, they developed a method called "implicit communication of system decisions" (Figure 31) which means that the actual system output of a decision is not represented to the user, but the user is able to see what the system sees. First study included a simulator with a windshield display which was able to project objects outside of the vehicle. In the study, a participant took a trip in an automated vehicle which drove a road in a foggy weather and the vehicle performed multiple overtaking manoeuvres. To increase distrust, some of the manoeuvres took place when the participant could not know if the overtake was safe to perform. Because of the technological advances, automated vehicles can drive faster and perform takeover manoeuvres even in heavy fog, which would be dangerous for a human. The participants performed the drive once with the augmented reality turned on and once without anything projected on the windshield. The trust was measured with technology acceptance mode (TAM )model with trust integration and with an additional questionnaire. TAM model included following sub scales; perceived usefulness, perceived ease of use, attitude towards using, intention to use and trust of the system. Version with the augmentation on scored higher values on every subset. Participants expressed that the trust factor is important and that taking a ride a "blind" mode left them feeling anxious. The version with augmentation on one participant felt more comfortable because he could see if there was a vehicle approaching or not.

Figure 31. Drive through a foggy road with "implicit communication of system decisions" on (left) and off (right) (Wintersberger et al., 2018)

In the second study Wintersberger et al. (2018) focused on a different aspect of automated driving. After the vehicle becomes SEA level 5, the need for the driver to face forward becomes absent. In this study, they wanted to find out if projecting the user with system decision would increase the trust and acceptance even if the user is facing the wrong way. The participant took a drive in a simulator in which he was facing backwards in comparison to the driving direction. There was a display which projected traffic behind the car. In addition, the participant wore Microsoft HoloLens. For the study, they developed a method called "explicit communication" which means that in contrast to previous study, now the actual output of the system is presented to the user. This output, for example a stop or a turn, was presented to the user through the HoloLens (Figure 32). During the test, participant took part in a skype call which was then interrupted couple of times to perform a task to search some words from a dictionary to reduce the focus on the driving situation. The incoming manoeuvres were presented in two different ways; by arrows pointing in a perceived direction and arrows pointing to the actual driving direction. Both presentation ways were tested with the participants in separate drives. As a control version, the participants took one drive without any presentation of incoming manoeuvres. After a drive participants fulfilled a questionnaire and were interviewed. TAM model was also used for the second study. All the sub scales and the after-study questionnaire answers were rated higher for the version which displayed the arrows in the perceived direction. In some of sub scales even the control version with no augmentation at all was rated higher than augmenting the logical direction. Comparing the tree different versions, we can see similar values for perceived usefulness and attitude towards using. We can see highest values for augmenting the perceived direction for perceived ease of use, intention to use and trust of the system. Also, the after-study questionnaire with analysis for perceived direction scored better than other versions. Overall, augmenting the perceived direction significantly increase trust towards the system and no augmentation at all was rated better than augmenting the logical direction.

Figure 32. “Explicit communication” versions. Arrow pointing in a perceived direction (left), Arrow pointing to the actual driving direction (middle) and no augmentation at all (right) (Wintersberger et al., 2018)

With the acceptance and rise of automated vehicles, there is a need for design solutions to counter a number of things. Implicit communication system by Wintersberger et al. (2018) in an interesting concept which deserves more studies around it. Do you show everything that the car “sees” or do u filter something out? What are the things to filter out and what is implemented? How do you design this information to more human friendly form? The questions go on. Explicit communication system is an interesting topic, since after automated cars are fully automated there really is no reason for even the driver face the road. The finding that projecting the perceived direction is the fascinating (Wintersberger et al., 2018). What other information might be useful to increase trust or other factor and how does this finding affect that?

### 4.3.2 Supporting desired behavior

Automated vehicles at SEA level 3 include situations in which driver must take over the wheel (Synopsys, 2022). To increase the situation awareness, it is important that the information shown on the windshield display to encourage the user to act properly. Good design can have a great effect on the outcome.

