Exterior Light Communication for Silent Bus

Development of a Vehicle to Vulnerable Road User Communication System

M.Sc. Thesis in Industrial Design Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

Department of Product and Production Development
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Master of Science Thesis

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PREFACE

This master thesis is the outcome of a product development project which was carried out during the spring semester of 2017 at Chalmers University of Technology. The project covered 30 higher education credits and was conducted in cooperation with Volvo Buses in Gothenburg. Behind the project and concept development are two students from the master's programme Industrial Design Engineering at the department of Product and Production Development.

ACKNOWLEDGEMENTS

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We would also like to thank Lars-Ola Bligård, our extraordinary supervisor and examiner, who supported us and kept us moving in the right direction. We are immensely grateful for the guidance and advice you have provide us with during the project.

Much appreciation and best wishes to our opponents and friends, Karin Karlsson and Victor Bergh Alvergren, for their encouraging words and inspiration to keep moving forward. We are grateful for the support and help that you have provided us with during the development of the concepts.

Finally, we owe a great debt of gratitude to the individuals who participated in studies and tests throughout the course of the project. The pedestrians, bicyclists and bus drivers provided great insights and we are grateful for your commitment in the project. Particularly, we would like to show our appreciation to the bus drivers of the electric bus line in Gothenburg and Daniel Lundgren for letting us disturb during the breaks. Thank you for the time you have sacrificed to help us understand your experiences and daily interaction, inspiring us to strive for a better end result.

ABSTRACT

Electric vehicles are superior when it comes to lowering the amount of pollution with regards to both the air and sound levels, but due to the vehicles' silent characteristics, pedestrians and bicyclists run the risk of missing their approach. Various auditory signals could potentially solve this problem, but due to their contribution to the sound pollution they might not be optimal for all situations. Therefore, this project was intended to create a concept using light as a mean of communication to alert and inform pedestrians and bicyclists near the bus, through signals emitted from the vehicle.

In this process, studies of theory and potential users were performed to acquire an understanding of the current problems concerning the interaction between vulnerable road users, or VRUs, and buses. The user studies found that there were three main problem areas connected to certain behaviours in traffic, namely distractions and inattention, hazardous behaviour and misunderstandings. Many of the issues seemed to originate from, or be strengthened by, a lack of communication, as VRUs had difficulties with interpreting the intentions of the bus drivers.

With the gained information and insights serving as a basis for a list of guidelines, the ideation was subsequently carried out iteratively in four phases where ideas and concepts were evaluated against a number of defined scenarios. Additionally, the different stages of the bus route were outlined, along with the suitable approaches for communication at each of these. With two concepts remaining, the suggested solutions were evaluated by both VRUs and bus drivers. The results from this then served as a foundation for the development and finalization of a final concept.

The final concept was a set of signals developed for the different stages of the bus. These signals fall under the categories of four key features namely progress bar, dynamic alert signal, zone alerts and preparatory light. Firstly, the progress bar shows the status of the bus at bus stops, thereby giving an indication as to how close the bus is to leaving. Furthermore, a dynamic alert signal is given when the bus leaves and approaches a bus stop, and similarly when alerting a vulnerable road user obstructing the path of the vehicle. The zone alerts are intended to mark out zones near the bus which vulnerable road users should avoid, while the preparatory light aims to render the bus easier to notice when the view is obstructed, through a projection emitted from the front.

NOMENCLATURE

EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
VRU	Vulnerable Road User

CONTENTS

01

INTRODUCTION

To introduce the master thesis project, the following chapter provides a background to the topic, problem area as well as a company description offering insight into the company that initiated the project. Additionally, the chapter includes the aim and objectives that the work and result were intended to reach. They are followed by the delimitations for the project as well as a general process description showing the different phases the project went through. Thereafter, a short summary of the final result is given, and lastly, the structure of the report is presented to pave way for the following chapters.

1.1 BACKGROUND

The transport sector has a great impact on the environment with regards to both ecological and societal aspects, especially in dense urban areas. With the increasing environmental demands for emissions and noise reductions, the technical development is further driven towards electric vehicles. These vehicles emit low levels of sound, which benefits the environment in cities, but also creates new potential issues concerning the safety of vulnerable road users. The silent vehicles are more difficult to detect for pedestrians and bicyclists, creating a need for an interaction between the two in order to achieve a safe traffic environment.

The existing warning systems found on the market have a focus on warning the drivers by making them more vigilant of the traffic situation. Pedestrians and bicyclists are on the other hand expected to pay attention to the surrounding traffic, and therefore, a very limited amount of attention has been paid to designing concepts for informing and alerting vulnerable road users, VRUs.

This is disadvantageous, as the interaction in traffic can be strengthened and made safer through better possibilities for communication between drivers and VRUs. Furthermore, since 90% of the information which drivers receive and interpret is visual (Chen, Wang and Duan 2014), it would be beneficial to lighten their cognitive burden by helping the VRUs interpret relevant information and make better decisions in the traffic context.

As of today, certain warning systems based on sound directed towards VRUs have been developed, but the implementation of light has received less attention. This in spite of the fact that the human response time to visual stimuli is fairly similar to the response time for auditory stimuli and much quicker than that for haptic stimulation (Chen, Wang and Duan 2014). The reaction time is 200 ms for vision, 150 ms for hearing and 700 ms for haptic stimulation. This indicates that alerts and information could be conveyed efficiently through visual signals as well.

Furthermore, an advantageous aspect of visual signals is that they have the ability to be limited to the relevant road users, while sound potentially reaches all individuals in the vicinity. With the usage of light signals, there is hence a greater possibility of tailoring alerts and information in order to reach the relevant road users while creating a pleasant city environment. There is therefore a need for investigating how light can be further used by vehicles in traffic.

On an international level, regulations have also been set with concerns to the production of new electric vehicles (UNECE 2016). Due to the problems that have been linked to the low sound emission from most electric vehicles EU regulations have been introduced, stating that artificial sound generators must be implemented in quiet cars by 2021. UNECE, United Nations Economic Commission for Europe, proposed a guideline for the AVAS parameters, including sound levels, spectrum and frequency shift.

Additionally, demands are raised regarding the artificial sound to reflect the speed of the vehicles in order to enable the VRU to audibly determine its speed. Therefore, light signals cannot be expected to entirely fulfill the previously utilized functions of sound. The potential of light lies instead within alerts and communication in specific situations.

The instigator of this project is Volvo Buses, which is a part of Volvo Group that is a world leading manufacturer of trucks, buses, marine and industrial engines as well as construction equipment (Volvo Group 2017). Within the bus sector, the most recently launched solutions include electric buses and electric hybrids (Volvo Buses 2017).

The market for these types of buses are continuously growing larger, a development in which Volvo Buses has played a substantial role. As Volvo Buses aims to develop innovative sustainable solutions to meet current and future demands of public transport, the investigation of the potential application of light signals can further strengthen their brand as a safety oriented and inventive company.

FIGURE 1.1 Volvo hybrid bus in Gothenburg

1.2 PROJECT SCOPE

Below the scope of the project is described in terms of the aim, objectives and demarcation. The aim highlights the desired outcome of the project and the concept development, whereas the objectives describe how this is reached. Lastly, the demarcation sets the boundaries in which these both can be performed.

AIM

The aim with this project is to create a safer traffic environment with electric buses as the target of improvement. Through this, a sense of security amongst the pedestrians and bicyclists moving in the vicinity of the bus is instilled. Furthermore, the aim is to achieve an efficient traffic flow and create a less stressful work environment for bus drivers.

OBJECTIVES

The main objective is to define a strategy and create concepts for how the buses could alert and inform pedestrians and bicyclists in the surroundings of the bus, through the use of light signals emitted from the exterior of the vehicle. This includes identifying the different stages in which the bus operates and defining the appropriate means of communication for these. The objective is furthermore to identify scenarios and personas to represent the needs and clarify the requirements which the situation poses on the lighting system. From the created concepts, one will be chosen for further development in order to obtain a final design proposal.

DEMARCATIONS

Due to geographical constraints and project scope, the user and usage studies are limited to Gothenburg, Sweden. This entails that the results are most applicable in areas with culture and regulations similar to Sweden, making Europe an appropriate market to target as an entry point for the solutions.

FIGURE 1.2 Electric buses in traffic

1.3 PROCESS DESCRIPTION

In order for the aim and objectives to be achieved, the different user needs were identified through user studies and thereby allowed for key problems to be highlighted. Simultaneously, benchmarking and literature studies were conducted in order to investigate the current possibilities and restrictions when it comes to lights and traffic. This information together with the results from the user studies then served as a foundation for the definition of personas and scenarios, intended to capture relevant behaviours and situations.

These were then followed by an ideation phase consisting of four iterative loops. During the iterations, further empirical and theoretical studies were also conducted so as to complete the project foundation and rationale. In the later loops, evaluations and user tests were also included in order to determine the continued direction of the development. In the end, the development resulted in a final concept using different light signals for communicating and alerting VRUs throughout the route of the bus.

FIGURE 1.3 Visual Representation of development process

1.4 FINAL RESULT

This project resulted in a concept involving light signals related to four different key features, namely the progress bar, the dynamic alert signal, the zone alerts and the preparatory light. Two progress bars are placed on the front and rear of the bus, indicating how close the bus is to its departure from a bus stop. This facilitates determining when it is appropriate to cross the road in front of the bus, and also helps potential passengers in concluding whether they will make it to the bus in time.

As the bus is leaving the bus stop, the dynamic alert signal emits a pulsating light from the progress bar, which are accompanied by projected lines on the ground. These are intended to warn VRUs of crossing the road in front of the bus. This signal is also activated when VRUs obstruct the path of an approaching bus, catching their attention through the light pulses and moving projections.

Additionally, the zone alerts include an alert signal for when the bus is pulling over to a bus stop. The signal's activation creates projected lines on the ground that move outwards from the bus, signalling that VRUs should keep their distance. Moreover, a turn signal is emitted as the blinkers are activated, thereby enhancing the effect of the conventional turn indicators. A projected triangle consisting of solid edge lines beside the bus displays the area which should be avoided, and it is accompanied by four pulsating light strands placed at eye level between the windows.

At bus stops, a stop line is projected from the back of the bus when VRUs walk behind it so as to warn them concerning the traffic and encourage them to be more attentive. Lastly, two lines are projected from the vehicle's front as the bus is moving so as to facilitate the discovery of the bus when the view is obstructed.

FIGURE 1.4 Example from the final result of the project

1.5 REPORT STRUCTURE

The introductory chapter to which this section belongs is followed by a presentation of the methods used in this project. Thereafter, the process is described, both in general terms and more specifically for each method applied. The traffic context involving buses and VRUs is subsequently introduced in chapter four, where amongst others, the topics of regulations, human behaviour in traffic as well as warning signals are processed.

This is followed by a chapter where all relevant aspects concerning light are compiled. These aspects include human vision and perception, light technologies, as well as currently existing light communication solutions.

Furthermore, the report contains a chapter describing the three different types of key users and their experienced issues in traffic, followed by the seventh chapter, concerning the contextual frames where the scenarios and personas are defined. Thereafter, the results from the ideation phases will be presented in three separate chapters, each describing one of the phases. The concept finalization is subsequently described in the chapter for concept development, followed by the twelfth chapter where the final concept is visualized, described and explained. After this, the methods and results of the project will be examined in a discussion chapter, which paves the way for the conclusions presented in chapter fourteen.

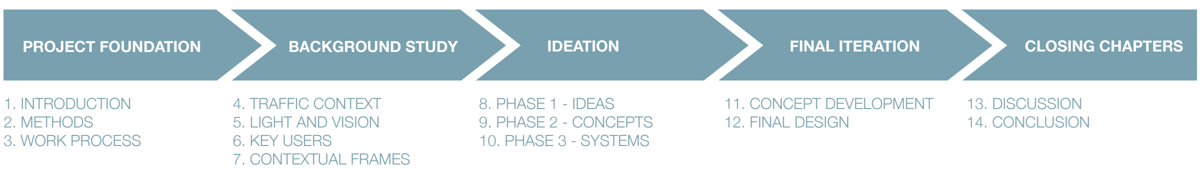


FIGURE 1.5 Visual representation of report structure

02

METHODS

In the following chapter, the methods used during the project are presented. The subchapter for theoretical studies, containing the literature study and market analysis, is followed by the empirical studies where interviews, observations and questionnaires are included. Furthermore, the methods affinity diagrams, personas and scenarios are described in the analysis section, followed by the ideation subchapter, where the methods for mood boards and brainstorming are presented. Finally, the evaluation section introduces Pugh matrices and the user evaluation.

2.1 THEORETICAL STUDIES

The theoretical studies were the beginning foundation of the project, and this section describes the methods used for these studies. Two methods were applied, namely literature studies and benchmarking.

LITERATURE STUDIES

In order to gain knowledge about a certain subject a literature study can be carried out (Liston n.d). The method can be divided into four parts, an initial one which leads to a broader sense of the topic and terminology. This is followed up by an exploratory phase where topic areas are identified, and the outline of the scope is becoming more clear. A focused literature study is then conducted within the outlined scope, where unresearched areas are mapped and the key findings can be discussed. Lastly, the refinement process is reached where the rationale of the study is finalized.

BENCHMARKING

According to the Business Dictionary (2017), benchmarking refers to the action of measuring the quality of a company's processes, products or strategies, and comparing them to similar ones of competing companies. The information gained can thereafter be used for determining which improvements can be made and where, as well as analyzing which factors give competitors better products.

FIGURE 2.1 Literature regarding ergonomics and lighting

2.2 EMPIRICAL STUDIES

The empirical studies, which were also a part of the project foundation, consisted of three methods. These are presented below, starting with interviews, followed by observations. Lastly, the method for questionnaires is described.

INTERVIEWS

Interviews can be conducted in different manners which enables them to be categorised accordingly. The most common category is the one-to-one interview where a single interviewee participates, contrastingly, when multiple interviewees attend it falls under the category of group interviews.

An interview can also be labeled depending on the structure of the interview. When a predetermined set of questions is used and strictly followed, it can be described as structured (Wilson 2014). A semi-structured interview is on the other hand defined by a more open technique for following the question template, thus allowing follow up questions and a more explorative approach. Lastly, unstructured interviews are built as a conversation between the interviewer and the participants around a topic, without a preset format.

Wilson (2014) states that, in order to facilitate the conversation around a specific subject, a mediating object can be utilized. This refers to an object, a model or an image which is used to represent a product or artefact that the interviewee will talk about.

OBSERVATIONS

Observation is a method conducted with the intent of studying and documenting situations and contexts that are of interest for the project in question (University of Strathclyde, no date a). The result can be quantitative in the form of absolute measurements or qualitative through record keeping of actions, procedures and identified concerns.

An unstructured observation provides a better understanding for the whole situation of use, generating a greater amount of qualitative data. On the other hand, the quantitative data is suitably collected through structured observations where fixed elements of the situation are documented. Observations function as a complement to interviews as the claimed actions or procedures can be confirmed or denied through what is detected.

The observation method can be divided into a number of subcategories based on the structure of the procedure (Key 1997). One of the subgroups comprises of the direct and natural observation, where the observation is performed in the authentic environment at present time. They can also be classified as open, where the observed party is aware of the presence of the conducting party and possibly the area of interest (University of Strathclyde, no date b). In contrast, hidden observations are carried out while the individual is uninformed of the observing party.

QUESTIONNAIRES

Questionnaires can be defined as documents that encompass a number of questions that respondents are invited to answer (Rowley 2014). The included questions can be of both open and closed character. Potential participants can be reached using distribution methods such as post, email or directly by hand. Generally, a questionnaire is designed to be answered without direct involvement from the instigator of the project. This entails the possibility to reach a great number of participants which can be geographically scattered, making it suitable for surveys.

FIGURE 2.2 Observation on site in Gothenburg

2.3 DATA ANALYSIS

The methods used for analyzing the findings from the theoretical and empirical studies were affinity diagrams, personas as well as scenarios. The three methods are all described in this section.

AFFINITY DIAGRAM

An affinity diagram is a tool used for organizing verbal data, information or ideas (Bergman and Klefsjö 2010). It is often applied when ideas need to be sorted into groups, or when organizing notes and insights from interviews as well as comments from surveys. Each idea or piece of information is noted on a separate piece of paper, and notes with similar data or information which seem to be related are grouped together until all notes have been categorized. Thereafter, the groups may be sorted into larger clusters or split up into more easily manageable subgroups, according to Bergman and Klefsjö.

PERSONAS

According to Pruitt and Adlin (2006), personas consist of fictitious and detailed portrayals of individuals who use a certain product or service. The descriptions are based on data collected from real users with the aim of presenting relevant aspects of the product usage in a relatable manner, which facilitates brainstorming and decision-making in the development process.

SCENARIOS

Scenarios are used to describe a system or situation with a complex interaction that is hard to convey unless put in context (Alexander and Maiden 2004). By describing systems and problems in story form the intended recipient can more easily understand and analyse the received information. Scenarios can vary from shorter descriptions to long analyses, depending on the message and purpose of the method implementation.

2.4 IDEATION

In the ideation phase, two methods were used to achieve the results. These comprised of mood boards and brainstorming, where brainstorming was the main focus, as it is a quite versatile method. Both of these methods are described below.

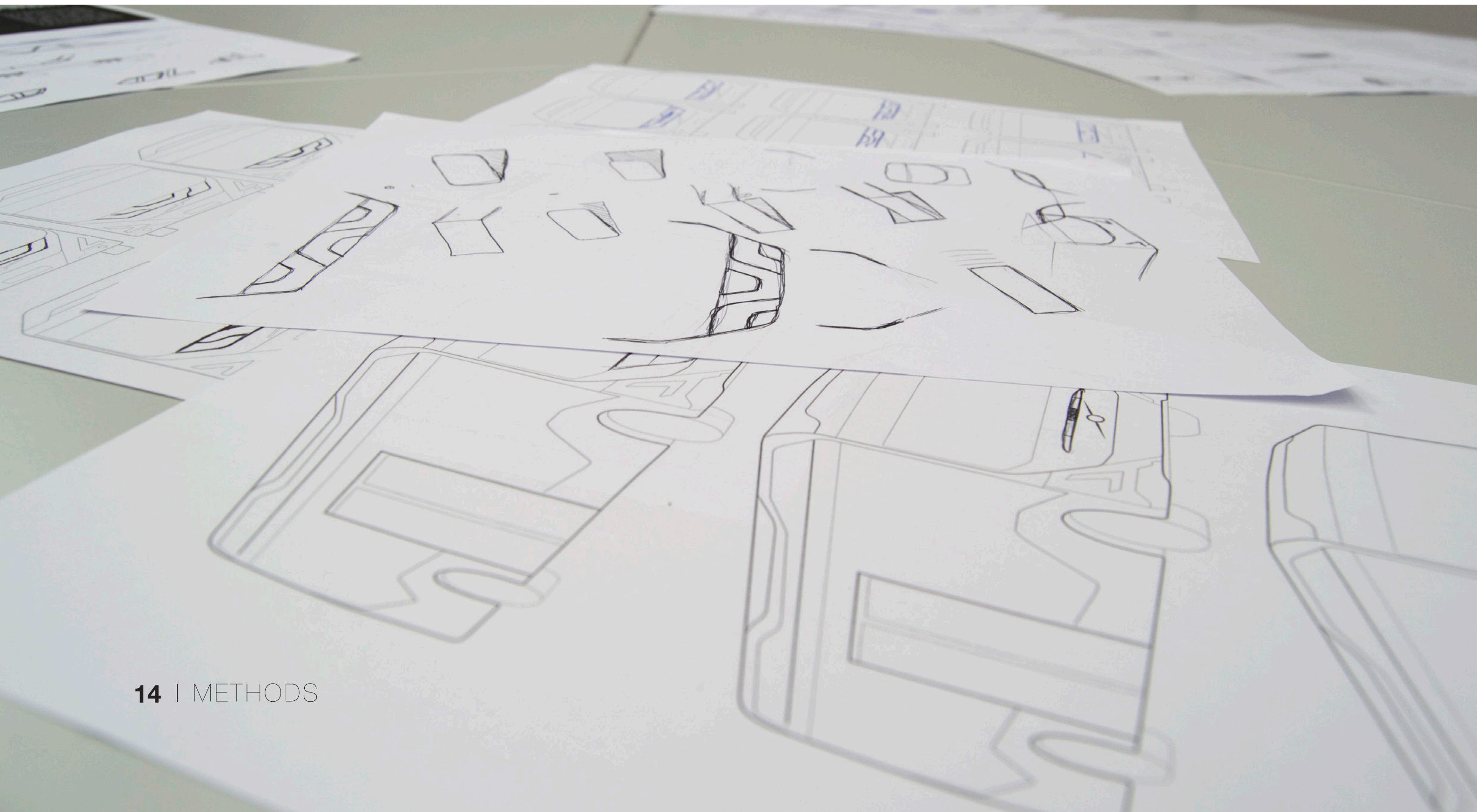
MOOD BOARD

McDonagh et al. (2002) states that a mood board consists of a collection of pictures, for example photographs or material samples, which are combined to convey the wanted emotion from a product. The pictures are meant to describe the overall expression of the product, and the images work together as an inspiration during the development phase.

BRAINSTORMING

Brainstorming is a commonly applied method, having the purpose of generating a wide variety of ideas or solutions to a problem (Berkun 2004). It is often performed in groups in a less structured manner where all participants are allowed to present ideas as well as discuss the suggestions of others. However, critique is not allowed in its early stages as it can impede the creativity to focus on evaluation and analysis.

FIGURE 2.3 Sketching



2.5 EVALUATION

The methods applied for evaluating the concepts in different stages of the project can be categorized under Pugh matrices and user evaluations. These two methods are both described in this section.

PUGH MATRIX

A Pugh matrix is an evaluation tool used for objectively identifying the best design proposals out of several candidates (Pugh 1990). The most important requirements are selected and listed in a matrix and serve as a basis for comparison between the new solutions and an already existing reference product. If the new design proposal is deemed as better with regards to a requirement it is marked with a plus sign, if the reference product is better it is marked with a minus, and if the two are seen as equally good it is marked with a 0. These estimations are thereafter summed up and the solutions with the highest scores are more suitable relative to the others when considering the set requirements.

USER EVALUATION

Usability testing is a method applied in a product development context with the aim of investigating how real users use a product, and what problems they might experience with it (Nielsen 1993). The tests are performed either with the intention of improving a product, or evaluating the overall quality of a product, for example when choosing between alternatives. These variants are referred to as formative evaluation and summative evaluation respectively. If the tests are conducted in order to compare variants, a further distinction can be made between within-subject testing and between-subject testing, according to Nielsen. In between-subject tests, different users evaluate the different variants of the product, while the same users evaluate both variants in within-subject tests.

The test subjects are generally asked to perform a set of tasks which represent the regular use of the product. These tasks are thereafter performed by the test participants in either a real context or a constructed environment, depending on what product is tested and what is safe as well as feasible in the test procedure. Depending on the tasks and context, the usage situation and goal can be presented via written or orally presented text, scenarios, images, films or models.

03

WORK PROCESS

The following chapter describes the process that constituted the work performed during the project. Firstly, the overall process is described and motivated, followed by the theoretical studies as well as the empirical studies. Thereafter, a description is provided regarding the process of the analysis as well as the ideation. Lastly, the implementation of the evaluation methods is described.

3.1 OVERALL PROCESS

In order to establish a steady foundation for the project with regards to issues in need of solving and guidelines which should be followed, theoretical as well as empirical studies were carried out. A few observations of bus stops and initial interviews with pedestrians and bus drivers were conducted so as to acquire a general understanding of the topic and enable a more specific approach in the continued studies.

This was followed by literature studies, benchmarking, more observations, interviews with individuals with impaired vision, and the distribution of four different internet based questionnaires. These were directed towards bus drivers, pedestrians, bicyclists and vulnerable road users with impaired hearing. The questions asked in the questionnaires were based on findings from the earlier interviews, which clarified what needed to be further investigated. Many of the questions were of an open character as they should not convey any bias, and it was deemed advantageous to create a possibility for the respondents to describe traffic situations quite freely.

The literature studies provided insights regarding light technologies, human behaviour in traffic as well as vision and perception, which contributed to defining appropriate guidelines. As for the benchmarking, it served as an inspiration for the ideation phases. Throughout the course of the project, the theoretical studies were complemented with additional information that was found to be necessary. This information along with the results from the empirical studies were thereafter analyzed in an affinity diagram so as to identify general patterns. The findings from this diagram and the preceding studies then formed the basis for the personas and scenarios, which were intended to highlight and summarize the found hazardous actions and attitudes in traffic. Subsequently, a list of weighted guidelines was written in order to define the aspects which were necessary to consider in the concept development as well as facilitate prioritization and an evaluation against them.

With this foundation, a mood board was created where a number of images were collected for inspiration, capturing the sought after essence of the concepts. Thereafter, the ideation comprising four iterations began. In the first phase, brainstorming was conducted around the leading words inform, guide and alert, as well as the sixteen scenarios, in order to include all issues. This resulted in 23 ideas for different signals, which were evaluated in a Pugh matrix against the scenarios.

Of the suggested solutions, twelve remained as the following phase started. In this phase, the relevant stages which the bus goes through on its route were defined, with the intention of further pinpointing in which situations signals are needed. The ideas were then combined, both in regular brainstorming, but also through randomly selected groupings so as to give inspiration for new solutions. The result was five concepts, which were evaluated against the scenarios, and by one VRU in a pilot user test in order to confirm the results from the matrix. In this evaluation, the test participant was presented with digital images of the signals containing animated elements, and was asked to interpret their meaning.

This lead to a narrowing down to a number of signals, which in the third phase were combined together into two concepts. These concepts were then evaluated both by potential users and bus drivers in order to collect all perspectives. The test procedure with VRUs was similar to the pilot test from the preceding phase, while the bus drivers, due to time constraints, were shown one concept which was described in more general terms. Thereafter, they were asked to give their opinion of the signals.

With these results in mind, the finalization of the chosen concept began, where a number of tradeoffs and compromises had to be made. Brainstorming was carried out around smaller details of the concept in order to connect all loose ends. Simultaneously, further empirical and theoretical studies were performed with the purpose of filling in missing pieces of information. The development ended in a final concept applying a number of light signals, communicating and alerting VRUs throughout the stages of the bus. This concept was lastly evaluated against the set guidelines in order to confirm its suitability.

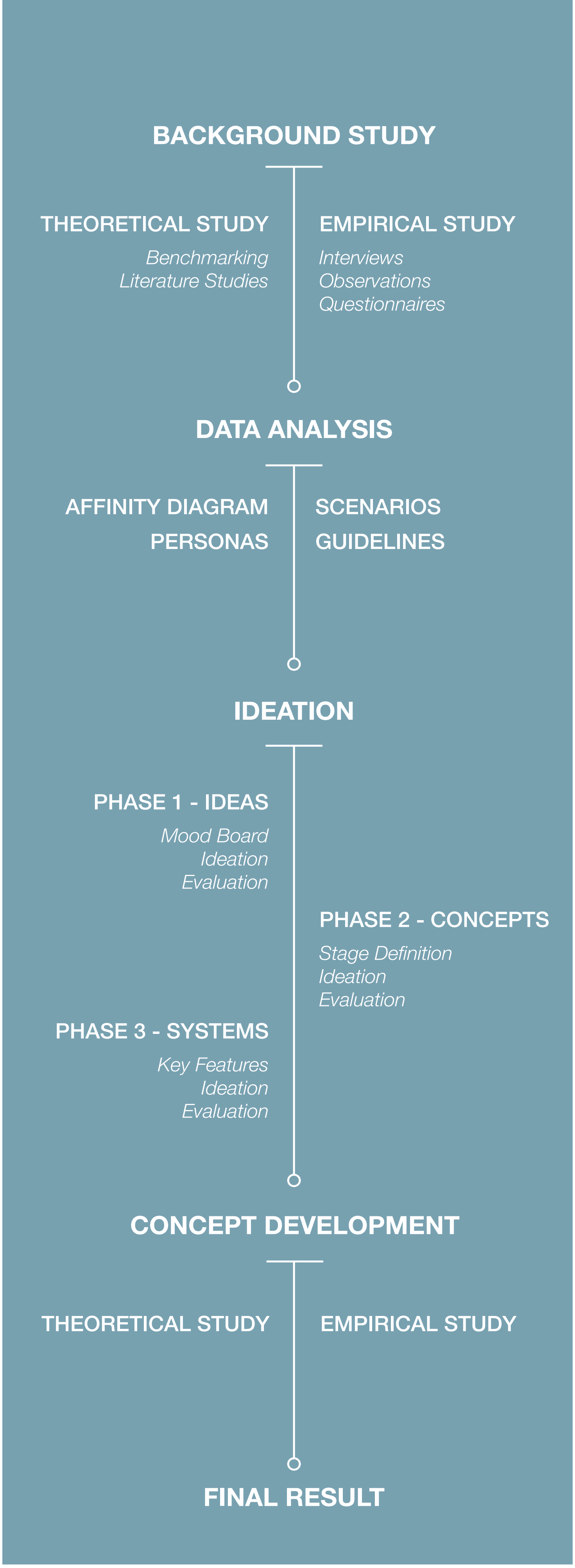


FIGURE 3.1 Visual representation of the process

3.2 THEORETICAL STUDIES

In this subchapter, the performed process of the theoretical studies is presented. It is divided into two sections according to the two main methods used, the literature studies and the benchmarking.

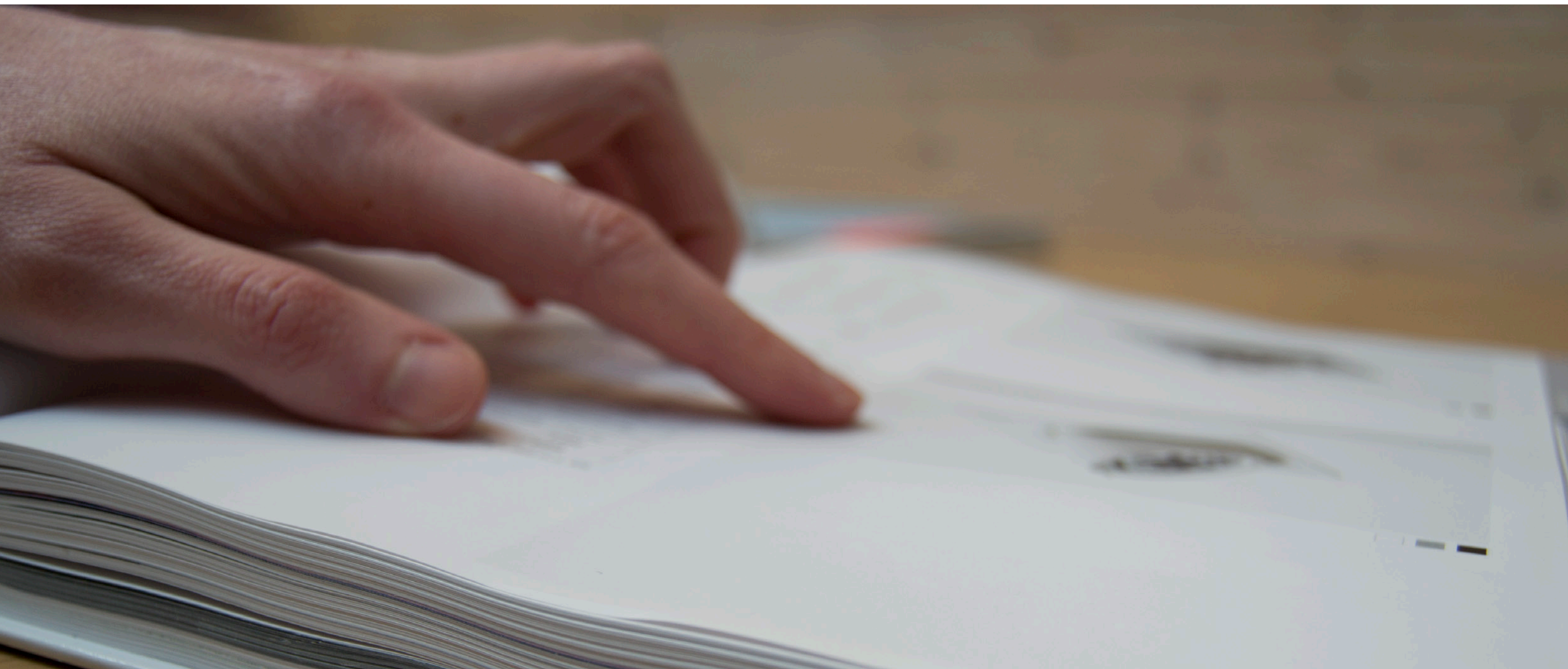
LITERATURE STUDIES

The performed literature study encompassed three different parts. Firstly, information was gained regarding traffic regulations and the use of light through legal documents. Scientific papers provided insight on the effect of different light characteristics and their possible applications. They also provided information regarding injury statistics in traffic as well as human behaviour and response to light and traffic. Lastly, news articles shed light on existing solutions, upcoming technologies and problems deriving from silent and autonomous vehicles. The results from these studies can be found in chapter four and five.

BENCHMARKING

The benchmarking was focused on the existing solutions within vehicle to pedestrian communication as well as different light signals on vehicles of various types. However, other fields were also studied, such as warning signals in traffic. Newspaper articles, company websites as well as academic papers about design projects contributed with information regarding the solutions that were found. In chapter five, these solutions are described.

FIGURE 3.2 Literature Review of Lighting Fixtures



3.3 EMPIRICAL STUDIES

The performed empirical studies had three different approaches; interviews, observations and questionnaires. These were used to map out the needs and problems of the different key users in traffic. Depending on the purpose of the method, the procedures were adapted to the situation at hand. The full procedures and adaptations are presented below.

INTERVIEWS

In the initial phase of the project, interviews were conducted with VRUs as well as bus drivers to explore the situation and gain an overview of the experienced problems. In total 12 interviews were held, where six of the participants were bus drivers and equally many VRUs. The participating bus drivers were all operating the electric line 55 in Gothenburg and had been doing so since the Electricity project commenced. Two of the drivers were women and the remaining four men. The results from these interviews are presented in chapter six, which concerns the key users.

By using a semistructured approach to the interview, it was possible to follow up topics that the bus drivers themselves brought up. This was particularly beneficial as the interviewers' knowledge of the drivers' situation naturally was limited, allowing the participants to lead the direction of the interview. For this a template of questions was used to provide support for the interviewer, which can be seen in appendix I. Beyond general questions concerning the bus drivers and their experience, topics such as problematic locations, situations and individuals were touched on as well as the cause of the problems.

Regarding the pedestrians, the range in age and gender varied. Two of the participants were female and the other three male, ranging in age from 24 to 62. Similarly to the bus drivers, the interviews were of the semistructured type allowing the participants to freely express their emotions and describe their experiences in traffic. The template of questions used for the interviews can be found in appendix II. Additionally, interviews were held via email with three pedestrians that had visual impairments (see template appendix III). In these interviews a greater focus was put on the experience and the perception of existing warning signals in traffic. This in order to gain a greater understanding for the situations where support is needed and which type of assistive tools are most functional.

In the third ideation phase, five interviews were held with drivers of the electric bus line in Gothenburg, with the intention of investigating how bus drivers viewed the potential of the concepts. The drivers were interviewed separately during their mid-day break, following a semi-structured interview template, as seen in appendix IV. Two additional drivers gave their opinion on parts of the solution, as they were shortly visiting the break room.

Since the drivers were on quite a busy schedule, the time for the interviews was limited, and only one of the two concepts was shown through pictures with animated elements. The functions of the signals shown in the images, as well as the purpose of them, were briefly described by the interviewers on a general level, thereby not focusing on the details which separate the two concepts from each other. For each signal they were asked what effect they thought it would have on VRUs, how they as bus drivers would be affected by it, and whether they preferred to control the signals themselves or for them to be autonomously started. The answers from the bus drivers are presented and analyzed in chapter ten.

OBSERVATIONS

For this project, the observations were direct and natural. They were conducted at various bus stops and interchange points around Gothenburg, as these types of places generate high levels of interaction between buses and VRUs. Furthermore, these locations were mentioned frequently as problematic in the interviews that were carried out during the same period of time. As calm streets were also mentioned as a problematic location, observations were carried out at a smaller street with a bus stop as well. The places were chosen with consideration to their size, amount of bus lines passing by and general layout, with the aim of achieving a variation in the observation spots.

The observations were unstructured to acquire a holistic view of the situation, and to ensure that all observed individuals behaved naturally, the observations were hidden. This was also the most reasonable method due to the size of the areas and the amount of people passing by. Each observation lasted for approximately an hour, during which the area was at times filmed, and notes regarding faulty or hazardous actions were taken. The films were subsequently processed, and noteworthy behaviours were described for the following analysis. Altogether, seven different places were observed during around eight hours (see figure 3.3), as one interchange point was observed during two separate occasions. As the information found concerns the key users and the places where they are exposed to hazards, the results from the observations are presented in chapter six and seven.

	Time (h)	Type
Hjalmar Brantingsplatsen	2	Interchange Point
Brunnsparken	1	Interchange Point
Kungsportsplatsen	1	Interchange Point
Nya Lundenskolan	1	Bus Stop
Chalmersplatsen	1	Bus Stop
Valand	1	Interchange Point
Sven Hultins Gata	1	Bus Stop

FIGURE 3.3 Matrix of observation locations

QUESTIONNAIRES

Four questionnaires were composed and distributed to four different groups of participants. All of the questionnaires were composed of a mix of open and closed questions, with the intent of collecting both qualitative and quantitative data. As the focus of the study and the purpose of the project concern the creation of a concept based on the experiences of drivers and VRUs, qualitative data and thus open questions became a necessity.

The closed questions, which is the natural format of questionnaires, were on the other hand included to provide clarity in previously known issues and experiences. All of the questionnaires were distributed through social media and web pages, either through specialized groups or on personal pages. The results from all four questionnaires can be found in chapter six.

Firstly, a questionnaire was sent to bus drivers with the intent of reaching a greater range of participants (see appendix V). This partly with regards to the number of individuals reached but also to attain information from bus drivers outside of Gothenburg. In total 216 bus drivers participated in the questionnaire, operating city and regional traffic as well as longer transports in coaches, as can be seen in figure 3.4.

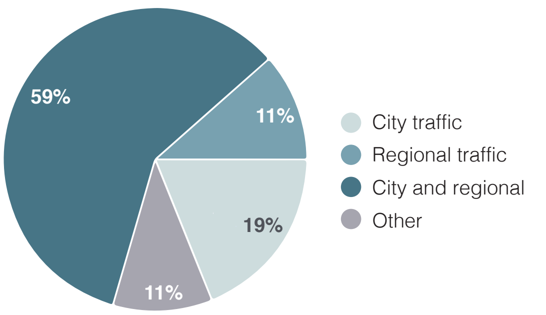


FIGURE 3.4 Diagram of bus drivers' work experience

A questionnaire was also distributed to bicyclists through a forum for cycling (see appendix VI). 71 individuals took part, providing insights from different parts of the country with varying public transport and city planning. The age range of the participating cyclists can be seen in figure 3.5.

Additionally, a questionnaire was sent to pedestrians resulting in 52 participants with an age distribution as seen in figure 3.6 (see appendix VII). The questionnaire was spread through social media and placement on the homepage of Fotgängarnas förening, an organisation for pedestrians. Lastly, another questionnaire was sent to individuals with hearing impairments (see appendix VIII). This was distributed through a page for Hörselskadades Riksförbund i Göteborg, an organisation for individuals with hearing impairments in Gothenburg. In total 13 individuals responded to this questionnaire.

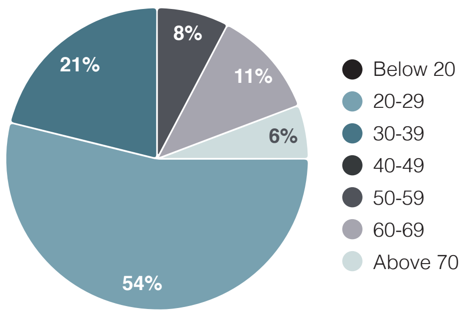


FIGURE 3.5 Diagram of participating bicyclists' age

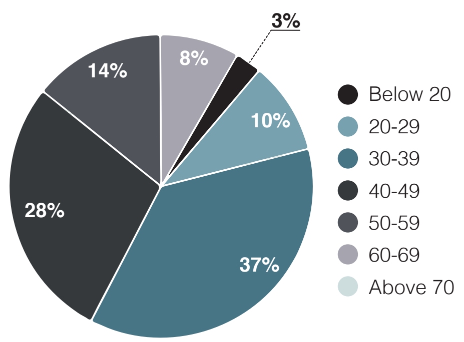


FIGURE 3.6 Diagram of participating pedestrians' age

3.4 DATA ANALYSIS

In this subchapter, the process of the analysis is described according to the three methods applied in the project. These comprise of the affinity diagram, personas and scenarios. The descriptions encompass the procedure used as well as the reasoning behind it.

AFFINITY DIAGRAM

When the literature and user studies were finished, two affinity diagrams were made where the data was noted and sorted into categories. When every note from the literature study had been placed in a group, the categories were discussed and reorganized to form clear and manageable groupings. Similarly, the data from the user studies was noted and grouped together. So as to acquire a holistic view of the mentioned situations and areas, all data concerning the same category from the different groups of road users were placed together. In order to be able to identify from which group of road users the information originated, the notes were colour-coded. After all notes were sorted, the groupings were reconsidered and discussed, and the notes were moved in iterations to find the most appropriate division. The final division will be found in chapter seven.

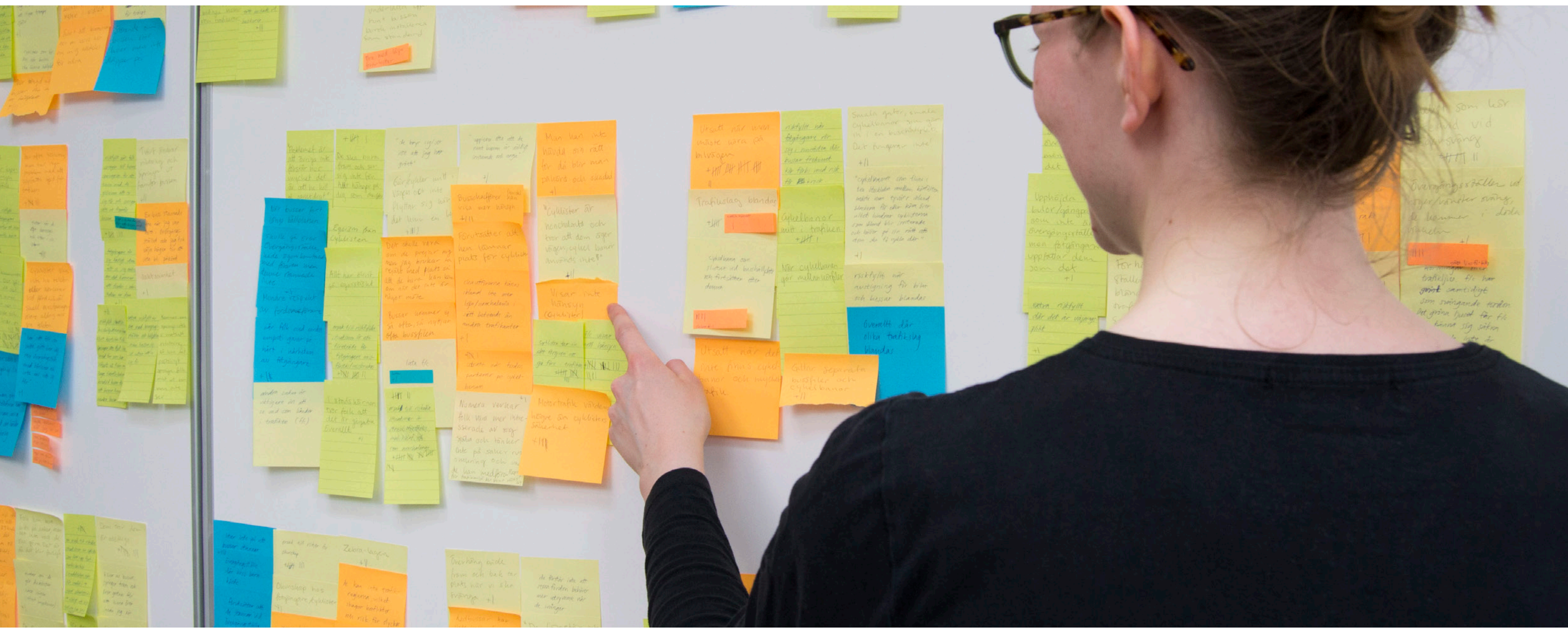


FIGURE 3.7 Creation of affinity diagram

PERSONAS

Personas were used as a method for acquiring a better understanding of the different types of vulnerable road users. They were created based on different personality traits with the aim of identifying and highlighting different motives and reasoning affecting the actions of VRUs and bus drivers. In order for the personas to be descriptively effective, the traits were exaggerated and one dimensional. In reality an individual would encompass multiple characteristics, depending on the situation and conditions they are faced with. The personas and how they will affect the final concept will be presented in chapter seven.