Lorenz et al. (2014) wanted to know if take over scenarios transition phase can be shortened and can the drivers’ actions be influenced by increasing situation awareness through augmented reality. Transition phase means the time between take over request and the time the driver engages into lane change or start breaking. They created two different concepts which they tried out in a simulator. In the simulation, participants rode in an automated vehicle while performing a visually demanding Surrogate Reference Tast (SuRT; ISO/TS 14198) on a tablet computer. After a while vehicle triggered a take-over request with flashing red light and an acoustic output because of a crash on the lane that the participant was driving on. Take-over request was performed seven seconds before the possible impact. First concept, called “AR red”, augmented the pathway which leads to the accident scene with red color and second concept, called “AR green” augmented a pathway to avoid the crash scene by switching to the other lane (Figure 33). As a control version there was a simulation with no augmentation at all. Participants were divided into three groups to carry out the study which all completed a different simulation. To match the research questions, the study focused on two aspects for all versions. Timing aspects of the take-over process and take-over behaviour and quality. Timing aspects included gaze reaction (the time it takes to move gaze from tablet), road fixation (the time it takes to move the gaze to the road), hands on (time it takes to grab the steering wheel), take-over time (time it takes to engage in steering or breaking), side mirrors (time until driver looks at sidemirrors) and indicators (time it takes for the driver to use indicators). Take-over behaviour and quality included choice of reaction (steering, breaking, or steering and breaking), lane change errors (gaze and use of indicators), trajectories and acceleration. For the timing aspects of the take-over process or in the use of indicator or side mirrors there were no statically significant differences between “AR red”, “AR green” and the control version. For take over behaviour and quality there we more differences. Choice of reaction distributed the following way: 56.2% of the “AR red” participants did steer and break, 25% did breaking only and 18.8% did steering only. 52.9% of the “AR green” participants did steering only and 47.1% did steer and break. In control group 80% did steering only, 10% breaking only and 10% steering only. We can see significant differences between the behaviour for all the versions. For the lane change errors, we can see a significant difference between both AR versions and the control group for if the participant checked the lane beside the car. None of the participants did this in group “AR red”, In group “AR green” and the control group 76.4% and 66.6% of the participants did not do this. For trajectories, “AR red” and the control group had more steep trajectories than “AR green”, and “AR green” had least spread among the trajectories. For the acceleration, there were no statically significant differences between the groups.

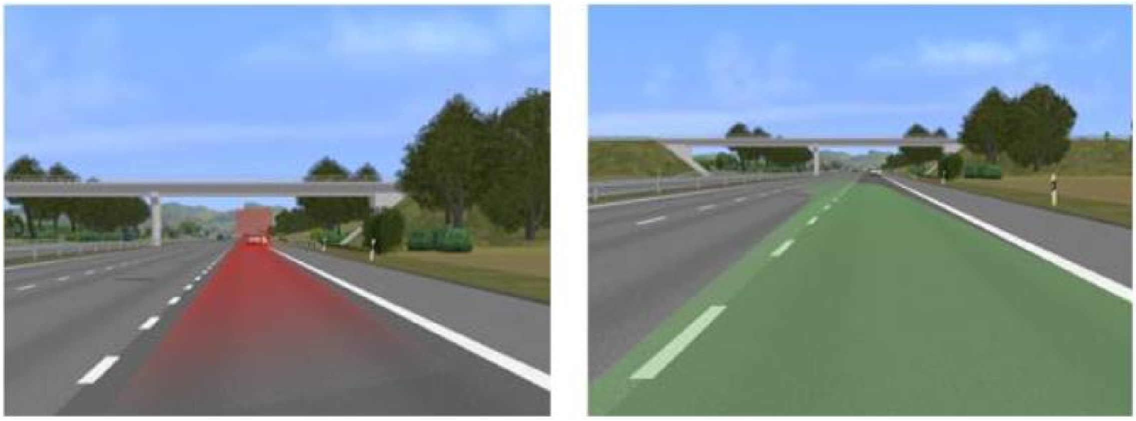

Figure 33. Red (left) and green (right) pathways to guide the participants (Lorenz et al., 2014)

Lorenz et al. (2014) gives us a great example of psychology factors when it comes to guiding the user the way we want. They used this on the takeover situations, but the point still proves itself with manual drive also. The situation explained in the study does not have to include the takeover situation, but the situation might be a manual drive with the accident ahead. A sophisticated car would know this and could then guide the user on the right path to avoid the crash. The difference in color and pathway result in two different outcome that we might be able to utilize. If the wanted outcome is to bring the car to a halt, according to Lorenz et al. (2014) the straight pathway with red highlight has the tendency to result in this. On other hand if we want to guide the user to another path the green pathway with the trajectory projected has the tendency to result in this (Lorenz et al., 2014).