SCENARIOS

The scenarios were composed based on the most commonly found problems and situations mentioned in the user studies, or situations which were considered important due to the risks which they create for a specific group. Twelve scenarios featuring problematic situations were described so as to ensure that the main issues were captured. For a larger context, they were grouped in three different categories, which described the more general issues the scenarios presented. Furthermore, four additional scenarios were created to highlight positive behaviour that was noted in observations or mentioned in interviews. This provided an aim for the concept development to not only prevent faulty or hazardous actions but also to promote correct ones. As the scenarios were also a part of the contextual framework, they will be described in the seventh chapter.

FIGURE 3.8 Bus in a traffic scenario

3.6 IDEATION

This section presents the application of the two methods which the ideation encompassed. A mood board supported the idea generation, a process mainly based on brainstorming. In all, the ideation composed of three exploratory phases and a final refinement in the form of concept development.

MOOD BOARD

The mood board was composed with the aim of finding images which convey a sense of safety, but also instill a feeling of caution regarding the dangers in traffic. Different kinds of light phenomenons, shadows and projections were also in the search scope, as well as images of technical products and traffic. The completed mood board is found in chapter eight.

BRAINSTORMING

The ideation phase was mainly conducted through the use of brainstorming. By listing the types of communication, a structure was provided to the ideation. These areas comprised of alert, inform and guide. Similarly, the 16 scenarios were used as an additional base from which ideas were generated. Each of these starting points had a set time of individual ideation, in which solutions were generated and put on paper. When the set time had passed, the ideas were discussed to provide further information and enabling elements to be added to the solutions. The results from this phase can be found in chapter eight.

After a set of ideas had been chosen for further development, a second phase of brainstorming was carried out, where the existing ideas were randomly combined in groups of three. All of the remaining twelve ideas were put on notes and randomly chosen in groups. This generated four different groups for each round, and in total three rounds of this method were performed. The aim was to find other ways to combine the solutions and become inspired from the challenge of combining ideas in new and unexpected formations. The resulting ideas are presented in the ninth chapter.

In the third phase, the basis of the ideation composed of five part solutions with different functionality. These part solutions constituted the main categories from which the ideation was performed. Each of the five categories were explored with regards to their design and implementation, creating a range of suggestions for the part solutions. The ideation was also carried out with the aim of investigating how lights on the bus and projections on the ground could be combined in a concept. The variety of ideas were then combined to create a full concept, including each main category. In chapter ten, these concepts are described and visualized.

3.7 EVALUATION

The evaluation was performed with two different methods, the Pugh matrix and user test. The procedure of these are presented below, including the different phases of implementation and the adaptations that has been made to the methods.

PUGH MATRIX

To evaluate the chosen ideas from the first round of ideation, a modified Pugh matrix was utilized. The concepts were evaluated according to how well they were considered to improve the situations encompassed in the twelve scenarios, as they represent the defined guidelines in a concise manner. It was therefore deemed as an appropriate method for receiving an indication as to which ideas should be further developed in the early stages.

All of the 23 concepts were given a number between zero and three representing to which extent the suggested idea solves the issue at hand, where three corresponded to a solution very well fitted for the scenario. In addition, the ideas were graded on their feasibility, also on a scale from zero to three. The points were then summed together to indicate a final score. As the ideas were not developed in detail at this stage, the grading was approximate and the final score was therefore considered as an indication. As this evaluation concerned the first round of ideas, the result can be found in chapter eight.

A similar evaluation procedure was carried out in the following round of ideation, where five concepts were defined. These five suggested solutions were compared to the twelve scenarios and graded between 0 and 3, and were also given a feasibility score. These scores will be presented in chapter nine.

USER EVALUATION

An initial user test was performed on the concepts created in the second ideation phase. The material constituting the foundation of the evaluation composed of simple digital sketches with animated lights, which represented the function and appearance of the developed light systems. Each function of the concepts were introduced to the participant, through this visual material, after the situation in which they would be applied had been described. Questions were asked, with regards to how the signal had been interpreted, its function and how the participant would respond to it. After the five concepts had been presented, a few concluding questions were asked concerning the signals' overall functionality and the comparison between them. The answers given from the test participant will be summarized in the ninth chapter.

FIGURE 3.9 User Evaluation

The two concepts from the third ideation phase were tested and evaluated by nine potential users. In order to compose a heterogeneous group of test participants, the aim was to include individuals of various ages, ranging from 24 to 70. Age as a factor for heterogeneity was chosen since the associations with technology and views on human-machine interaction might vary between individuals of different ages.

As the test procedure applied in the initial user test was found to give clear indications as to how the light signals were experienced, the test procedure for this phase was similarly composed (see appendix IX). The purpose of the tests was to compare the two concepts, therefore, the evaluation was summative. All test participants were presented with nine situations for each concept, meaning that it was a within-subjects test where all variants of the light signals were introduced to all participants. This made it possible for the participants to compare the signals to each other and choosing their preferred signals.

In addition to the questions asked regarding their interpretation of the signals and their responses to the signals, the participants were asked to fill in a semantic word scale for each light signal. Since the test participants would fill in word scales for a total of 18 signals, the word scale was as concise as possible, comprising of three word pairs. The words were imperative - guiding, clear - vague, and safe - unsafe. The results and analysis from the user evaluation can be found in chapter ten.

04

TRAFFIC CONTEXT

The traffic context comprises many different elements, with the ones relevant for the project presented below. Firstly, the regulations concerning the use of light on vehicles and the electric vehicles are introduced to explore the boundaries and needs for a potential solution. The areas of interest regarding the bus, are then examined to further define the demands. With regards to the human, their behaviour and actions in traffic as well as the perception of safety and risks are explored, and later related to the warning signals that currently exist in traffic. To give a broader perspective on the issue, accident statistics involving buses and VRUs are presented.

4.1 BUS

In 2015, the urban planning project Electricity launched a new bus line in Gothenburg, where three of the ten buses were entirely electric, developed by Volvo Buses (Electricity 2017). These electric buses are concept vehicles with the aim of testing and evaluating new solutions to develop public transport of the future. The other buses are electric hybrids which Volvo Buses has launched worldwide. As these two types of buses are the main focus of this project, their exterior features are of relevance for the possible lighting solutions. Both the front and the side views differ somewhat, as can be seen in figure 4.1-4.4. Regarding the front, the main difference is the shape of the headlights, while on the side, the placement and width of the doors vary.

The main limiting factors for the placement of new lighting solutions on the front are the headlights and the license plate, as the placement of these are controlled by regulations, as well as the windshield since it must provide the driver with an appropriate field of vision. Furthermore, the destination display above the windshield must be visible for potential passengers and should therefore not be moved.

When it comes to factors of the bus affecting the bus drivers' interaction with VRUs, the blind spots of the bus are of importance (Société de l'assurance automobile Québec 2017). Every vehicle has blind spots, but the blind spots increase with the size of the vehicle. Blind spots can appear due to low visibility around the vehicle, but also be caused by side mirrors or pillars beside the windshield. For city buses, there is a small blind spot at the front of the vehicle, and also one at the rear. The biggest blind spots cover some of the area next to the bus quite close to the front part on both sides. These two blind spots reach a significant distance away from the sides of the bus creating an area which VRUs should avoid being in. As a significant aspect of traffic is the interaction between different types of road users, it is important that all road users are aware of the blind spots of vehicles, in order to avoid hazardous situations.

FIGURE 4.1 Hybrid bus in side view

FIGURE 4.2 Hybrid bus in front view

FIGURE 4.3 Electric bus in front view

FIGURE 4.4 Electric bus in side view

4.2 STAKEHOLDERS

The main stakeholders comprise of seven different parties with varying interests in a communication system using light. Volvo Buses is the one disbursing for the communication system and therefore has to find the incentives or potential profits that a solution can bring. This can either be in terms of the system itself, the contribution it has to the development of the electric and hybrid buses or the promotion it brings to the company as a whole.

Another important stakeholder comprises of the bicyclists and pedestrians. The VRUs constitute the primary user of a potential light communication system and are the ones meant to interact in response to it. Therefore it is important to ensure the acceptance of the signals, especially due to the exposure they are faced with relative to the bus. With the goal of being on time yet safe, the VRUs' perspective on light communication must be considered.

The VRUs also play an important role for the customers of Volvo, the company handling the public transport service. Many of the VRUs are likewise passengers, thereby making them the customers of Volvo's customers. Due to their role as a coordinator of bus traffic, they have an interest in making vehicles run on time and arrive safely, thereby maintaining a content customer base. In order for Volvo to promote their buses and a potential communication system to public transport service companies, there have to be benefits that interest the second level of customers, the VRUs.

Currently, much of the responsibility to ensure the safety of surrounding VRUs is placed on the bus drivers. With them handling the bus and potentially controlling parts of the lighting system, the bus drivers become a secondary user of the solution. With the drivers follow also the bus operating companies which handle the provision of bus drivers. These want to ensure the wellbeing of their drivers, relating to the conditions in which they work, which in turn enables them to guarantee the quality of the company's service.

Beyond the primary user and the secondary users, there are also side users in the car drivers also interacting with the bus and the VRUs. The light communications are not targeted towards these individuals but nevertheless they will be reached by the signals. As the drivers must remain attentive to the task of handling the car, the signals must not disturb or redirect their attention. Furthermore, there is also a stakeholder in the city of which the system is implemented. With the system's ability to change the cityscape, the environment of the region can change and develop.

4.3 REGULATIONS

With the many interactions that the traffic context encompasses, regulations have been set to ensure the safety of all involved road users. These concern the traffic as a whole as well as specific vehicles. Below, the regulations concerning the use of light and sound are presented which influence the demands on the signaling system for silent vehicles.

Transportstyrelsen stipulates that vehicles are allowed to emit only white and yellow light from the front, and only red light from the rear (TS 201513). However, exceptions have been made for rescue vehicles and taxis, which are allowed to show blue and green light respectively. In addition, it is not permitted to show switchable or moving texts and images.

Furthermore, there are seven different variants of blinking lights that are allowed in traffic. These are rear lights on bikes, direction indicators, hazard lights, warning lights on road maintenance vehicles, alarm devices on rescue vehicles, stop signals on police vehicles, and emergency stop signals which on some cars activate at a sudden deceleration.

Moreover, the lighting fixtures must be approved for that type of vehicle, be manufactured with the intention of being mounted on a vehicle, and must hold an EU approval, according to Transportstyrelsen (TSFS 2016:22). Furthermore, it is relevant to note that the same rules apply both for situations where the vehicle is moving and when it is standing still. On buses it is also allowed to place a lamp above the doors intended to light up the ground below them. This fixture should not protrude more than 50 mm, and be shielded so that it does not expose other road users outside of a ten meter radius to glare.

Transportstyrelsen further states that in daylight, vehicles should have low-beam headlights on (TS201513). It is also allowed to use other lights, which refer to daytime running lights, fog lights and low-beam headlights with lower voltage. These lights cannot be used at the same time as the low-beam headlights. At night, high-beam or low-beam headlights should be used, depending on the distance to other vehicles, in order to minimize the risk of glare.

4.4 PERCEIVED RISKS

Risk taking in traffic is dependent on many different factors, some of which are brought up in Wilde's (1998) theory of what circumstances make road users less careful. The author claims that road users always try to maintain an optimal level of subjectively perceived risk, through balancing the accepted risk level against the risk to which one is subjected. The accepted risk level is affected by how the road user estimates the expected gains and losses related to the hazardous behaviour as well as the safe behaviour, for example the time saved or the costs from a speeding ticket.

As Wilde states that road users continually evaluate the risk they are subjected to, compare it to their accepted level of risk, and adjust their behaviour accordingly, safety measures in traffic might not always give the expected effect. If the road users perceive the situation as more safe they are prone to take greater risks. On the other hand, when road users perceive the situation as less safe, their behaviour might become more prudent. Therefore, one can aspire to change the level of the perceived risk for the road users, or their accepted risk.

Osvalder and Rosenberg (2014) also claim that the traffic behaviour of vulnerable road users is affected by their perceived safety. For example, they have found that when a green light informs pedestrians that they can cross the road, they are less attentive of the surrounding traffic. However, when a red light signals that pedestrians should stop, and there is no signal given for when they should pass, the vulnerable road users are more attentive while crossing.

Papadimitriou (2016) also brings up perceived safety in a study which found that road types directly affect pedestrians' tendency to cross a road. It is most common to cross the road where there is no marked pedestrian crossing, so called mid-block crossings, in smaller streets.

Furthermore, the traffic volume also affects the mid-block crossing tendency; when there is much traffic, more pedestrians will choose to cross the road at a protected crossing. Pedestrians also tend to take more risks at a lower traffic volume, and the more risk-taking pedestrians show a tendency to cross the street while keeping a higher walking speed.

Regarding traffic violations, individuals who often commit violations and consider themselves as better drivers seem to believe that rules do not necessarily apply to them, according to Forward and Lewin (2006). Furthermore, Parker et al. (1992) claim that individuals who commit violations think that their hazardous behaviour is generally accepted by others. Changing the behaviour of road users in traffic is hence also related to altering their view on risks and their perception of how others see risk-taking.

Additionally, the perception of risks does not only vary between road users, but also within individuals depending on the situation and the parties involved. According to Lundholm et al. (2001, referred to in Forward and Lewin 2006), individuals who were asked to estimate risks in traffic for themselves as well as for other road users rated the personal risk lower than the general risk.

Furthermore, there is a well-known tendency of believing that accidents will not happen to oneself, which McKenna (1993) relates to an illusion of control that many road users seem to experience.

The low levels of estimated personal risk also suggest that there is in certain situations not enough motivation to refrain from engaging in hazardous behaviour. The belief that one has control over the situation can also lead to more risk-taking, and it is hence advantageous to try to give the road users a more appropriate level of perceived control.

When it comes to encouraging individuals to engage in less hazardous behaviour in traffic, Linderholm (1997, referred to in Forward and Lewin 2006) has found that different approaches suit different target groups. For thrill seekers, it is important to provide them with information as to why they should act in a certain way, while risk-takers should receive information which deters them from committing violations. The responsible road users should be provided with a confirmation of their correct behaviour, and those striving for security need to receive information that can help increase their control of the situation.

FIGURE 4.5 Interaction between bus and pedestrian

4.5 WARNING SIGNALS

Eriksson, Dahlman and Osvalder (referred to in Osvalder and Rosenberg 2014) have formulated five guidelines for designing warning signals in traffic contexts, which are presented below. The first guideline concerns the complexity of the warning; it is advised to minimize the number of irrelevant elements which call for the attention of pedestrians. Secondly, the attention of pedestrians should be directed towards elements which are relevant in order to be able to perceive and interpret the traffic situation.

Furthermore, the authors recommend pedagogical uniformity, which in this context means utilizing the same element in all warnings, if possible. The fourth guideline emphasizes the importance of designing clear and simple elements as well as using well-known stereotypes, for example the colour red for stop signals. Lastly, the possibility of executing conscious or unconscious faulty actions should be eliminated.

Osvalder and Rosenberg (2014) claim that, for pedestrian crossings over tram rails, a thick yellow line is the most efficient for marking out the tram rail area and making pedestrians aware of the fact that they are entering a new area where other rules apply. Furthermore, the authors state that a light signal in combination with a sound signal enhances the effect of the warning as long as it can be perceived despite traffic noise. In those cases where a sound signal is used unaccompanied by a light signal, pedestrians might feel insecure as to where they should direct their attention.

Furthermore, Osvalder and Rosenberg state that light signals with a blinking yellow light increase the pedestrians' level of attention, as blinking lights are efficient carriers of information. These signals are especially effective when combined with sound, however, pedestrians stop more often when a red light is shown in combination with the auditory signal.

Regarding the frequency and timing of warnings, Chen, Wang and Duan (2014) have found that a warning which is given too early runs the risk of being ignored if the reason for the warning cannot be identified. It might also create a distraction or cause discomfort. Furthermore, an alarm which is given very early on might be considered a false alarm (Dingus 1998, referred to in Chen, Wang and Duan 2014). The timing of a warning or an alert is therefore of great importance.

The authors further divide the process of travelling in traffic into three phases; the comfort zone, the safety zone and the time zone of lost control. In the comfort zone there are no hazards in traffic, but when a potential hazard arises one will have to be more attentive to prevent emergencies, which is referred to as the safety zone.

The zone of lost control is described as the phase where no appropriate action is taken in time to prevent an accident from happening. It is appropriate to present information to the individual that can help them avoid leaving the comfort zone. If any potential hazards arise a pre-warning signal can direct the attention towards where it is needed and thereby assist the road user in keeping inside the safety zone, according to Chen, Wang and Duan. It is hence advantageous to not only consider how a system acts in a critical situation, but also how these situations can be prevented through information or alerts given early on. Warning signals concerning the context can also derive from the vehicle itself. ADAS, Advanced Driver Assistance Systems, support the driver in the driving process and thus increase the safety for both passengers as well as other road users (Chen, Wang and Duan 2014). The level of automation can vary amongst the systems but can be categorised into three main groups; information and warning, active assistance as well as high automation.

Within all of these levels and the ADAS as a whole, there are some parameters that can create issues. These issues comprise of timing, type of modality, information transparency and false alarm rate. If these parameters are set incorrectly the system cannot support the driving process but also cause additional stimulus for the driver to perceive and handle without cause.

FIGURE 4.6 Examples of warning signals

4.6 ACCIDENT STATISTICS

According to statistics from Transportstyrelsen, the number of accidents involving VRUs and buses in Sweden was 1278 over the past seven year period, resulting in an average of 183 accidents per year (Yamazaki 2017). The accidents range in consequences from minor to fatal, where an average of approximately 4 per year result in the later. In 2016 the total number ended up below the statistical average, with 170 accidents and 3 fatal cases.

Amongst the registered incidents, the accidents mainly derive from two locations. These locations are constituted of bus stops, including interchange points, and VRU crossings for both cyclists and pedestrians respectively. 56% of accidents on record occur at locations where the buses drop off and pick up passengers, whereas the VRU crossings are attributed to 41%. Of the total number of registered accidents 61% takes place during daytime, meaning most of them occur at a sufficient level of light.

Regarding silent and electric vehicles, there is an increased risk of accidents. In comparison to ICE-cars, statistics show that pedestrians are 40% more likely to be involved in a collision with a silent car. In addition, the number of accidents between silent vehicles and pedestrians increased with 54% between 2012 and 2013 (Welsman 2013). Studies by the NHTSA (2011), provided similar statistics with EVs and HEVs being 1.38 times more likely to be involved in pedestrian crashes. Similarly, the risk is increased when involving cyclists, with an increased risk of 33%. Furthermore, the EVs and HEVs have a double likelihood of partaking in a collision with a pedestrian in low speed traffic situations (NHTSA 2009).

The risk of accidents is further increased for individuals with visual impairments. Studies conducted by Parizet (2014), show that ICE cars were detected by a blind pedestrian at a 10 meter distance when moving 10 km/h on a smooth surface. An EV was, on the other hand, detected later with only a handful of meters to spare.

The difference in response times varied up to 1.5 seconds for the EVs compared to the ICE-vehicles. EVs proved to emit a low level of noise below 20 km/h, thus creating difficulties for visually impaired individuals to detect them at low speeds (NHTSA 2016). When maintaining a speed above 30 km/h, tests have shown that noise generated from wind and tyres are equivalent to the noise of the engine of an ICE car. It is therefore of greater relevance to investigate the interaction between VRUs and buses at low speeds.

4.7 CONCLUSIONS

As this chapter shows, many factors affect how people act in traffic. Individuals who cross the road where there is no pedestrian crossing tend to walk faster, meaning that people can appear suddenly in front of a bus. This leads to the conclusion that an early prevention of VRUs passing in front of the bus would be beneficial, as opposed to only focusing on creating a warning signal for when someone is in front of the bus.

Furthermore, as the behaviour of road users is affected by what they believe that others view as an acceptable behaviour, it is important to clearly show what is tolerable, as well as what is expected of VRUs in each situation. Research has also shown that risk-takers should be given information which can deter them from committing a violation, while responsible individuals should receive a confirmation of their correct actions. Road users who strive for security, on the other hand, need to be provided with information contributing to an increased sense of control in traffic situations. It is therefore important to create signals which are clear and well motivated in the situations where they are utilized, and that the signals help VRUs feel in control. However, as research has also found that some road users commit more violations when they experience an illusion of control, it is important to give an appropriate level of perceived control that does not lead to hazardous behaviour.

With regards to the design of warning signals in general, it is beneficial to consider using established norms for warnings, for example using colours as markers. However, as Transportstyrelsen stipulates that red light cannot be emitted from the front of a vehicle, there are limitations regarding the applications of certain norms. According to the current regulations, only white and yellow light can be emitted from the front of the bus. On the other hand, yellow is also a common colour for warnings, for example it is used for increasing VRUs' attention at tram crossings.

Furthermore, combined sound and light signals have been found to be the most effective for warnings, as it clarifies towards which element VRUs should direct their attention. To time an alert correctly is also essential since signals given too early or in uncritical situations might be ignored. Lastly, it is advantageous to present information which helps VRUs to keep an appropriate level of control, and stay in the comfort zone or safety zone where measures can still be taken to avoid possible hazards. This again emphasizes the importance of presenting signals which facilitate an early prevention of hazardous situations.

05

LIGHT AND VISION

The following chapter concerns the possibilities and limitations within the use of light. Firstly, the preconditions set by the human eye and mind are examined and described to further set a framework for potential solutions. The light technologies are then explored both with regards to conventional lighting as well as upcoming means of communication based on light. Finally, existing solutions of light signals and vehicle warning systems are presented.

5.1 VISUAL PERCEPTION

In this chapter the perceptual abilities of the human eye are explored both in terms of the peripheral field of view as well as the visual detection. Similarly, the limitations are investigated with regards to the effect of glare. Lastly, the impact of light usage in daylight is described through the existing studies on Daytime Running Lights.

PERIPHERAL PERCEPTION

Huestegge and Böckler (2016) state that the processing of hazards in the periphery functions remarkably well, and that it therefore can direct the eye towards possible dangers. In their study of eye movements and peripheral processing of traffic scenes, the authors found that when observing a traffic situation, the peripheral hazard processing began at around 200-400 ms after fixating the eyes on a specific point. They further state that previous research has indicated that the time required to locate an object within the field of vision and guide the eye towards it, is around 175-200 ms (Becker and Jürgens 1979, referred to in Huestegge and Böckler 2016).

Furthermore, color vision is the most accurate in the central parts of the field of vision, and Mullen and Kingdom (2002) claims that in the human peripheral vision, the colors which can be distinguished are mainly blue and yellow. However, at the section of 10-30 degrees, a certain level of trichromacy remains. At night, the human vision is most receptive to blue light and generally light at the short wavelength end, according to de Bruijn, Rookmaaker and van der Weide (no date).

GLARE

When it comes to glare, it is described by Wördenweber et al. (2007) as a phenomenon occurring when the luminance of a specific light source is more than approximately two log units higher than the average luminance in the surroundings. There are eight different types of glare; flash blindness, paralyzing glare, retinal damage, distracting glare, adaptation glare, disability glare, discomfort glare and saturation glare (Vos 1999, referred to in Wördenweber et al. 2007). In traffic situations, the four latter are of greater interest.

Additionally, Wördenweber et al. (2007) state that glare is most likely to cause a decreased level of visibility when the origin of the glaring light is close to the line of sight of the observer. However, distraction caused by glare can be created in a wider part of the field of vision and is most often the result of smaller sources with a high luminance. There is a correlation between the created glare and the luminance regarding the size of its origin. For drivers, a light source with a larger amount of energy at the shorter wavelengths, as well as smaller headlights and a longer duration of exposure are likely to create discomfort.

VISUAL DETECTION

Regarding the circumstances affecting the ability of the human eye to discover objects, Wördenweber et al. (2007) states that there is a difference between visibility and conspicuity. The factors affecting the visibility of an object are size, contrast and difference in color between the object and the surroundings. To achieve conspicuity, the object must have some characteristic which makes it stand out from other surrounding items. Features which can assist in achieving conspicuity are color, shape, size, flicker, movement and luminance, which should be chosen with the surrounding objects in mind.

As for visibility in relation to lights, different lighting technologies create different conditions for visibility. For projections, Laserworld (no date) recommends projecting on surfaces with a light color, when the environmental brightness is low. If the surroundings have a dim light, however, middle grey surfaces are better suited. In general, it is preferable to project the laser on even surfaces.

When it comes to visual detection of warning lights, Bullough and Rea (2015, referred to in Bullough 2015) have found that a luminous intensity at approximately 530 cd results in the best response times during daytime. 180 cd is sufficient for nighttime, so as to avoid glare and a decrease of the visibility of objects with a lower contrast. Furthermore, Bullough states that flashing lights with a 10:1 ratio between the maximum and minimum intensity are detected 1-2 seconds faster than on-off flashing lights (Bullough and Rea 2014, referred to in Bullough 2015).

Regarding the color of lights, Bullough et al. (1999) claim that the yellow signal in traffic lights generate the fastest reaction time, while green lights require the longest time, when the lights follow the ITE luminous intensity recommendations. Moreover, there is no difference between incandescent traffic signals and LED signals. However, the yellow and green signals require higher luminances than the red light in order to make sure that they generate the same reaction time and rated conspicuity.

The constellation and dynamics of lights can also affect their visibility and response time; Lee et al. (2003) have found that lights with a sweeping pattern are detected faster in the periphery than other types of signals. In addition, rapidly flashing rear lights on vehicles were found to generate a quick response from the test subjects in case of a sudden deceleration. Furthermore, Skinner and Bullough (2014) claim that the response time to a sweeping turn signal on a vehicle is considerably shorter than it is to ramp-up lights. The sweeping turn signal generated fewer response times above 2.5 seconds than other types of signals, and the time required for identifying the signal was shorter for the sweeping lights than it was for conventional flashing turn signals. It should therefore be noted that the dynamics and movement of light signals can play an important role in if and when a signal is perceived.

DAYTIME RUNNING LIGHTS

The perception of objects is highly dependent on its conspicuity, as previously stated. How well a light diverts from its context thus determines the individual's ability to note and process it. Therefore, the environmental lighting has a great influence on the detection of light signals in outdoor contexts. A brighter environmental lighting entails a decreased conspicuity for an outdoor light. However, in the automotive and traffic context studies indicate that active headlights in daylight make a difference for the accident occurrence (Cairney and Styles 2003).

Studies show that failure to note other vehicles in the proximity has a great impact on the number of collisions occurring (Cairney 1991). To tackle this issue, Daytime Running Lights, DRLs, were implemented in vehicles to increase the contrast in brightness between it and its surroundings (Cairney and Styles 2003). DRLs are required under regulation in Sweden and other parts of Europe (Bergkvist 2001).

In several studies the effect of DRLs have been tested. The National Highway Traffic Safety Administration conducted a study which presented results showing that the DRLs lead to an estimated reduction of 7% in multiple vehicle daytime crashes (NHTSA 2000). Similar reductions were presented in a study by Tofflemire and Whitehead (1997), who compared collision rates in Canada between cars with and without DRLs installed. The result showed a 5.3% decrease in crashes, where a large contribution was derived from a reduction in head-on collisions with oncoming vehicles.

In a report by Bergkvist (2001), results from a study were compiled where crash rates were compared. It suggested that DRLs reduced the number of vehicle to vehicle collisions with 5.3% and vehicle to pedestrian crashes with around 9%. In all, the studies indicate that lights indeed draw attention in daylight and the use of light as a way of signaling has a function in bright environments as well.

FIGURE 5.1 Daytime running lights on hybrid bus

5.2 LIGHT TECHNOLOGY

The light technology is a multifaceted area of science with many different applications. A light source can be made in various ways, with a range of qualities following each of these. Additionally, this section explores the boundaries for the use of the light sources, where the delimitations are not set on a general spread of light but extends to the surfaces it illuminates and the transmission possibilities in the transportation of light.

INCANDESCENT LIGHTS

Incandescent lights are the traditional type of lighting, that has been around for approximately 120 years. The light burns through wire filaments that are heated with electricity thus generating a glow (Wördenweber et al. 2007). This method creates a heat production greater than the light emissions with regards to the output of energy. Therefore, the incandescent light is considered to be inefficient in terms of the electricity it consumes, and the production is regulated in many parts of the world. The incandescent light bulbs fade with age and last between 750 and 1000 hours, which in relation to other alternatives is quite short.

HALOGEN LIGHTS

Halogen lights share many similarities with the incandescent lights and are based on a thin tungsten filament, which is protected by halogen gas (Wördenweber et al. 2007). Due to the halogen gas prolonging the runtime of the filament, the lifespan of a bulb ranges from 2250 to 3500 hours, thus surpassing the life of a traditional incandescent light. In comparison to incandescent lights, halogen bulbs also burn brighter due to the thin tungsten filament which emits a bright white light. Regarding the cost, it is a cheaper alternative to LED lights.

LED LIGHTS

LED lights produce light by passing energy through semi-conductors (Wördenweber et al. 2007). In comparison to other light systems, LEDs are more energy efficient with a small amount of heat development. The lifespan for a LED light is up to 30 000 hours, making it outperform many other options. Its light intensity is not the strongest of the options but nevertheless emits a clear white light, which provides a long distance illuminance. Additionally, the LED lights are more visible from an angle relative to a traditional incandescent light, due to a wider beam.

LASER LIGHTS

Laser lights is an upcoming technology, especially within the automotive industry. BMW, the initiator of the implementation of laser headlights in the automotive field, claims that these new headlights have an illuminance 1000 times stronger than LED lights (Ulrich 2013). This also brings the benefit of them being possible to make much smaller than conventional lighting systems and with a lower energy consumption.

Ulrich continues to state that safety is usually a concern connected to the use of laser, but the construction does not allow the laser to be directed straight outwards. Instead the light is comprised of blue lasers that are directed towards a set of mirrors which in turn focus the laser to a lens filled with yellow phosphorus. This activates the compound which starts to emit an intense white light. In turn, this light bounces onto a reflector that sends a diffused beam of light forward, which is powerful yet not damaging to the eye.

The lighting type is expensive if used for general lighting, but the price is decreasing. It would allow a higher packing density in comparison to LEDs and has the potential to be more flexible, where a simple switch can change it from functioning as a spotlight or a floodlight. With the great intensity and control of the light it is also possible to create a highly focused light and a subsequent distinct light cast off.

PROJECTION TECHNOLOGY

The projection technology has been making great progress and is implemented in many different products, using various methods. Mercedes-Benz has developed a headlight that can project light symbols and markings on the ground using over one million micro-mirrors that can be controlled like pixels on a screen. More simple light cast-offs can be created through spotlights, which have an intensity and illuminance that are focused to create a concentrated light point on a surface.

LI-FI

Li-Fi is a Visible Light Communication system which supports wireless communication in high speeds (Frishberg 2015). The technology shares many similarities with Wi-Fi but is based on light waves instead of radio waves, enabling a much greater transmission speed. It functions by a router using normal LED lights to send data in a manner comparable to Morse code, which means that currently existing light fixtures can be used to disperse the information. With the LED's ability to flicker with high speeds, billions of times per second, the transmission is performed without being registered by the human eye. The light flickers are picked up by a photodetector which receives and decodes the information. As the technology is based on light emission, it is also affected by environmental lighting and may thereby face difficulties in strong sunlight.

FIGURE 5.2 Li-Fi connection

5.3 EXISTING SOLUTIONS

Already existing solutions within the field of warning and communication systems, for use in traffic or on vehicles, are quite few but varied. When it comes to auditory warnings, there are a number of concepts and products which emit sound specifically designed to make electric cars more easily detectable.

As for the usage of light, there are certain conceptual solutions within vehicles' interaction with pedestrians. One example is Semcon's smiling car concept for autonomous vehicles, which features a display on the grille that mimics facial expressions, thereby allowing for the car to interact with pedestrians (Semcon no date). Similarly, Viktoria Swedish ICT has, in collaboration with master students at Chalmers, designed a concept where a LED-bar at the top of the windshield indicates the car's status (Lagström and Malmsten Lundgren 2015).

Regarding projections, there are bike lights which create laser projections in the form of lines on the ground around the bike so as to inform about the distance one should keep to the bike (Ward 2012). Additionally, it alerts other road users of the presence of the bicyclist. Furthermore, a special traffic light has been developed in the Netherlands, where a glowing line has been added on the ground at kerbs along monitored pedestrian crossings (Sulleyman 2017). This facilitates the perception of a red light for pedestrians looking down at their phones.

Another concept solution has been developed by Mercedes-Benz, namely a new headlight technology. The concept is called Digital light and is based on dynamic light functions created by chips which control over one million micromirrors per lamp (Mercedes-Benz no date). Brightness levels for each of these are calculated in real time through algorithms based on data received from sensors on the vehicle. This gives the lighting system a dynamism, and precision, to control the light distribution in accordance to the surrounding conditions. It enables a projection of light onto the roads, guiding and supporting the driver and other road users by sending messages or warnings, for example through crosswalk markings or symbols.

When it comes to facilitating the discovery of an approaching vehicle, there are lamps mounted on forklifts projecting a spot on the ground some distance away from it (Linde Material Handling 2013). Through this, approaching forklifts can be detectable even when hidden behind a corner.

5.4 CONCLUSIONS

There are many aspects to take into consideration in relation to the technology and perception of light. Beyond the light source, the context, the observer and the light characteristics have to be specified and acknowledged. In regards to the context, it is important to consider the surroundings of the light signal to maximize its conspicuity. Therefore, a potential solution must be assessed based on the qualities that enable the light to be discernable for an observer. This concerns the size, contrast difference, flicker, movement and luminance of the light source in relation to its background.

Additionally, the dynamic elements and colour choice have proved to have great impact on the perception in the peripheral field of view. To gain the attention of a VRU, a light signal is discovered faster by being bestowed with a pulsating signal with a 10:1 ratio between the maximum and minimum luminance. Similarly, a sweeping motion has the effect of shorter response times. In terms of colour, blue and yellow are more easily detected in the periphery where yellow also has a positive impact on the response time.

For the observer it is important to consider the glare caused by the light. A light signal should, if possible, not be placed directly in the line of sight of the surrounding VRUs or drivers. Furthermore, to avoid glare smaller sources with high luminance are not recommended and the duration of exposure should be limited. The luminous intensity should vary during night and day, with appropriate levels of 530 cd during daylight and 180 cd at nighttime, to not cause glare when the environmental light is dimmed.

Naturally, the conspicuity and thus the detection level of a light signal is lower in daylight. However, studies have proven that Daytime Running Lights have had a positive effect on the accident rates, indicating that light signals would have an effect on the detection of approaching buses even in lighter environments.

In regards to the light technology there are many options to explore, especially in terms of the light source itself. The more traditional incandescent light and halogen lights might have run their course in comparison to other alternatives. In contrast, laser lights are on the rise and show great potential but are yet in their early stages of development with a hefty cost. LEDs, on the other hand, have been on the market for a while with benefits such as low cost and high energy efficiency. The Digital Light from Mercedes-Benz also indicates the inherent potential and flexibility of the light type. For projections, traditional laser can also be used but the safety hazards have to be considered.

Light can be used in many different ways, not being limited to the central emission of light. Through light, there are possibilities to communicate with other devices and display messages on other medias. Existing solutions have explored some of the opportunities that light entails in systems meant to enable communication between road users. Few solutions are however focused on the area of buses, thus leaving the market open and unexplored.

06

KEY USERS

This chapter presents the key users of the concept, along with their opinions, experiences and concerns regarding traffic as well as buses. They are categorized according to the three main groups that have been identified, namely pedestrians, bicyclists and bus drivers. Within these heterogeneous groups one finds the experiences of all types of road users of different ages, residence and abilities.

6.1 PEDESTRIANS

In this section, the experiences, self-reported behaviours and opinions collected from pedestrians are presented, together with findings from observations and previous studies concerning the actions and experiences of pedestrians. The information is structured according to five main categories consisting of traffic experience, behaviour, communication, cues and external factors.

TRAFFIC EXPERIENCE

The pedestrians' experience of the traffic environment varies, where some expressed that they often felt exposed and unsafe. Crossing roads and interacting with other roads users were considered to be hazardous as drivers would not yield as expected or as regulated. This lead to a distrust in other road users and a cautious behaviour, with the hesitant individuals acting from the belief of rather being safe than sorry.

Furthermore, the pedestrians expressed an issue with vehicles not navigating as expected, thus surprising the VRUs. This was especially emphasized by individuals with impaired hearing or sight as a consequence of their difficulties perceiving signals based on certain modalities. Amongst these pedestrians, some expressed that they feel unsafe or even stretched as far as calling the traffic experience horrible. Others, on the other hand, described it as neutral as can be seen in figure 6.1. Previous studies show a similar result, where many individuals with visual impairments rarely or never use public transport or move in traffic (Ståhl 2015). Over half of the participants, claimed that their visual impairment is the reason for this, whereas a third considered the traffic environment to be unsafe and scary.

A specific situation mentioned in the empirical studies, where all types of pedestrians felt exposed to danger, was when the bus came too close. When they walked on a pathway in close proximity to the roads problems could occur when the bus was to turn in a crossing further ahead. The bus would then infer on the space of the pathway, forcing the pedestrian out of the way. Similarly, the pedestrians had felt at risk when passing in front of a bus due to the uncertainty of what is hidden behind it and at what speed it might be approaching.

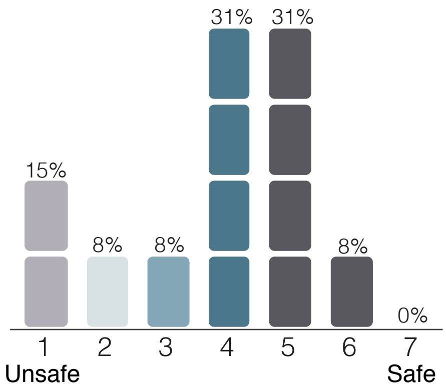


FIGURE 6.1 Traffic experience for individuals with hearing loss

BEHAVIOUR

Many pedestrians also mentioned that there was a lack of respect for VRUs from other road users, especially those using motorised vehicles. There were many incidents both observed and mentioned by participating pedestrians where buses approached a crossing with a high speed, leaving pedestrians surprised by their passage or hesitant due to an unclear deceleration of the bus. On the other hand, many pedestrians also described their traffic experience as well functioning. They expect other road users to follow the regulations and yield for them, feeling safe knowing that they, as pedestrians, have the right on their side.

The pedestrians often seem to be aware of their violations when acting with a risk-taking behaviour. They mention that the fault often is their own, being prepared to face the dangers that potentially could occur. However, little attention or thought is put on the effect their actions have on others. Few mentioned the experience of other road users, much less indirectly affected parties such as the passengers of the public transport.

Dangerous situations were also connected to stress, both by the pedestrians themselves as well as through what was seen in the conducted observations. Pedestrians admitted to taking more risks and breaking more rules when under time pressure.

The observations indicated similar behaviours where the passengers ran to and from public transport vehicles at interchange points, gambling that they would make it over the street before the approaching vehicles passed or a bus left the bus stop. This indicates that many VRUs make fast decisions when moving in traffic while at the same time estimating a potential gain of taking a chance as very high.

Another topic that was brought up by many of the pedestrians was inattention. It was often mentioned that they at times were not paying full attention to the traffic situations around them, sometimes they would simply move automatically. The inattention can also be reinforced through the use of mobile phones and headphones, which many claim to handle in traffic. These individuals admitted that accidents have been close to occurring, but stated that it usually works out well in the end.

Others, on the other hand, proclaim the importance of paying attention and avoiding any distracting elements. The observations showed that the problem with inattention and phone use mainly occurred on calmer streets and crossings, unlike bigger crossings and interchange points where the attention level was slightly higher.

COMMUNICATION

When describing the communication between bus drivers and themselves, the pedestrians mainly considered the drivers' speed and deceleration when determining their intentions, as can be seen in figure 6.2. Eye contact also followed as an answer, however some mentioned an uncertainty when trying to read the driver's facial expression through the windshield. It was not always considered to be straightforward and clear. Many described it as an understanding which could overrule regulations, which others recounted to have created issues as the understanding proved to not be mutual.

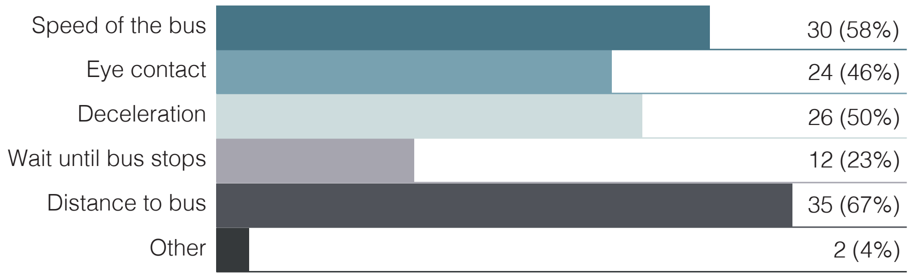


FIGURE 6.2 Signals used by pedestrians to determine the state of the bus at a VRU crossing

This type of situation creates a particularly difficult situation for pedestrians with visual impairments who cannot fully see the facial expression of the drivers. Unknowing of the impairments of the pedestrian, the drivers interpreted the situations as a mutual understanding thus creating issues as to whom should give way. Generally, there was an uncertainty and fear amongst the pedestrians that the driver of a bus had not spotted them.

Furthermore, the communication was difficult for pedestrians with impaired hearing. Firstly, difficulties arose when vehicles approached from behind leaving less of an opportunity of spotting them using their vision. Many expressed their need for maintaining constant attention on the traffic situation around them, visually scanning the environment for potential dangers that they might have missed due to their hearing loss. In addition, some expressed problems arising from their difficulties of determining the source of sounds. This lead to issues with determining the direction of warning signals, thus hindering them from assessing if it was directed towards them.

The pedestrians with visual or auditory impairments expressed a desire for warning signals that they can perceive. Optimally, these would be audiovisual so as to provide redundancy or alternatives for perceiving the signals.

This is also supported by Ståhl (2015) who claim that audiovisual information should be provided at bus stops and on the bus. Today's warning signals were considered to be unhelpful by many with a hearing impairment as can be seen in figure 6.3.

Many also expressed a wish for more traffic situations to be provided with signals that can support the pedestrian in the performance of required actions. Regarding VRUs with impairments it is also important to consider the placement of the information as many have a limited field of view and therefore require information to exist in a central line of sight (Synskadades Riksförbund 2015). Others suffer from light sensitivity and poor contrast vision, putting further demands on the potential use of light signals in terms of avoiding colour contrast, glare phenomenons and optical illusions.