# 5 Discussion

In this chapter I will reflect my work and the findings. This chapter includes the overall findings from the literature review, limitations of my work and further research. The goal of the literature review was to explore how augmented reality is implement through windshield display in visual context.

This thesis has given an overall picture of what kind of factors should one consider when designing visual augmented reality for a passenger car through windshield display. In addition to an overview of the matter, this thesis has shown gaps in the current research and gives directions for future research.

As discussed earlier, augmented reality can be enabled in passenger cars though windshield displays. Augmented reality has come a long way from first head-up displays to augmented reality head-up displays. The current implementation technique, augmented reality head-up display, can achieve good results regarding content design possibilities and locating possibilities, including static and dynamic positioning. Near future implementations can include even more possibilities though wider content area enabled with the extra space.

Regarding color and opacity, there is a lot more to study to better understand the subject for better implementations on these matters. What we've learned, is that colors with low dispersion and color shift perform well, for example blue, yellow and green (Gabbard et al., 2022). Perceiving colors vary between different user groups. For example, older people receive colors differently from young people. This should be taken into consideration when designing colors for windshield display. Also, the accessibility of these colors should be studied to maximize the inclusivity of the solution. Using colors as an aspect of visual design benefits users with unaltered color vision.

Regarding size, minimal size of an individual element is 0.6° to 0.8° on 35° x 15° grid (Haeuslschmid et al., 2017). This information can be utilized with bigger screens also. Same limitations as in colors affect the minimal size. Minimal size which some might find suitable are too small for other user groups. This especially highlights with older people, but also people with impaired vision are affected.

Desired content types include a lot of information that is already available on passenger cars. Regarding automated vehicles, a lot of entertainment content is desired. These content types need to be accommodated on windshield displays, which needs more research. Including entertainment windows on the windshield display is an uncharted territory. This kind of solution heavily relies on legislation on the matter. Time will tell if we are able to watch television in our cars in the near future. Information that is desired changes between user groups. People who enjoy social media have a larger urge to have it on the display than users who do not use social media. In contrast, a user who enjoys receiving as much information as possible of the driving itself might want to replace the social media windows with speedometer. This is why some type of user profiles or information categorization should be studied.
As my literature review indicated in chapter 4.2.1, best location for information lies in the middle of the windscreen just above the steering wheel. Secondary places include the sides of the driver's field of view. Arranging locations for the information is important. This way the most important information can be located so that it serves the user the best possible way. Locations in the proximity of the steering wheel and right in the drivers' field of view are encouraged to be used for the most vital information. In addition, periphery of the windshield can be used for information in certain situations. This is especially functional in automated vehicles. The periphery of windshield would most likely contain information that is not in the direct need of the driver. If the information in the periphery of the windshield could be implemented so that the driver does not see the content, the periphery could be utilized as an entertainment window for the side passenger even in manual driving. Depth is encouraged to be utilized since different depth levels for the information results in better user experience. Depth is also a necessity for true augmented reality. Placing information in relation of the surroundings needs depth to be utilized. Dynamic positioning of information on the windshield seems like a promising solution to increase user experience. Of course, static information should be implemented also. Dynamic position works best for information that is in some sort of relation with the surroundings. For example, attaching the speed of the car in front of your car could be done with dynamic positioning because the information is related to the car ahead. In contrast, the speed of the car that is being driven should be static, since the information is in relation with the vehicle. All information cannot be dynamically located since the overall view would turn into a mess with too many moving parts.