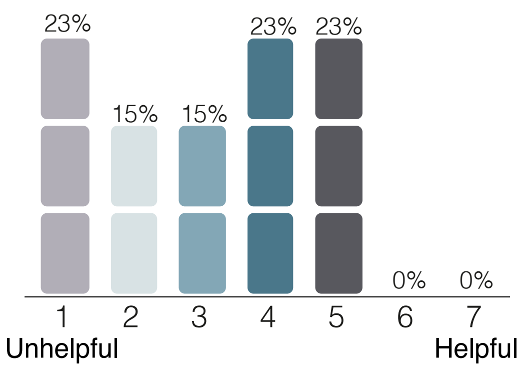


FIGURE 6.3 Experience of traffic signals for individuals with hearing loss

CUES

When determining the status of the bus at a bus stop, the pedestrians mainly look for indications from external signals. A majority claimed to decide whether to run or not based on the movement of people aligning to enter the bus at the bus stop. If there were many travelers left on the platform, there was often still time to catch the bus. Another external indication was the status of the doors, where closed doors was mentioned as a sign of it being too late. Beyond the previous mentioned cues, turn signals and eye contact were brought up as aspects determining the status of the bus. Others mentioned that they did not try to analyze the possibility of making it to the bus before its departure, but rather took a gamble of catching it in time.

For those trying to determine the status of the bus, some mentioned the difficulty of doing this from afar. If positioned on the wrong side of the street or approaching the bus from behind, it was harder to assess whether it was worth hurrying. In regards to the status of the bus, some pedestrians also mentioned a feeling of annoyance when being unsure if one should move hastily or not. This especially at a terminus, at the end of routes, where the buses might stop for longer periods of time. Similarly, irritation arose when a passenger reached the bus before it left the bus stop but the driver did not let the individual enter.

EXTERNAL FACTORS

The risk-taking and hazardous behaviour were also connected to external factors. Darkness was claimed to aggravate or cause problematic situations and the lack of safety reflectors further contributed to the issue. Additionally, icy roads and sidewalks created issues for both pedestrians themselves but also became a point of concern in connection to the vehicles approaching them. Beyond the weather and time of day, insufficient visibility close to roads due to contextual factors such as buildings and shrubbery was brought up by the pedestrians.

An additional problem arising from external factors that was noted in observations as well as it was brought up in interviews was the difficulty to detect approaching vehicles when hidden by other oncoming vehicles or environmental obstructions. Similar concerns were also highlighted in a report by Osvalder and Rosenberg (2014) who state that problems are generated when there is a tram in each direction, resulting in the opposite tram being hidden for VRUs aiming to cross the street.

6.2 BICYCLISTS

The following section presents the collected information from the questionnaire distributed to bicyclists regarding their experiences and opinions of the traffic situation. The categories bring up experiences, judgement and awareness, communication, attitudes and risk-taking, and individual factors.

EXPERIENCE

Many of the bicyclists who shared their experiences of traffic and the interaction with buses claimed that they often felt exposed and unsafe. They feel especially exposed when a bus comes very close and they are unable to avoid it, which happens often, according to some of the cyclists.

Furthermore, a few considered some bus drivers' manner of driving to be uneven and aggressive, making it more difficult to predict. Many cyclists also stated that they prefer to wait and give way to the bus, even when they have the right to go first, to avoid accidents. They also stated that cyclists need to be very attentive in traffic, since one cannot always trust that other road users will follow the rules and do what is expected of them.

JUDGEMENT AND AWARENESS

Another problem which some cyclists mentioned was that it is difficult to foresee when one will be overtaken by a bus, and be prepared for it. Therefore the risk of being frightened or hit by the bus increases. Furthermore, certain cyclists mentioned that it can be difficult to know how the bus will move, specifically when turning.

It can be difficult to judge how much space it is appropriate to leave for the bus, and a few cyclists felt that some bus drivers have very little control of the overhang. From the bicyclists' perspective, it seems as though some bus drivers are not aware of the size of the bus in general, but certain cyclists also admitted that they themselves have misjudged the distance needed to overtake the bus.

COMMUNICATION

Uncertainty as to whether one has been noticed by the bus driver was also a commonly mentioned problem for the cyclists. Some mentioned the blind spots of the bus, but were unsure of which areas that were actually hidden in the blind spots. Even when being outside of the blind spots, the communication is not direct. When interpreting the bus drivers' intentions, many claimed that they look at the turn signals, try to establish eye contact with the driver, or simply know the usual route of the bus.

A few cyclists also mentioned that the speed of the bus helps them determine the intentions of the bus driver. As for the external factors contributing to creating riskful situations and hindering communication, the cyclists mentioned snow as well as darkness and time of day. Poor urban planning was also brought up by some cyclists.

ATTITUDES AND RISK TAKING

Certain respondents mentioned that bus drivers often seem to be stressed and in a hurry, while some noted that other cyclists are also stressed and keep a higher speed nowadays. A few cyclists also stated that some bus drivers seem quite nonchalant, that they should show more consideration in general, and that motor traffic seems to be valued higher than the safety of cyclists. However, some of the respondents also said that cyclists show a lack of consideration, and a few admitted that they sometimes break rules on purpose. For example, one cyclist claimed to be using the bus lane regularly, since it is often unoccupied.

INDIVIDUAL FACTORS

When it comes to individual factors affecting how the traffic is handled and experienced, the respondents with a hearing impairment stated that it can be difficult to notice vehicles behind them. Some also brought up the fact that even if a sound signal is audible, it can still be difficult to determine from where it originated. Many of the individuals with a hearing impairment therefore stated that they need to be extra vigilant, and some try to notice and interpret the actions of other vulnerable road users nearby.

FIGURE 6.4 Bicyclist in traffic

6.3 BUS DRIVERS

The section below brings up the collected data from and about bus drivers. As the project focus is on the vulnerable road users, the greater part of the presented data concerns the bus drivers' experiences from, and opinions about, VRUs' interaction with buses in traffic. The information is sorted under the themes of awareness and knowledge, hazardous behaviour, inattention, stress and fatigue, attitudes and communication.

AWARENESS AND KNOWLEDGE

The bus drivers' experiences of the traffic situation are quite varied, however, most of them mentioned problems in relation to their interaction with vulnerable road users. Many drivers claimed that pedestrians and bicyclists seem to have little knowledge regarding traffic rules as well as heavy vehicles, which places them in hazardous situations, sometimes without the vulnerable road users even realizing it. An example of this was constituted by bicyclists sometimes confusing pedestrian crossings with bicyclist crossings and assuming that the bus will leave way at pedestrian crossings as well.

When it comes to knowledge of heavy vehicles, many road users seem to be unaware of the blind spots of the bus and simply assume that the bus driver has seen them, according to the drivers. Furthermore, in the drivers' experience, the pedestrians and bicyclists show a lack of understanding when it comes to the long stopping distance of a bus, and the fact that the passengers in the bus might fall in case of a sudden stop. In addition to this, the vulnerable road users seem to be unaware of how a bus moves when turning, and fail to leave enough room for it to do so safely. These three issues all imply that the vulnerable road users tend to come too close to the bus, exposing themselves to risks.

HAZARDOUS BEHAVIOUR

Furthermore, the bus drivers mentioned the hazardous behaviour of certain vulnerable road users. Some ignore red lights at intersections, while others run or walk in front of the bus at bus stops as it is about to leave. Regarding this behaviour, stress appears to be a considerable motivator, as the bus drivers often stated that the pedestrians are running to catch a bus or a tram when they run in front of the bus.

Some bus drivers also mentioned that passengers tend to disembark, hurry alongside the bus, brush against its right front corner and then move diagonally in front of the bus towards the opposite side of the road. This often comes as a surprise to the drivers who find these passengers somewhat difficult to spot, as they appear quickly and sometimes just as the driver intends to drive off. These hazardous behaviours of running in front of the bus were also frequently noticed during the observations, and described by Osvalder and Rosenberg (2014) in their report concerning warning signals in traffic and their effect on VRUs.

Another behaviour the drivers mentioned was the tendency to move in clusters in front of the bus when it is about to leave a bus stop, thus hindering the bus from leaving. Pedestrians who see others walking in front of the bus might get the impression that they too can make it before the bus leaves, which means that the bus drivers sometimes have to brake to let the optimistic pedestrians pass. This was noticed during the observations as well.

INATTENTION

The bus drivers also frequently mentioned inattentive pedestrians and bicyclists as a contributing factor to hazardous situations. Many drivers claimed that they often see vulnerable road users who cross the road without looking first, and pedestrians as well as bicyclists who look at their phone or wear headphones while navigating in traffic.

The electric bus drivers also said that the electric buses are even more difficult for inattentive people to notice, since they are silent. However, the drivers also pointed out that many VRUs do not notice the less silent buses either.

Crowded bus stops increase the risk of people standing too close to the curb, a problem which was both mentioned by the bus drivers and noticed during the observations. This exposes them to the risk of being hit by the bus or its side mirrors, and the bus drivers are often forced to drive very slowly until the people move away from the edge in order to avoid a collision.

STRESS AND FATIGUE

The aforementioned hazardous behaviours tend to result in stress and fatigue for the drivers, who know that they have to be extra vigilant. However, they also know that vigilance is not always enough if a pedestrian or bicyclist does something unexpected or misjudges the situation, which generates even more stress. If, for example, a pedestrian runs in front of the bus and falls, the driver might not be able to stop the vehicle in time.

Due to the drivers' need to be constantly watchful, they often become very tired towards the end of their shift, which increases the risk of accidents as well. The pressure of following the timetable was also mentioned, which means that they have to keep up the pace, otherwise they will not have time for recovery at the terminus. However, at the crowded stops where many vulnerable road users are passing in front of the bus, it can be difficult to not fall behind schedule.

ATTITUDES

Another issue that the bus drivers brought up was the attitude of certain other road users, which they interpreted as nonchalant. The drivers described vulnerable road users who did not seem to care that they walked or bicycled in front of the bus, thereby hindering it and making it wait as they pass. The drivers also spoke of foolhardy cyclists who cycle too fast at crossings and intersections, or cycle right beside the bus. They had also noticed people who grab onto the bus so that they do not have to pedal.

COMMUNICATION

When it comes to currently used signals for warnings and communication for buses, many drivers claimed that they rarely or never use the horn to communicate with vulnerable road users. Many stated that they only use it in case of an emergency, for example when someone is suddenly blocking their path and they would not have the time to stop in order to avoid a collision.

The most common method for communicating with VRUs was eye contact, which 91% of the bus drivers claimed to use, as can be seen in figure 6.5. It was also common to communicate through the speed of the bus, as well as gestures. A reason to the low reported usage of the horn might be the fact that 47% of the bus drivers claimed that pedestrians and bicyclists react with anger when the horn is used, as figure 6.6 shows. Common reactions were also confusion, indifference and fear. None of these reactions were what the bus drivers usually hope for; with them saying that the VRUs should be thankful for the warning as it might have saved their lives.

Furthermore, from the bus drivers' perspective, certain external conditions affect the traffic situation and the possibilities for communication, such as the weather, the conditions of the road, and whether it is dark or daylight. These factors affect how easy it is to spot the vulnerable road users, and also how long the required stopping distance will be if the bus drivers need to brake suddenly.

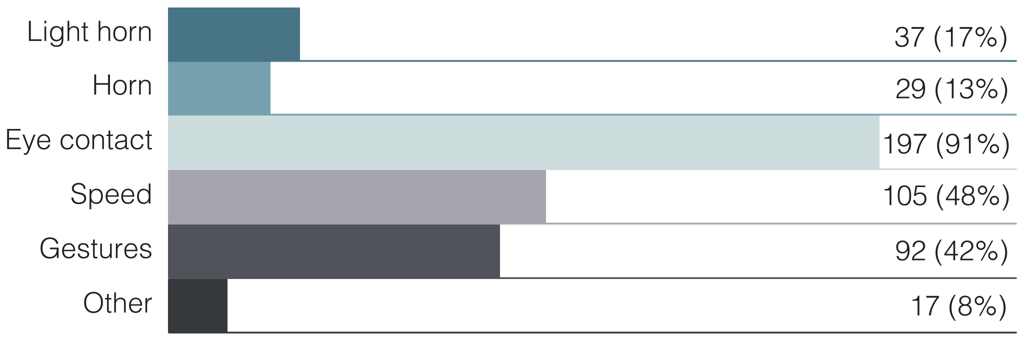


FIGURE 6.5 Means of communication used by bus drivers

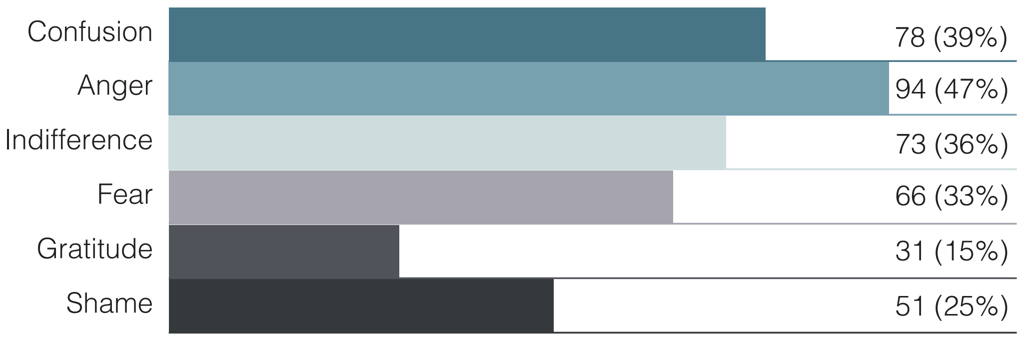


FIGURE 6.6 VRUs' response to the use of the horn according to the bus drivers

6.4 CONCLUSIONS

An initial conclusion that can be drawn from the information that has been presented in the chapter is that many of the issues described amongst the different key users are coherent. However, the stated reason for them occurring differ between the groupings.

Both bicyclists and pedestrians explained their negative experience and fear connected to buses that drive too close. Similarly, the bus drivers mentioned their difficulties to maneuver the bus as people were moving close to the bus and thereby hindering it from making its way forward. In relation to this, a lack of respect is often mentioned as a cause. All parties claimed that the others did not act in a way that took their respective needs into consideration in terms of space and general rights. From the perspective of the drivers there is a lack of knowledge or recognition for the size and weight of the bus, which impacts the maneuverability of the vehicle. The VRUs, on the other hand, feel that motorised vehicles do not yield for them in a proper manner, making them hesitant in their own actions.

In general, the breaking of rules is a common theme brought up in the studies. Risk taking behaviour from VRUs was claimed to be the cause of hazardous situations that the bus drivers had faced. Pedestrians and bicyclists confirmed that they would, in moments of stress, act in a more volatile manner and take more chances. However, they also thought that the bus drivers' behaviour added to the problems with them prioritizing their own time keeping before the safety of other road users.

The friction between the VRUs and the bus drivers seem to stem from, or be reinforced by, an insufficient communication. Pedestrians and bicyclists have a hard time predicting the movement of the bus and reading the intentions of the driver. Many look for external cues to determine the status of the bus, thus relying on indirect information. Similarly, this is also the type of communication that the bus drivers claimed to mainly use for conveying their intentions. This creates issues for VRUs with impairments, which limits the ability to perceive more discrete signals that mainly depend on one modality.

Due to the experienced disrespect from all involved parties, the erratic behavior and lack of clear communication, there is a general distrust in other road users. This has lead to many VRUs and bus drivers experiencing a need to remain attentive and vigilant at all times to counteract the faulty actions of others. Especially when the environmental conditions are not in their favour.

07

CONTEXTUAL FRAMES

This chapter presents the conclusions and problem definitions which followed from the analysis of the collected data. The information presented below is therefore considered to be the basis for the subsequent ideation phase. In this chapter, the sections concern the affinity diagram that was created, the defined personas, descriptions of problematic location types, the scenarios, as well as a matrix presenting the suitable design approaches for the scenarios. This finally leads to the guidelines, setting the framework for the ideation and possible solutions.

7.1 AFFINITY DIAGRAM

The following section presents the collected information from the questionnaire distributed to bicyclists regarding their experiences and opinions of the traffic situation. The categories bring up experiences, judgement and awareness, communication, attitudes and risk-taking, and individual factors.

The affinity diagram gave an overview of the collected data and supported the structuring process. It resulted in a problem formation as can be seen in figure 7.1, where stress and ignorance affected the demeanor of pedestrians, cyclists and bus drivers. This resulted in behaviours such as risk taking, nonchalance, inattention and unawareness; which in turn influenced their decisions and actions in traffic.

In addition to the personal factors, there were also external factors affecting the traffic situation. In general, more issues occurred in areas where different road users were forced to share the space, subsequent to the need for increased interaction of the involved parties. This is also reflected in a number of locations which were frequently mentioned as problematic.

Within the external factors category, inadequate infrastructure and city planning were often mentioned as well as contextual factors including weather, road conditions and time of day. In turn, the external and personal factors affect the traffic situations together with the communication between different road users. In the end, this leads to the experience of the involved road users.

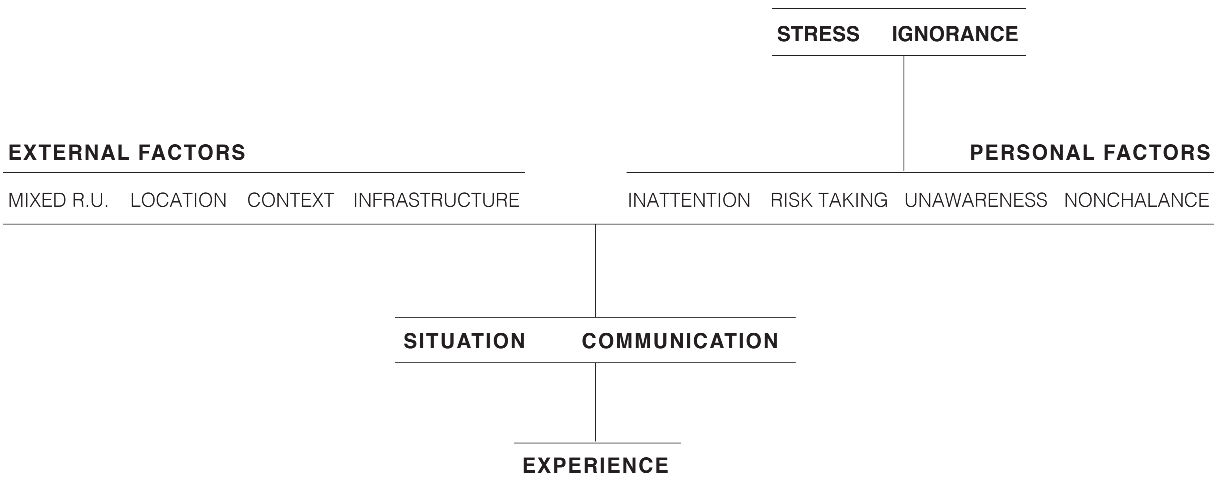


FIGURE 7.1 Mapping of affinity diagram result

7.2 PERSONAS

Five personas have been created, emphasizing different behaviours that proved to be highly involved in problematic situations or very affected by them when moving in traffic. These behaviours compose of risk taking, nonchalance, inattention, caution and consideration. However, a single person can encompass many or all of these traits depending on the situation and conditions that they are faced with.

THE RISK TAKER

The Risk Taker is an optimist in traffic situations and sees the possibilities rather than the risks involved. Time is often lacking, which makes stress a considerable motivator when it comes to traveling in traffic. Zigzagging between cars and buses, the Risk Taker gets from A to B. When in a hurry, the Risk Taker sometimes forgets that the interaction in traffic also involves other people with their own needs for reaching their destination. He/she only needs a few extra seconds to make it in time, and sometimes you just have to risk it.

THE INATTENTIVE

The Inattentive knows that there are many road users who need to interact with each other and get along in traffic, but experiences that it tends to work out just fine. It is often enough to simply look up now and then to get a good view of the situation, leaving plenty of time for responding to a text and starting a new playlist on the phone. For the Inattentive, being able to shut out the noise from traffic and enter his/her own world is perfect. Sure, it has happened once or twice that he/she has suddenly gotten in the way of another road user, but those things are bound to happen sometimes.

THE NONCHALANT

The Nonchalant is aware of the fact that he/she is a vulnerable road user but does not see it as a con, in fact, it means that other road users must stop and give way for you. If they do not want to collide with the Nonchalant, they need to stop, since she/he does not care who is approaching and whether they will be able to avoid a crash. The fact that other road users have to stop and wait is not his/her problem. The Nonchalant is a natural part of the traffic, whom others should learn to respect.

THE HESITANT

The Hesitant feels that there are many hazards in traffic and as a vulnerable road user, your safety is in your own hands. Rules cannot guarantee anyone's safety, as other road users sometimes show a lack of consideration, and misunderstandings can easily arise. The best solution is therefore often to stand by and wait, since the intentions of others can be difficult to interpret and trust. Attention is vital, as you can only trust yourself.

THE CONSIDERATE

The safety of all road users is important and the Considerate realizes that your own personal interest should not always be the top priority in traffic. He/she is aware of the importance of maintaining a smooth traffic flow and his/her own part in achieving it. Following rules is a solid foundation and he/she wishes that everyone would act more carefully with regards to others' lives, as well as their own.

IMPLEMENTATION

To conclude, the personas highlight different traits that affect the interaction between different road users, thus also impacting the communication. For the first persona, the Risk Taker, the communication needs to support the VRUs in order for them to make better decisions and realize the consequences of their actions. Similarly, the nonchalant behaviour requires a focus on the consequences of one's actions and should promote a greater understanding for the limitations of other road users.

With regards to the Inattentive, the potential of attracting attention and emitting alerts of hidden dangers must be considered in order to prevent unconscious risk taking. The Hesitant, on the other hand, needs clear information about the status of the traffic and confirmation that other road users have intentions that are as expected. Lastly, the considerate should be provided with information that helps them maintain a smooth traffic flow and keeps them motivated to follow the rules as well as consider the perspective of others.

7.3 LOCATIONS

Based on the information gained through the empirical studies, a number of locations proved to host more frequently occurring hazardous situations. The situations vary both in terms of problem causes as well as involved parties, leading to different needs of communication. These locations compose of VRU crossings, bus stops, interchange points, calm streets, intersections and shared roads.

VRU CROSSINGS

All types of road users mentioned VRU crossings when asked about the types of places in traffic where hazardous situations are more likely to occur. This might be due to the fact that it is a place where the vulnerable road users meet larger vehicles, and the communication and interaction is therefore of the utmost importance.

The pedestrians and bicyclists claimed that they felt more safe at these crossings, since they know that they have the right to cross. However, the bus drivers experienced pedestrian crossings as a place where many vulnerable road users assume that they can cross the street regardless of the approaching traffic. This manifests itself when certain pedestrians and bicyclists do not take the time to show their intentions to the drivers, and simply make a sudden turn out onto the crossing, to the drivers' great surprise.

Furthermore, the drivers stated that there are many bicyclists who seem to be unaware of the difference between crossings for pedestrians and those for bicyclists, and hence assume that the bus drivers will leave way for bicyclists at pedestrian crossings. Naturally, this can be hazardous if the bus driver is not prepared for bicyclists crossing the road.

From the perspective of the VRUs, there was also an issue with how drivers behaved in the vicinity of the pedestrian and bicyclist crossings. Many claimed that drivers slowed down very little, or not at all, before a crossing even when the intention was to let the vulnerable road user pass, which made them uncertain as to whether they could cross the street.

INTERSECTIONS

The pedestrians and bicyclists face several risks at intersections as the many different road users have to meet and interact with each other. Particularly when turning, both the bus drivers and bicyclists have a limited view, and the movements of the turning bus can be difficult to predict. This might lead to bicyclists suddenly finding themselves being too close to the bus. A turning bus also obstructs the view for the oncoming traffic.

Furthermore, the turns can be problematic when a vulnerable road user crossing the road has a green light at the same time as a turning bus. This could give the pedestrians or bicyclists a false sense of safety, as the driver might not see them if they approach the intersection fast and are in the driver's blind spot.

BUS STOPS

The bus stops constitute a hazardous place due to the interaction which follows from the boarding and disembarking. Since the buses move at a low speed or stand still, people dare to come close, an effect which is augmented when the bus stop is crowded. As a consequence, people risk being hit by the bus or its side mirrors.

Another problem arises when passengers walk behind or in front of the bus in connection with the boarding or disembarking. Passengers who have disembarked tend to brush against the front corner of the bus and walk diagonally across the street in front of the bus, which makes them more difficult to see for the drivers, due to blind spots.

As the bus is leaving, passengers can walk very closely in front of the bus which means that the driver needs to stop quickly. This leads to a very short stopping distance. Similarly, when passengers approach the bus from the opposite side of the road and pass in front of the bus in the hope of stopping it from departing, they expose themselves to a risk. Additionally, the passengers of the bus are put in a hazardous situation if the bus driver is required to make an urgent deceleration.

Furthermore, the pedestrians' view might be obstructed when they pass in front of or behind a vehicle at the bus stop, which hinders them from seeing vehicles overtaking the bus, or oncoming vehicles respectively. Other problems arise where there is a bike lane laid out by a bus stop, which means that the bus drivers will have to traverse the bike lane, thereby annoying the bicyclists and making them feel unsafe. Due to the blind spots of the bus, it is also a problematic situation when bicyclists try to overtake a bus at a bus stop.

INTERCHANGE POINTS

At the interchange points there are many VRUs and vehicles moving around continuously, and this combination of road users in such a large scale creates a complex interaction. People move fast and irregularly across the area, which makes it difficult to predict intentions and behaviour. The less linear patterns of movement mean that the vulnerable road users can approach the bus from many different directions and make it more difficult for the drivers to keep a good overview of the situation.

In addition to this, it is quite common that pedestrians and bicyclists try to take the shortest route possible, zigzagging between the heavy vehicles and passing very closely by them. Furthermore, crowds can become problematic when the vulnerable road users move in clusters past the bus and hinders it from leaving.

SHARED ROADS

In areas where the road is shared by motor vehicles and bicyclists, problems might arise due to the closeness of the bicyclists and buses. The bicyclists stated that they feel crowded and unsafe as motorized vehicles can come quite close. The bus drivers, on the other hand, claimed that they sometimes have no other choice than to occupy a part of the bike lane, since buses are big and ungainly to navigate.

Furthermore, due to urban planning, bus drivers are sometimes forced to cross the bike lane which could annoy and also frighten an unprepared bicyclist. There is also a risk for misunderstandings and accidents when bicyclists expect that they are visible from the driver's position in the bus, but are in reality in a blind spot.

CALM STREETS

Motor vehicles in general are not expected to appear on calm streets, which might result in less attentive vulnerable road users experiencing a false sense of security. Heavy vehicles are even less expected, and also demand more room on the often narrow streets, which in combination with the low level of attention creates a risk. Certain VRUs also believe that they can walk safely in the middle of the street if the road is calm and narrow, which increases the risk of hindering the bus or being hit by it.

This means that the bus drivers need to be extra attentive, especially when driving a silent vehicle. The electric bus drivers stated that they had on several occasions surprised vulnerable road users in calmer and quieter areas, and had to slow down and wait until the bus had been noticed. There is also an issue where the view around corners is obstructed, as the approaching of the bus is silent. It is hence difficult to foresee the bus's approach, creating a risk of collisions.

FIGURE 7.2 Hybrid bus on shared road

7.4 SCENARIOS

With the defined places and personas as a basis, twelve scenarios were created as a way of describing common traffic situations where the communication or the lack of it poses a problem. The scenarios are sorted according to three different categories; distractions and inattention, hazardous behaviour and misunderstandings. The first of these comprises the behaviour and situations that occur on account of a lack of focus from the VRU. This ranges from a total absence of awareness concerning one's surroundings, to being unable to foresee the traffic interplay.

Included in the hazardous situations, on the other hand, are risk taking behaviours that are considered to generate unnecessary dangers. It encompasses conscious decisions and actions, that are made either to save time or energy, or simply because the individual feels entitled to act in that manner. The third and last category embodies issues concerning the misunderstandings in the communication between different road users. This includes situations where road users miss warnings, and communications that are not mutually understood. Furthermore, it also encompasses overestimations of others' abilities as well as problems that occur due to a lack of communication.

As a complement to these twelve scenarios, another four were developed where the focus was placed on correct and constructive actions in traffic so as to define what behaviours the solutions should promote. These four scenarios highlight the actions of giving way for the bus as it is leaving the bus stop, waiting patiently when crossing the street, striving to reach mutual agreements and communicating one's intentions.

The scenarios describe many different situations, but were found to include essentially three variants of the communication between buses and vulnerable road users. The first one is to inform the VRUs, for example by clearly indicating the status of the bus. The second is to guide the VRUs in the vicinity of the bus in order to encourage them to keep their distance around the bus and avoid the driver's blind spots. Thirdly, there is a need to call for the attention of the VRUs, as well as to warn them in critical situations, which falls under the category of alerts.

DISTRACTIONS AND INATTENTION

1 PERSONAL DISTRACTIONS

A pedestrian is moving towards the bus terminus at an interchange point, while wearing headphones and looking at a smartphone as he/she crosses the bus lane. The pedestrian is not in a hurry, but the approaching bus is definitely in a rush, leaving the driver with no choice but to slam on the brakes in front of the inattentive pedestrian. He/she is surprised, but carries on across the lane while the bus passengers collect themselves after the unexpected ride.

WHO
The Inattentive
The Nonchalant

WHERE
Bus Stops
Intersections
Calm Streets
VRU Crossings
Interchange Points

2 EXTERNAL DISTRACTIONS

WHO
The Inattentive
The Nonchalant
The Risk Taker

WHERE
Bus Stops
Intersections
Calm Streets
VRU Crossings
Interchange Points

A bicyclist is about to cross a road where buses often pass. After having looked left and let a buss pass, the bicyclist continues out into the road without noticing the bus approaching from the right. The bus driver sees the bicyclist and honks instantly. The collision is avoided in time, but both the bicyclist and the bus driver are left shocked.

3 CLOSE PROXIMITY

As the bus approaches the bus stop, a group of people stands there waiting. The space is limited, making the bus stop quite crowded. Close to the edge, there is a couple talking, where one of them has their back turned towards the bus. The approaching bus has not yet been noticed by the couple, who the driver fears might run the risk of being hit by the side mirror. Slowly, the bus edges closer until the couple finally notices the bus and moves out of its way with an embarrassed look on their faces.

WHO
The Inattentive
The Nonchalant

WHERE
Bus Stops
Calm Streets
VRU Crossings
Interchange Points

4 OVERTAKING THE BUS

WHO
The Inattentive
The Nonchalant
The Risk Taker

WHERE
Bus Stops
Intersections
Shared Roads

A bicyclist approaches a bus that has arrived at a bus stop. He/she sees a group of people at the bus stop and therefore decides to overtake the bus on its left side while the passengers enter the bus. When the bicyclist has reached the middle of the bus, it pulls out, and the bicyclist is forced to brake and swerve. The bus carries on as if nothing had happened, since the driver had not seen the bicyclist at all.

HAZARDOUS BEHAVIOUR

5

WHO
The Risk Taker
The Nonchalant

WHERE
Bus Stops
Interchange Points

A bus is at the bus stop letting passengers board. When the driver gets ready to leave the stop, a person comes running in the hope of catching the bus before it leaves. In order to be noticed by the driver and hold up the bus, he/she runs in front of the windshield just as the bus starts moving forward. The driver stops quickly and lets the passenger board the bus, but silently curses at the hazardous behaviour.

RUNNING LATE

6

WHO
The Inattentive
The Nonchalant
The Risk Taker

WHERE
Bus Stops
VRU Crossings
Interchange Points

A stressed out passenger descends from the bus at the middle doors and hurries towards the block at the other side of the road. At the front of the bus, he/she brushes against the right corner of the bus and walks diagonally towards the opposite kerb. The bus driver is getting ready to drive off when the passenger appears in the field of vision right in front of the bus. In spite of good knowledge regarding the blind spots of the bus, the driver is surprised and realizes that the situation could have ended badly.

CUTTING CORNERS

7

WHO
The Risk Taker
The Hesitant

WHERE
Bus stops
Interchange Points

A bus is at the bus stop, where a pedestrian wants to cross the road. The bus doors appear to be closed, but the bus is not yet moving. Therefore, the pedestrian hesitates whether or not he/she could pass, but is thereafter passed by a group of pedestrians crossing the road. He/she therefore assumes that it is safe to pass and hurries after the group. At the same time, the driver gets ready to leave after the group has passed and has to slam the brakes to let the laggard cross the street as well.

FOLLOWING THE CROWD

8

WHO
The Inattentive
The Nonchalant
The Risk Taker

WHERE
VRU Crossings

A pedestrian is walking along the sidewalk aiming to get to the area at the opposite side of the street. At the nearest pedestrian crossing, he/she quickly turns to cross the street and assumes that the traffic will give way. An approaching bus has to stop abruptly to avoid a collision. The pedestrian is offended by how close the bus comes before stopping, unaware of the long stopping distance of heavy vehicles.

ASSUMPTIONS

MISUNDERSTANDINGS

9 IMPOSED ON

As a bus approaches a turn, a bicyclist catches up with it on its right side. The bicyclist is in the driver's blind spot when the bus is about to turn. He/she tries to keep a good distance, but is still surprised by the space the bus occupies. The overhang of the bus forces the bicyclist towards the right as he/she swerves at the best of his/her abilities.

WHO
The Inattentive
The Nonchalant
The Risk Taker
The Hesitant

WHERE
Intersections
Shared Roads

10 MISCOMMUNICATION

WHO
The Hesitant

WHERE
Bus Stops
VRU Crossings
Interchange Points

A bus approaches a pedestrian crossing, where a pedestrian with impaired vision is about to cross the road. The pedestrian hears the sound of the bus and slows down in order to determine the velocity and distance of the bus. The bus driver sees the pedestrian and gives a friendly nod to signal that it is safe to pass. Still uncertain whether it is safe to cross, the pedestrian stops entirely and waits for the bus to do the same. The bus comes to a halt, and the pedestrian stands still, which leads to both of them assuming that the other has given way, and both of them start moving over the crossing.

11 MISSED WARNING

A bicyclist with a hearing impairment is bicycling towards the park. He/she is vigilant and constantly checks the surroundings in order to compensate for the information which cannot be taken in via the auditory sense. A faint sound of a horn reaches the bicyclist at the straight passage before the turn, but he/she has a hard time locating its point of origin. Nobody is visible in the closest vicinity, but right before turning, the bicyclist glances one more time over his/her shoulder and is surprised by the bus right behind him/her as the driver gives an annoyed look.

WHO
The Hesitant

WHERE
Shared Roads
Calm Streets
Intersections

12 TIMING

WHO
The Inattentive
The Risk Taker

WHERE
Bus Stops
Interchange Points

At the bus stop, passengers are boarding the bus as yet another person approaches the bus stop from the opposite side of the road. He/she is uncertain of how long the bus will stay and therefore hesitates over whether to hurry. Since it will be quite a while before the next bus comes, he/she decides to take a chance and run for it. When he/she is almost at the stop, the bus leaves and he/she is left embarrassed and slightly annoyed over the fact that the bus did not wait.

GOOD BEHAVIOUR

A passenger scans the surroundings to locate the nearest kiosk, which appears to be across the street. He/she exits the bus and moves toward the front of the idle vehicle. As the passenger passes the front doors, they close. The passenger notices this cue, realizing that the bus might leave soon and decides that it is better to be safe than sorry. Therefore he/she decides to stay put and let the bus continue its route before crossing the road.

WHO
The Hesitant

WHERE
Bus Stops
Interchange Points

A

GIVE WAY

B

After exiting the bus, a passenger sets course towards the tram stop on the other side of the interchange point. When reaching the kerb, the passenger scans the traffic noticing an approaching bus from the opposite direction and decides to wait for it to pass. Other pedestrians start making their way over, stopping halfway to let the bus pass. Meanwhile the bus which the passenger disembarked from, leaves the bus stop forcing the pedestrians to return to the sidewalk and join the passenger who is still calmly waiting by the kerb.

WHO
The Hesitant

WHERE
Bus Stops
Interchange Points

PATIENTLY WAITING

A bicyclist and a bus move alongside each other when approaching a bus stop. The bus driver needs to cross the bike lane to get to the bus stop, thus cutting off the bicyclist. Noticing the bicyclist, the driver signals early on and thereby informs the fellow road user of the oncoming maneuver. The bicyclist perceives the signal, waves to confirm that it has been acknowledged and slows down to let the bus safely cross.

C

WHO
The Hesitant
The Considerate

WHERE
Shared Roads
Bus Stops

MUTUAL AGREEMENT

D

A bus approaches a VRU crossing and the driver notices a pedestrian swiftly walking towards it. The pedestrian scans the surroundings, spots the bus in the distance and slows down. To convey the message that it is safe to pass, the driver decelerates distinctly while still having a considerable safe distance to the pedestrian. The pedestrian is then assured that he/she can pass, thus neither the pedestrian nor the bus has to come to a full stop.

WHO
The Considerate

WHERE
VRU Crossings

CLEAR INDICATIONS

7.5 SCENARIO DEFINITION MATRIX

The scenarios set the demands for possible solutions and defined what is required in the concepts, which is displayed in figure 7.3. By categorising the modality, approach and communication type, a structure was generated for the ideation. Regarding the modality, about half of the scenarios proved to have a gain in combining the visual and auditory signals to avoid incidents.

A similar division was also made with regards to the approach where some scenarios would benefit from a preventive solution avoiding critical situations whereas others required a signal as the situation occurs. The communication type varied amongst the scenarios, where many had multiple alternatives for handling the interaction, depending on the severity and acuteness of the situation.

SITUATION	MODALITY	APPROACH	COM. TYPE
Personal Distractions		Reactive	Alert
External Distractions		Proactive	Guide | Alert
Close Proximity		Reactive	Guide | Alert
Overtaking the Bus		Proactive	Guide | Inform
Running late		Proactive	Guide | Inform | Alert
Cutting corners		Proactive	Guide | Inform
Following the Crowd		Proactive	Inform | Alert
Assumptions		Reactive	Guide | Inform
Imposed On		Proactive	Guide | Inform
Miscommuncations		Reactive	Inform
Missed Warning		Reactive	Alert
Timing		Proactive	Inform

FIGURE 7.3 Scenario Definition Matrix

7.6 GUIDELINES

The findings from the user studies, which were analysed and synthesised in the chapter, comprise the foundation for the guidelines of a possible solution. Within these guidelines, specifications are set regarding the visual qualities of the signal with focus on the avoidance of disturbances for the bus driver or other road users. Technical aspects are handled for the solutions to meet the preconditions of the bus as well as the context.

For the perception of the signal to be facilitated, guidelines are included regarding the use of modalities. Additionally, the personal aspects and experience of the signal and traffic situations are considered and specified. Lastly, the communication requirements and limitations are examined with regards to the type, timing and intention. These were weighted with regards to their importance for the concept solution.

	GUIDELINE - the concepts should:	**EXPLANATION**	**WEIGHT**
Vision and Perception	not visually disturb the bus driver	The driver must have a clear view of the surroundings and not be distracted by visual elements	4
	not obstruct the view of the bus driver	The driver must have a clear view of the surroundings that is not hindered by physical objects	5
	not blind any road users	The concepts must not shine with an intensity or direction that creates a glare	5
	not distract road users	The concepts should not have an appearance that distracts road users from their main task	4
	not interfere with other traffic signals	The concepts should not hinder other traffic signals from being seen and perceived	4
	not contradict other traffic signals	Road users should not be confused by the concepts' appearance in relation to other traffic signals	5
Modality	minimize the dependency on sound warnings	The concepts should explore other means of alerting road users and add qualities that sound signals cannot achieve	3
	provide redundancy	By offering signals from sources of different modalities, the signal is more easily perceived by all RUs	4
	not create extensive cognitive weight	The interaction should not require an extensive amount of time, effort or attention from the driver	4
	be possible to perceive and interpret quickly and easily	The processing of the concepts should not require extensive time or effort, thus avoiding a lack of focus on other traffic elements	4

Technical Aspects	be possible to add to existing buses	The concepts should be limited to installment in production	3
	not extensively protrude	The concepts should not hinder the bus's navigational range or risk colliding with other RUs and objects	4
	be visible in different light conditions	The concepts should be visible in daylight and at night	3
	be visible in different weather conditions	The concepts should be discernible in rain, sunshine, fog and snow	3
	be visible with different road conditions	The concepts should be discernible with snowy, icy, wet and dirty conditions	3
	be visible on different ground surfaces	The concepts should be discernible independently of coarseness and colour	3
	abide by regulations	The concepts should abide by regulations concerning colours, direction, intensity and placement	5
	be conspicuous	The concepts should have a contrast and intensity that stands out from the background	5
Emotional aspects	instill a sense of security in VRUs	The VRUs should feel safer through the interaction with the concepts	4
	exude a sense of safety	The concepts should be identified as a safety feature	3
	exude a sense of friendliness	The appearance of and interaction with the concepts should generate positive emotions	3
	enable VRUs to be more confident in their actions	The VRUs should be able to know what the right action is and have the willingness to execute it	4
	induce a sense of wrongdoing in case of faulty actions	The VRUs should be made aware when they are acting in an incorrect manner and be discouraged from such behaviour	2
Communication	communicate and clarify the intentions of the driver	The intentions of the drivers should be easily perceived and interpreted by the VRUs	4
	communicate and clarify the status of the bus visibly from all sides	The status of the bus should be easily perceived and interpreted by the VRUs	4
	inform about the appropriate behaviour in the vicinity of the bus	The VRUs should be enlightened regarding the hazardous areas around the bus	4
	call for attention in critical situations	The VRUs should be warned when in immediate danger	3
	call for attention in hazardous situations	The VRUs should be alerted of dangers deriving from the bus to prevent critical situations from occurring	5
	prevent critical situations from occurring	The concepts should function proactively to avoid hazardous situations	5
	be compatible with exisiting communication signals	The function and appearance of the concepts should not divert from established norms	4
	minimize the amount of false alarms	The VRUs should not be warned unless there is a critical situation, in order to maintain the connection between warnings and danger	3
	present the warning or information at the appropriate time	For maximum effect, the signal must match the situation well	4
	raise awareness regarding personal risks	The VRUs need to acknowledge hazardous situations in order to make sensible decisions	3
	raise awareness regarding one's own actions in relation to the repercussions for others	The VRUs need to acknowledge the hazardous situations for others generated by the actions of the individual	2
	enable communication adapted to the situation	The drivers need to be able to communicate clearly with VRUs in different situations	4
	be consistent within itself	The elements of the concept should be perceived as coherent and carry a communal meaning	4

7.7 CONCLUSIONS

The affinity diagram showed that there are many factors affecting the traffic situation, amongst them stress and ignorance which resulted in behaviours such as risk taking, nonchalance, inattention and unawareness. This in turn affected the decisions and actions of VRUs in traffic to a great extent. The concepts which will be generated should therefore target these behaviours and facilitate correctly performed decisionmaking for the VRUs in order to minimize the effects of stress and ignorance.

Furthermore, the personas highlighted the different personal qualities which affect the actions of VRUs in traffic situations, and showed the importance of adjusting the concepts to their different needs. Some road users require light signals which make them feel secure, while others need to be deterred from faulty actions. The multifaceted qualities which are required from the solution were also brought forward through the definition of the hazardous types of places where it is necessary that an interaction between VRUs and the bus takes place.

This information then served as a basis for the defined scenarios, aiming to capture all of the relevant issues in traffic. The scenarios were then further defined in a matrix showing suitable approaches to the different issues. With these scenarios, it became clear that the issues belonged to three main categories, namely risk taking, distractions and inattention, as well as misunderstandings.

These categories of course generate different demands on the solution, which were defined in the list of guidelines. The guidelines brought up aspects within vision and perception, technical aspects, modality, emotional aspects as well as communication, in order to set the framework for a holistic concept.

The end of this phase therefore made three main goals for the following ideation phases become apparent. These comprise of finding a way to help VRUs alter their behaviour in traffic, to call for attention in those situations where it is needed, and prevent misunderstandings in the communication from arising.