Regarding automated driving, design solutions such as implicit and explicit communication systems provide a good view on improving user experience in automated vehicles.

Implicit communication system can increase the trust and acceptance for automated vehicles (Wintersberger et al., 2018). This is most beneficial to a user group who suffers trust issues with automated driving. User groups who suffer from the trust issues with automated driving are hard to define since this kind of prejudice probably exist in all user groups. Explicit communication system benefits users also with increase of trust and acceptance. The user groups who benefit from this are the same that in implicit communication system. Implicit communication system might provide good results for manual driving also. For example, seeing what the car sees with its sophisticated sensors would probably increase the safety of manual driving also.

## 5.1 Thesis limitations

The literature review could have been broader and more specifically defined. The search parameters used could have been more specifically defined to achieve this. Also, sources that were included could have been narrowed down by year of release, which would have enabled me to include more recent studies. The amount of research on the matter turned out to be great, and with the resources at hand there had to be some cutdown regarding the number of included studies. The fact that I only used ANDOR and google scholar databases limited the available studies. The time management on behalf of writing the literature could have been more structured. Also, the review is hard to produce since the criteria for exclusion and inclusion are not provided.

Thesis limitations also include the fact that enabling augmented reality was only done in the context of windshield displays. Augmented reality can be enabled with other features other than windshield display which were excluded out of the scope. In addition, enabling augmented reality was only explored in the visual context. Other modalities such as haptic actuators, for example including haptic feedback in the steering wheel (Kim & Dey, 2016), were excluded out of the scope of the thesis.

## 5.2 Further research

Regarding color, further research could focus on the changing color scheme based on lighting conditions and changing background of the windscreen. This could improve the readability of the content in various situations. Also, combining color and text usage with transparent background could be researched to better accommodate the information on the windshield. Using opacity to make things transparent in the traffic could be further researched by combining situation assessment with the increase of opacity of the traffic or such. For example, an imminent threat recognised by the vehicle's sensors could lead to making some of the traffic higher in opacity. Including color of graphical elements and text with the minimal size should be researched. Different coloring will probably influence the minimal recognizable size.

Future research subjects could include if this is truly the desired way, which could lead to removing the whole of classic instrument panel. Even though large, the windshield display size is limited and research on prioritizing the information is needed. That said if for example the engine status is the desired content on the windshield display, one should research if the information should be copied from the instrument panel or improvised with the capabilities of the extra size.

Future research regarding the content types and which of them should be located on the windshield display could focus on the matter of moving the information from classic instrument panel and infotainment system. What are the content types that would benefit from this change? Also, grouping the available information should be researched.

Position of the content should be researched in the context of more complex information structures. How does the complexity of information structures affect the two-row preference and left alignment of the content? Also, how does these preferences change with automated vehicles and with the extra room on the windshield they bring to the table.

More research is needed to know which content should be placed on which depth levels, and which of the factors result in this. How does color, location on the windshield and the minimal size affect the usable depth level is also a research matter that should be investigated. Vice versa, the minimal size on different depth levels should be investigated also.

Dynamic positioning and which content types would benefit from this needs more research. Also, how colors behave on dynamic positions needs more research. This could be combined with the research questions regarding the color.

Regarding implicit and explicit communication systems, more research is needed on the matter of how the information that the vehicle can sense can be turned into human friendly form in addition to what are the key information points that should be presented to the driver.

# 6 Conclusion

This thesis has given a broad view on the matters that affect user experience while designing content on windshield displays with augmented reality. I hope that this thesis has expanded the understanding of the reader regarding how to design colors, which size the content should be and what to consider when designing size, what types of content user desire on their windshield display, how to arrange and locate information across windshield display and behind it what and what design implications to consider when designing augmented reality for automated vehicles.

Through my literature review it is shown that there have been a lot of studies regarding the use of augmented reality on windshield displays. What I though lack in these studies is the fact that most of the simulations were run on low fidelity protypes that leave room for in interpretation regarding the results. Participants had to use a lot of imagination to fully comprehend how these solutions would look and feel on production ready applications. This is something that might be worthwhile considering with future studies.

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