08

PHASE 1 - IDEAS

The following chapter presents the first iteration phase of the ideation. In this stage, the ideation was supported by the creation of a mood board which was intended to inspire and guide the expression of the solutions. Based on the mood board and the framework set in the previous chapter ideas and solution principles were generated, which are described and displayed in full. Included in the chapter is also the outcome of an evaluation and subsequent discussion of the solutions.

8.1 MOOD BOARD

The mood board, which can be seen in figure 8.1, aims to describe the expression of the light signal, as well as the emotions it should instill within VRUs. The lighter images are intended to represent the sense of safety and encouragement to make safe and correct decisions in traffic, while the darker images relate to the aim of deterring risk takers and nonchalant VRUs from exposing themselves to hazardous situations. The images also represent different light phenomenons which can give inspiration in the following ideation phases, such as focused light areas, shadows and projections.

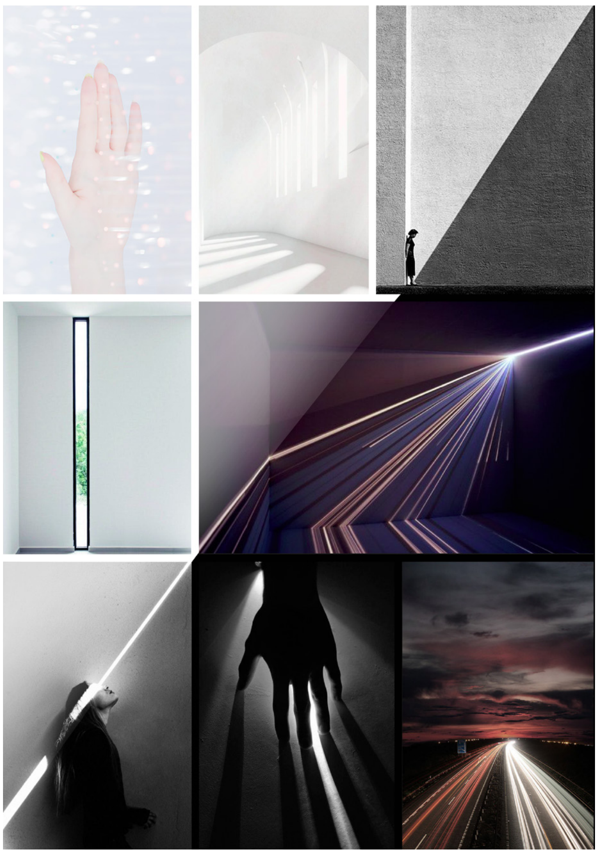


FIGURE 8.1 Mood Board

LIGHT

CARING

INTERACTION

REFLECTION

ELECTRIC

SHADOWS

DETERRING

8.2 IDEATION

The ideation resulted in just above 50 different ideas and variants of solutions with varying light applications and targeted issues. Subsequently, more than half of these early ideas were eliminated due to low feasibility or a lack of potential for solving the issues at hand. Alternatively, they were simply merged with another similar idea.

This quick phase of thinning resulted in 23 solutions with varying time frames for implementation as well as different lighting principles. The ideas were thereafter structured according to which light technology they utilized, resulting in six categories, namely conventional lighting, projections, section lighting, directed lighting, device connection, and displays.

Conventional lighting refers to the more traditional lights on vehicles, while projections describe the technology for projecting lights or symbols on the ground. Section lighting composes of enlightened areas on the bus, and directed lighting refers to lights which are specifically targeted at an object or person in the vicinity of the bus. The category of device connection consists of solutions where an external device beside the bus is connected to the lighting system, and displays encompass ideas where a display was placed on the bus in order to show signs or symbols. In order to keep the focus on the lighting principles, the greater part of the concepts were visually represented with white light, except in those cases where the color had a clearly defined function.

As these concepts only focus on light signals, they might require a sound signal for critical situations where a warning must reach the VRU. However, as the sound signals are out of the project scope, the concepts were simply designed with the aim that they can be combined with a sound warning or alert that remains unspecified in this report.

Regarding the alerts, a key factor is that they stand out in the given situation, but also from the other signals which the bus emits, in order to prevent VRUs from becoming too used to the signal. It is therefore advantageous if the signals are not likely to be ignored by the relevant VRUs. As stated earlier in the theory section, the risk of ignored signals decreases if alerts and warnings are only given when they are necessary, and at the appropriate time.

CONVENTIONAL LIGHTING

PULSATING LIGHTS

For situations when the bus needs to catch the attention of the VRUs, an eye catching stimuli which can be perceived in the peripheral vision field is required. Therefore, it is suggested that the front of the bus has lights which begin to pulsate whenever VRUs need to be alerted or informed about the status of the bus. Depending on whether it is used for signalling that the bus will leave the bus stop, or for alerting inattentive VRUs, the pulse frequency needs to be adjusted. When it is necessary to alert VRUs who are too close to the sides of the bus, a LED light strand on its side starts to pulsate.

SWEEPING LIGHTS

In this concept the attention of VRUs is caught through a series of activating lights with a sweeping effect, as the peripheral vision notices moving stimuli better. The sweeping motion also makes it possible to indicate a direction and gives the lights a clear meaning, which in this case is used to signal that pedestrians should move away from the front of the bus and give way.

DUAL-COLOURED HEADLIGHTS

When VRUs move in front of the bus at an inappropriate time, for example when the bus is about to leave the bus stop, the headlights turn orange so as to inform the VRUs about the faulty action. The signal of the bus indicates that the action was wrong or hazardous, by alerting the VRUs. To achieve redundancy and reinforce the warning, this light signal is suitable to combine with sound.

PROJECTION

RESTRICTING LINE

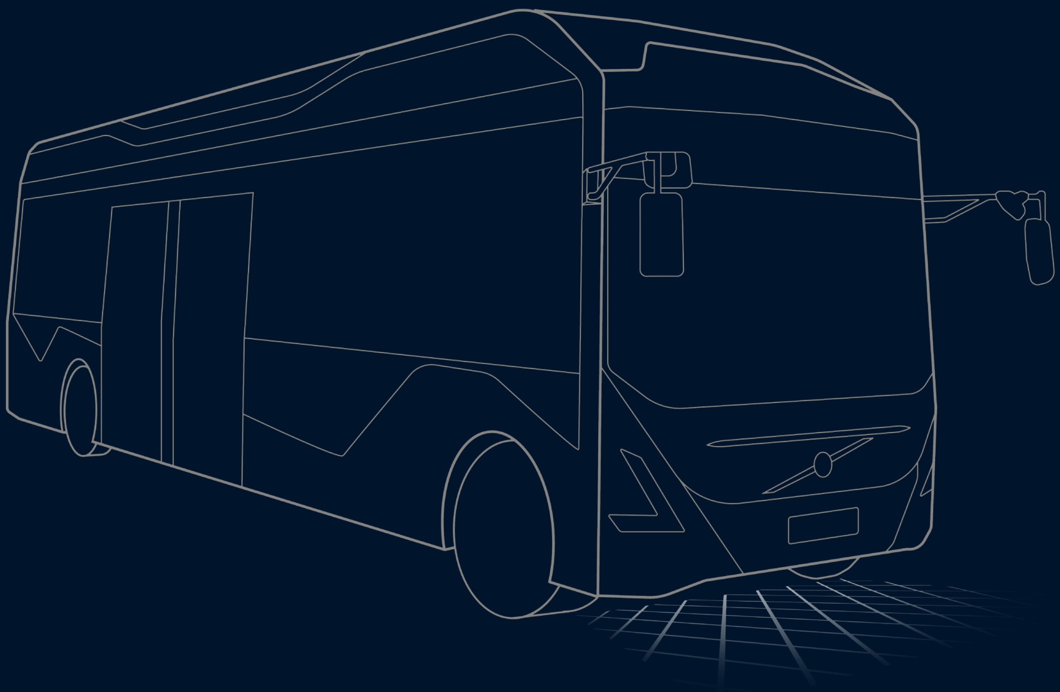
This concept encourages VRUs to maintain a distance to the bus by projecting a line on the ground close to the bus, indicating hazardous zones and showing the appropriate distance to be kept. As a way of catching the attention of the VRUs, the line moves outwards from the bus, signalling that the VRUs should move further away.

ZONE INDICATOR

Since it is not always safe to cross the road in front of, or behind, the bus a projected line on the ground appears when the bus driver is about to drive off. The line is also projected when an oncoming vehicle in another lane is approaching, hidden behind the bus. This helps the VRUs to make better decisions in the context of the complex traffic situation which extends beyond the bus itself, where other vehicles are a part of the interaction as well.

PROJECTION

CHECKERED FIELD



This concept uses a projected light to indicate when it is not appropriate or safe to walk in front of the bus. With a checkered pattern, it clearly shows a zone which VRUs should not be in, using typical form language related to restricted areas. This prevents VRUs from crossing the marked out area, and encourages them to keep a safe distance.

UNDERGLOW

As a way of highlighting parts of the bus which are more hazardous to be near, the concept bestows the bus with a lighting system which creates an underglow. The projected light displays a clear hazard zone, thus encouraging VRUs to keep a distance to the bus. When turning, it emits an underglow from the rear part of the bus so as to bring attention to the overhang which can move unexpectedly. This way, pedestrians and bicyclists will be able to see which distance is appropriate to keep.

PROJECTION

SHADOW FIGURE

This concept uses emotional reactions within the VRUs to inform about the hazards around the bus. By using shadows to display intimidating patterns, the concept reflects and communicates the dangers of the bus and subsequently the hazards of moving close in front of it. It is intended to alert and remind the VRU of the caution that needs to be taken when maneuvering in traffic.

DIRECTION MARKINGS

As a way of helping VRUs to predict the route of the bus, projected lines from the front of the bus indicate which way the bus will maneuver. When the bus is going straight forward, the lines are projected in that direction as well, and when it is about to make a turn, the lines are projected towards that specific direction. This makes the indications of the bus more available and, as it is on the ground, possibly easier for pedestrians to spot in the periphery when looking at a smartphone.

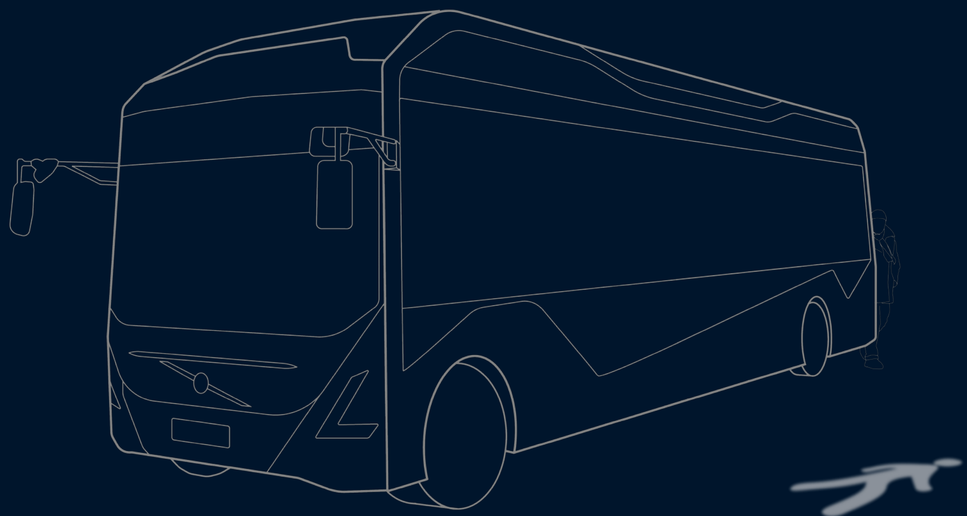
PROJECTION

PREPARATORY LIGHT

Buses are not always visible, as they are sometimes hidden behind a corner or another vehicle, making it advantageous if the bus can be spotted earlier. This concept is composed of light that is projected on the ground a few meters in front of the bus, thus revealing approaching vehicles. With the ground as a projection surface, the concept is also easier to notice for pedestrians who are looking down at their smartphones.

CAUTION LIGHT

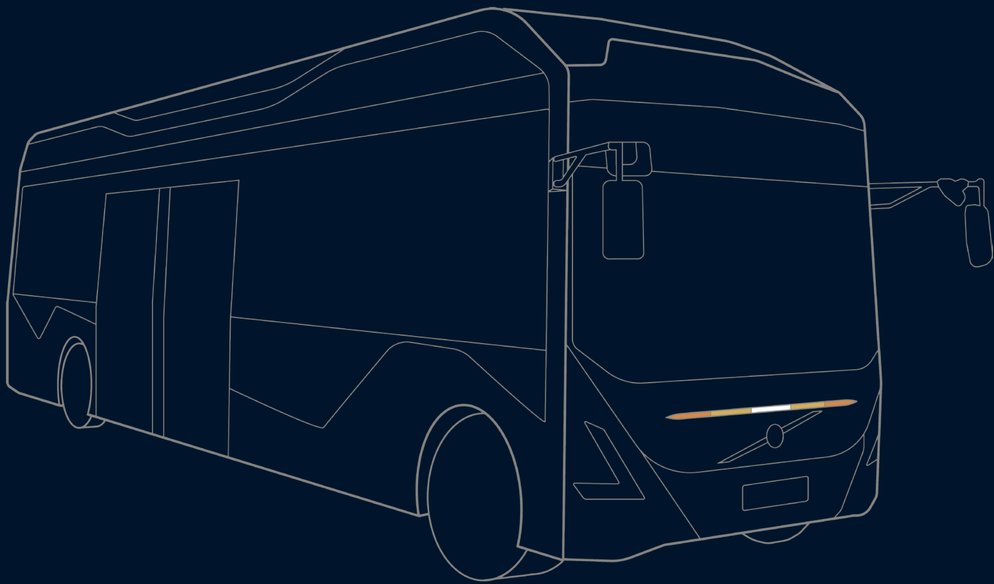
Accidents easily occur when the view of the RUs is obstructed. A bus leaving a bus stop can visually block the presence of a VRU as well as an oncoming vehicle. By projecting a warning symbol on the road, approaching vehicles can be alerted of individuals passing behind the bus onto the road. The concept takes into consideration that there are other vehicles in traffic and the consequences they may have. By addressing the drivers of these vehicles, an extra safety net is created for the VRUs.



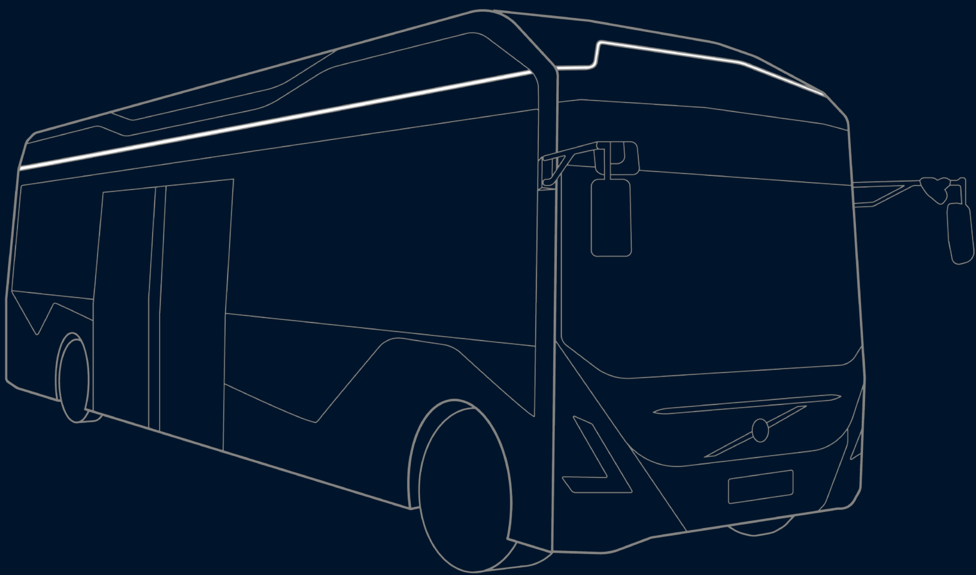
SECTION LIGHTING

PROGRESS BAR

The status of the bus is communicated through a progress bar on the front of the bus, indicating which action that is currently being performed at a bus stop. The bar consists of a series of sections, where the middle one lights up first, followed by the others in pairs. This way, the bus can communicate that the doors are closed and when the driver starts to accelerate, for example. As the pieces light up, the bar goes from a white to an orange color showing the level of acuteness to give way for the bus.



LIGHT STRAND



As a way of indicating when the bus is preparing to leave the bus stop, a LED light strand placed along the top of the windows shows the status of the bus. When the bus is idle, the light strand pulsates slowly, turning into a steady light as the bus doors are closing before fading away as the bus accelerates. This light strand is visible from a distance and all directions, thereby functioning as an indicator for pedestrians hoping to catch the bus.

DIRECTED LIGHTING

PATTERNED LIGHT

A directed light can be used to highlight when a VRU is moving too close to the bus. During specific stages of the bus, positioned lights will activate and shine forward, thus illuminating individuals moving in those areas. This communicates to the VRU that the area they are entering is claimed by the bus, indicating that it is a hazardous zone. As it only affects the person crossing the area, the concept marks the individual responsibility of the VRU. By making the light create a pattern on the person whom is illuminated the appearance has an eye-catching quality, diverting from normal vehicle lights.

SPOTLIGHT

Many individuals believe that there is safety in a crowd and the herd behaviour is common, leading to VRUs making hazardous decisions to follow others. To guide the pedestrians out of the dangerous areas in front of the bus, a coloured spotlight can be used to break up crowds and single out the individuals that will not have time to cross the road. The directed light has a personal quality which highlights the VRUs' own responsibility whilst sending a clear message of the status of the bus to others following behind the illuminated individual.

DEVICE CONNECTION

DRONE

To warn a VRU in a hazardous position in front of the bus, a spotlight placed on a drone can be used to highlight the incorrect behaviour. The isolated area of the directed light clearly marks out the VRU, either alerting the VRU of an unconscious faulty behaviour or individualizing the blame of a conscious violation. By using a drone the direction and altitude of the light can be adjusted to the specific context and situation.

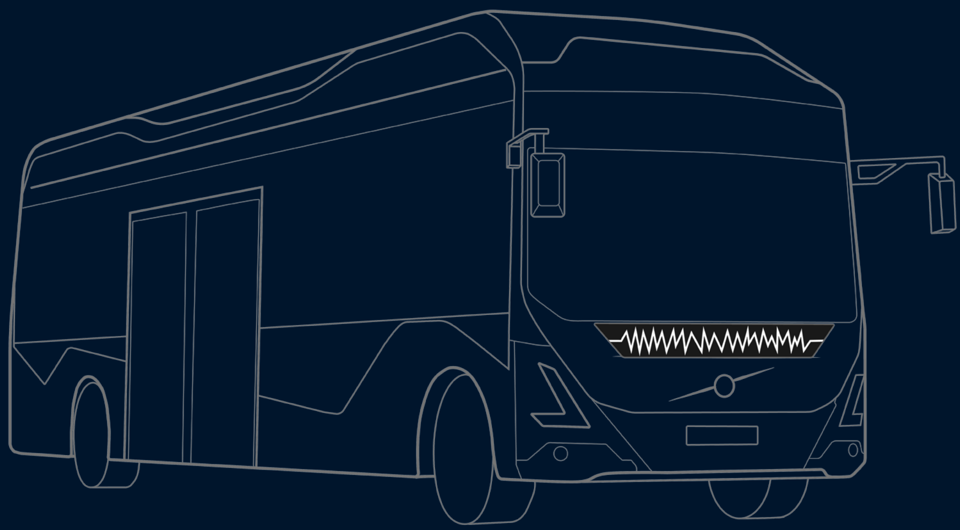
LI-FI

For VRUs who handle their phone whilst maneuvering in traffic, a notification alert can be sent through the use of Li-Fi. Li-Fi is a Visible Light Communications system which supports wireless communication in high speeds. The technology shares many similarities with Wi-Fi but is based on light waves instead of radio waves. In short, it functions by using normal LED lights to send data in a manner comparable to Morse code. The light is then picked up by a photodetector which decodes the information. Thereby information can be sent through the headlights of the bus to the location of VRUs' attention, namely the phone, thus alerting the VRU when moving closely in front of the bus.

DISPLAY

STATUS CURVE

The status curve is an indicator of the bus's state. Through its varying oscillating motions the concept can inform or alert the VRU of the bus's status and thereby communicate the expected behaviour of the VRU. Depending on the degree of acuteness the curve will adjust, having a smaller wavelength and greater amplitude when warning a VRU who is hazardously moving in front of the bus. The wavelength and amplitude follows the acceleration and deceleration of the vehicle, hence flat-lining when in the idle state.



TWINKLE

The twinkle has its base in light movements on a display. By mimicking the visual experience of falling snow, the concept has a positive connotation and a friendly aura. A steady flow of moving lights indicates the steady speed of a moving bus, where the initial acceleration and deceleration is represented by a greater light density and speed respectively a sparser, decreasing flow of snow. Through this status indication, the VRU is provided with clearer information, with which they can make better decisions more confidently.

DISPLAY

HANDGESTURES

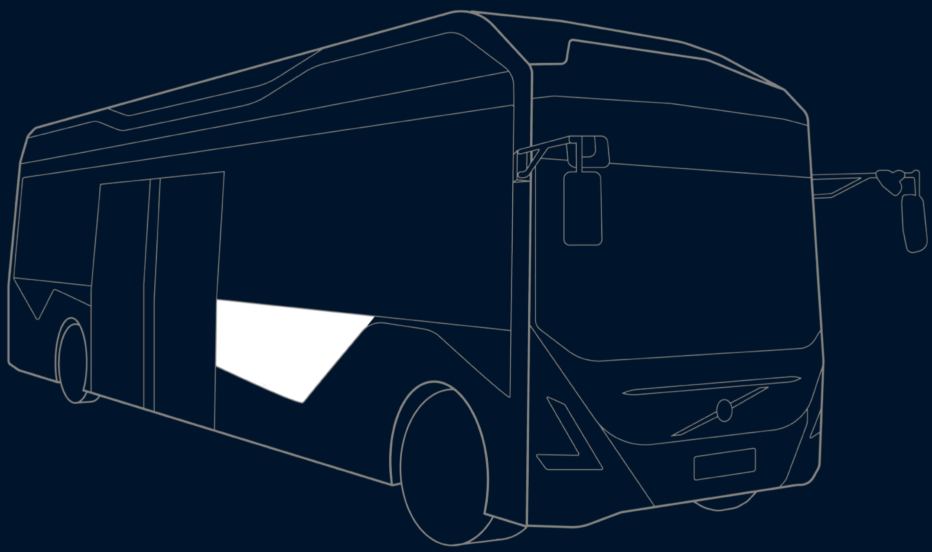
The concept Hand Gestures is based on the natural communication of physical, non-verbal type. Depictions of a range of established hand and finger positions are displayed on the front of the bus, depending on the situation at hand. It is intended to convey expected behaviour of the VRUs in a friendly manner as well as provide positive feedback to praise and promote appropriate demeanor.

ENHANCED EYE CONTACT

To reinforce the interaction between the VRU and the bus, eye contact can be utilized as a natural mean of communication. By providing the bus with eye-like lights, the bus can communicate the detection of pedestrians and bicyclists to the VRUs as well as provide feedback on their behaviour through its adjusting appearance. It would also provide support to individuals with visual impairments and difficulties reading the facial expression of the bus driver.

SECTION LIGHTING

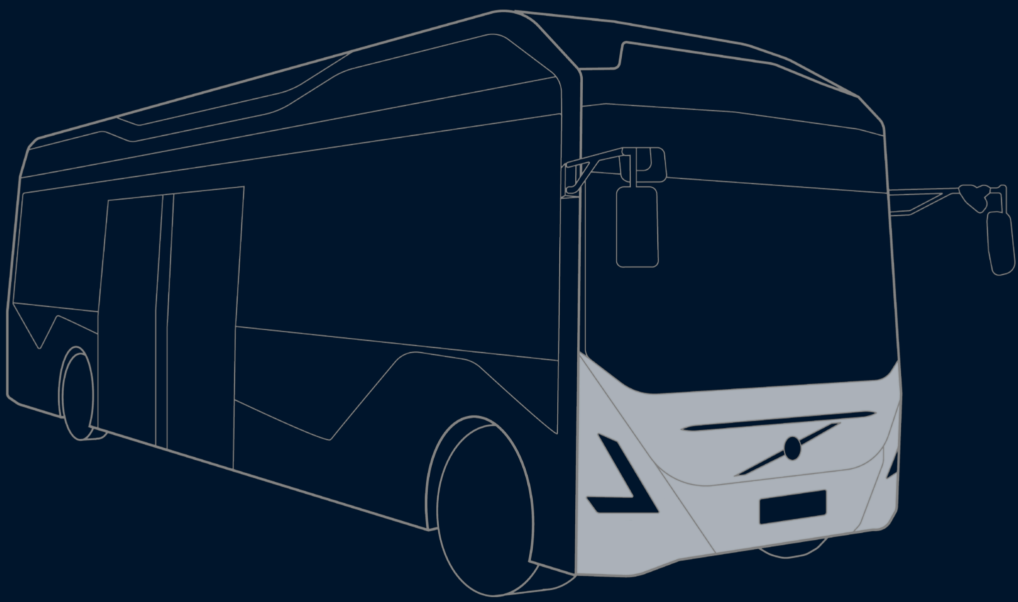
CANDESCENT SECTIONS



As certain parts of the bus exterior can become more hazardous to be near, candescent sections along the side of the bus light up when a VRU is too close. This alerts the VRU of the danger as well as guides them away from the critical zones. The sections mark out parts which are likely to move unexpectedly in case of a turn, or parts which are hazardous in other ways. They also mark out the side mirrors as they protrude from the rest of the bus. Since the relevant section only lights up when VRUs are close, it is clear what has triggered the reaction of the bus.

CANDESCENT FRONT

When alerting VRUs in situations of different levels of acuteness, this concept lights up the entire segment below the bus's windshield, creating an eye catching effect which can be used by itself or be combined with a sound signal. When used in combination with a sound signal, it supports the identification of the source emitting the sound, increasing the chance that the information reaches the VRU.



8.3 EVALUATION

The evaluation of the ideas indicated that some had greater potential than others, as can be seen in figure 8.3. By comparing the concepts' capacity in relation to the previously defined scenarios, it stood clear that some solutions lacked in the range of problems that were handled whilst others tackled many issues but to a low degree. The feasibility score further separated the concepts, indicating which of them are more realistic to implement.

From the evaluation matrix the concepts with total scores lower than ten, or a feasibility score lower than two, were eliminated, thus leaving twelve concepts to continue with. These comprised of pulsating lights, sweeping lights, progress bar, LED strand, restricting lines, zone indicator, direction markings, checkered field, underglow, preparatory light, candescent sections and enhanced eye contact.

	1	2	3	4	5	6	7	8	9	10	11	12	Feasibility	Result
Pulsating lights	2		1		3	2	3	1		1	2		3	**18**
Sweeping lights	2				2	1	3	1		1	2		3	**14**
Dual-colored light	1				1	1	1				2		0	**6**
Restricting line	3		2	1	2	2	3	1	1		1		2	**18**
Zone indicator	2				2	2	3	2		1			2	**14**
Checkered field	2				3	3	3	1		1			2	**15**
Underglow	1		2	1	1	1	1		2			1	2	**12**
Shadow figure	1		1		3	3	3	1		1	1		1	**15**
Direction marking	2	2		1				1	2		1		2	**11**
Preparatory light	2	3						1			2		3	**11**
Caution light	1	3											2	**6**
Progress bar				2	2		2			1		2	3	**12**
LED strand				2	3	1	2	1		1		3	3	**16**
Candescent section			2	1					3				2	**8**
Candescent front	2				1	1	1			1	1		1	**8**
Patterned light	1		2				1		1				1	**6**
Spotlight	1				1		3			1	1		2	**9**
Drone	2	2	1				2				1		1	**9**
Li-Fi	3		1										1	**5**
Status curve					2		2	1		1	1		2	**9**
Twinkle					1		1	1		1			2	**6**
Hand gestures					2		2	1		1			2	**8**
Enhanced eye contact					2		2	1		2	1		2	**10**

FIGURE 8.2 Evaluation against scenarios

Candescent sections received a total score lower than ten, but was kept for further development since it was the only concept that received a maximum score in relation to the ninth scenario. It was considered important that situations where bicyclists would benefit from a more clear indication for when the bus will make a turn were not forgotten, as it is a quite common and hazardous situation.

However, the other concepts which received low scores were deemed as rightfully eliminated from the following phase. The concepts with a low feasibility score were amongst others dual-colored headlights, shadow figures and Li-Fi. For dual-colored headlights the low score was based on information from the project instigators at Volvo who believed that it would not be an option, due to technical limitations of the headlights as well as legal regulations. Shadow figures also received a low feasibility score, although an acceptable score in all, due to the visibility factor. Clearly discernible shadows in a pattern in front of the bus might be difficult to create in full daylight. Additionally, the instigators of the project advised against creating negative emotions towards the bus. For Li-Fi, the issue was partly the potential usage in daylight which could interfere with its light signals, and partly the time frame for implementation, as it would require that all smartphones are equipped with a receptor for the signals.

The eliminated concepts which received a higher feasibility score were instead excluded due to their lack of ability to improve the situations described in the scenarios. For example, twinkle and patterned light were only deemed as slightly useful for four different scenarios, while the concepts which got total scores above 10 were generally considered useful for many scenarios. Within the twelve concepts, potential was seen in either their approach to a problem or the execution of the communication, which were to be explored in the following phase of ideation.

8.4 CONCLUSIONS

This chapter presented the mood board as well as the results from the first phase of ideation, which gave 23 ideas targeting the different identified problem areas. The ideas ranged in simplicity and the time span for realization, where some ideas were more futuristic and technologically complex. The ideas were divided in six categories, namely conventional lighting, projections, section lighting, directed lighting, device connection, and displays.

Thereafter, the concepts were evaluated against the defined scenarios in a Pugh matrix. This showed that some solutions were flawed in the range of problems that they handled while others tackled many issues, but to a lower degree. The feasibility score further made certain ideas stand out in a positive or negative way.

A limit was set at ten points for the overall score, and two points for the feasibility score, where all concepts falling under those limits were eliminated. This left twelve suggested solutions for further development. These twelve ideas composed of pulsating lights, sweeping lights, restricting line, zone indicator, checkered field, underglow, direction markings, preparatory light, progress bar, LED strand, candescent sections and enhanced eye contact.

A great variety within the group of solutions thereby remained after the thinning process, constituting a solid foundation. Within these twelve solutions, potential was found in either their approach to a problem or the method for communication, which were to be further explored in the following phase of ideation.

09

PHASE 2 - CONCEPTS

Based on the results of the evaluation in the previous ideation phase, the best ideas were brought into a second phase of concept generation. By defining and structuring the stages of the bus, which are presented in this chapter, concepts were created by combining the previous solutions. These are described and illustrated in the chapter along with the results of another evaluation against the scenarios, accompanied by the answers from a short user evaluation. Additionally, the trade-offs of the signaling system are discussed.

9.1 STAGES OF THE BUS

As a way of setting the aims for the following ideation phases and structuring the concepts, a regular bus route was defined, where all stages deemed as essential for the project scope were included. To optimize its applicability, the definition was general and not bound to a specific city, bus route or type of city bus.

The term stage refers to a set of actions which the bus goes through at a specific type of location in order to complete a subtask. Findings from the user studies regarding problematic situations were used as a basis for the selection where the relevant stages were considered to be those where some sort of interaction between the bus and VRUs is required.

As can be seen in figure 9.1, three main categories were found to be relevant, namely bus stops, intermediate distances and VRU crossings. The category for bus stops was divided further into the bus approaching the bus stop, being idle, as well as leaving the location.

Intermediate distances comprised of turning, regular driving, and critical situations where a VRU needs to be alerted or warned in order to ensure that the path of the bus is clear. The last category, VRU crossings, consisted of subcategories similar to those of bus stops, namely approaching the crossing, being idle, and passing the crossing.

These stages all demand that the bus and surrounding VRUs interact, communicate or convey and receive information regarding the intentions of the other party. Certain stages are also related to types of locations where accidents are prone to occur, a factor which contributes to the importance of their being included in the route. As approaching and leaving a location as well as being idle at it might create different requirements for a light signal, these phases have been separated into different stages.

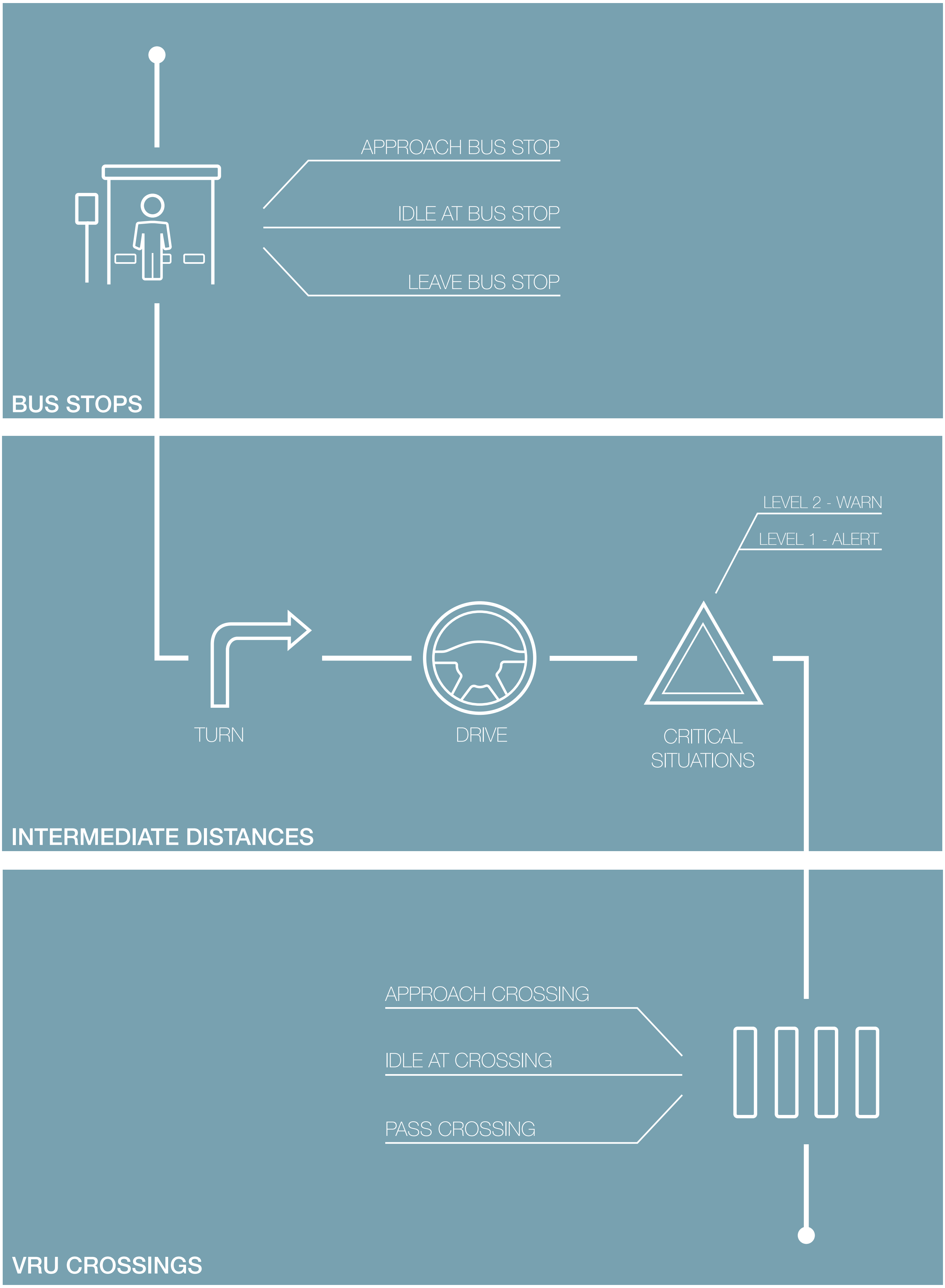


FIGURE 9.1 Stages during a route of a bus

FIGURE 9.2 Sketching in progress

9.2 IDEATION

With the chosen twelve concepts as a basis, a new ideation phase started with the focus of finding the optimal combinations of the ideas. The randomized combinations resulted in a number of new variants of solutions. In the end, these solutions became five concepts applying different lighting technologies, and targeting various behaviours as well as situations.

During the development of these concepts, the focus was directed towards the general principles and how they could be combined for the best effect, and more detailed parameters such as luminous intensity, colour of the light, exact placement and size of the source were not defined. The concepts were defined based on the different stages of the bus and what actions were deemed suitable in each of these.

1

CONCEPT GENERATION PHASE 2

ZONE MARKINGS

Zone markings is a concept based on the idea of dividing the area around the bus in zones according to the level of safety. When approaching a bus stop, the bus will project light on the ground in the form of lines which move outwards in a wavelike formation. This is done on the corresponding side, towards the bus stop, as well as at the front. The projection is intended to raise awareness amongst the pedestrians in the vicinity of the bus and thereby make way for the bus to pass. As the projection is not static, the concept is more likely to be noticed by the VRU as well as it sends a clear message of the expected response, to back away from the bus.

When the bus is idle, picking up and dropping off passengers at the bus stop, the projections are turned off. By avoiding a constantly active state, the light projection will not be a constant stimuli. However, as the bus is in the process of leaving the bus stop, the front line is activated and starts moving with a greater frequency than when the bus was approaching.

As the driver begins to accelerate the line moves forward and shortens, creating an arrow-like formation. This creates an indication for individuals moving close to the front of the bus, that the bus is about to leave therefore making the area a hazardous zone. The activation of the projection calls for attention and with it being seen on the ground it is more likely to be detected by individuals looking down on their phone. Additionally, the movement and shape variation of the line indicates the expected action of the pedestrian, to distance themselves from the bus, as well as the intended action of the bus, to accelerate and leave the road side.

In the driving state, the line at the end of the created pointer becomes a preparatory light which unveils the approach of the bus. It provides an early alert to VRUs moving close to the path of the vehicle. The line moves from side to side in order to be perceived more quickly and cover the width the hazardous area. This allows people to be alerted about the presence of the bus, for example in calm streets where pedestrians can walk in the road, not expecting a bus to approach and much less a silent one. Additionally, it functions as an early warning when the sight of the pedestrian is hindered by other vehicles or objects in the surrounding.

The line in the driving state also has a function when approaching VRU crossings. With its preparatory qualities, the projection can alert VRUs that are about to suddenly turn into the street. This situation can be further improved with the line position being adjusted to the speed of the bus. When the bus decelerates, the line is moved closer to the bus and thereby reflects the increased stopping distance to the VRU. In turn, the VRU receives more cues to make an informed and confident decision, whilst it also can eliminate the need for the bus to make a full stop.

In stages where the bus is required to make a turn the concept also provides support for surrounding VRUs. When the driver turns on the turn signal, the front line is moved sideways and connects to a diagonal line projected along the side. This highlights the hazardous zone that is created by the bus, both with regards to blind spots as well as overhang. It indicates the need for the cyclist to keep their distance to the bus when cycling next to it in a turn or when overtaking a bus at a bus stop.

WHO

The Risk Taker
The Inattentive
The Nonchalant
The Dedicated

SCENARIOS

Personal Distractions
External Distractions
Close Proximity
Overtaking the bus
Imposed on

BUS STOPS

APPROACH:
Front and side repelling lines

IDLE:
Off

LEAVE:
Front repelling lines to arrow formation

INTERMEDIATE DISTANCES

TURN:
Triangle marking

DRIVE:
Preparatory light point

ABRUPT DECELERATION:
Repelling lines

CROSSINGS

APPROACH:
Preparatory light point

IDLE:
Off

PASS:
Preparatory light point

2

CONCEPT GENERATION PHASE 2

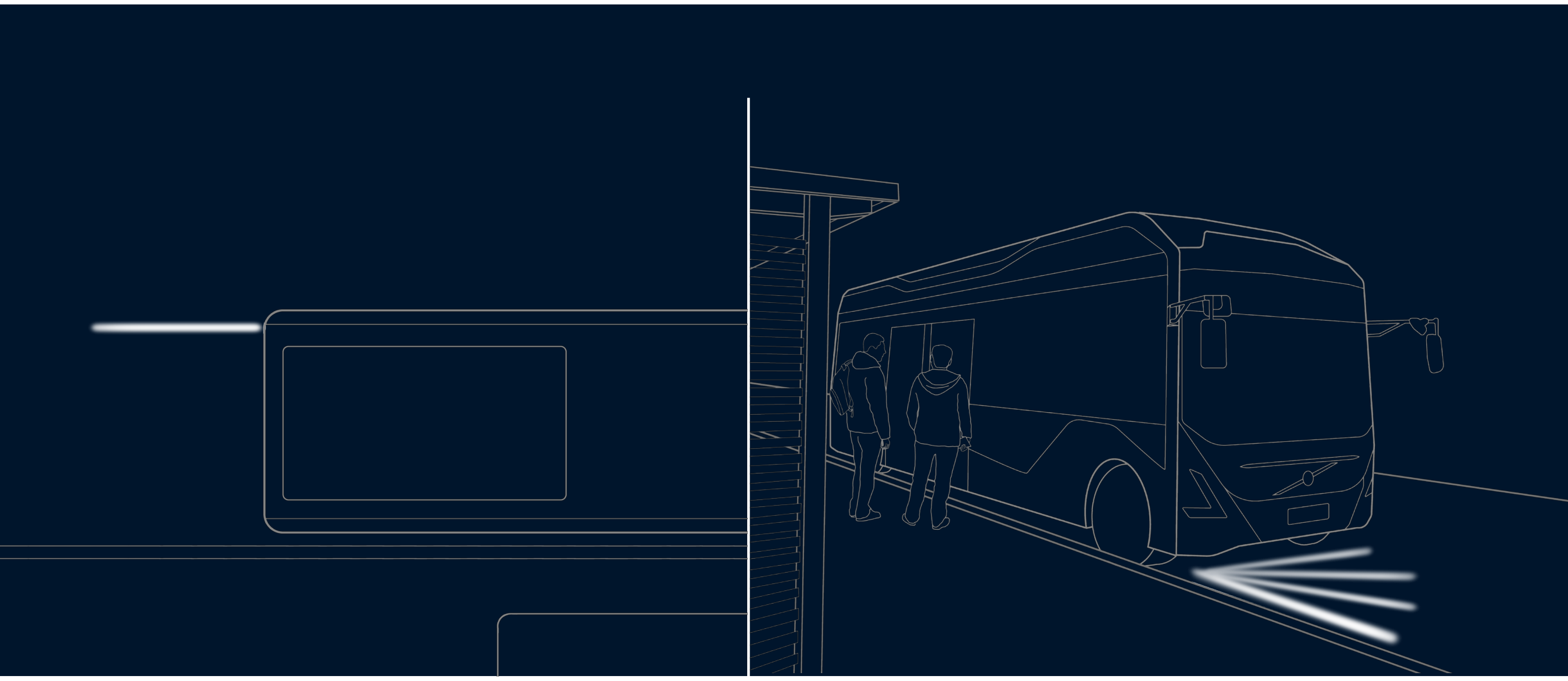
GUIDING LINES

The concept Guiding lines supports the VRU to make better decisions by indicating the boundaries of safe areas. In the case of the bus approaching a bus stop, the concept is thought to project lines on the ground in front of the bus. These lines move in a rotational pattern, much like that of windshield wipers. The frequency of the motion is quite low, intended to indicate the need for VRUs to move out of the way and let the bus pass. When the bus is at an idle state, the lighting system is not active to enhance the effect of the active system.

However, if a pedestrian were to move behind a bus that is standing still on a bus stop, a sensor will be triggered and a line will be projected at the back of the bus. This to alert the pedestrian about their decision to cross the street and encourage them to be more cautious for oncoming vehicles that might be hidden behind the bus.

At the stage when the bus is leaving the bus stop and the doors close, the concept changes character to return to the alerting lines, moving in rotational patterns at the front of the bus. This is thought to send a signal to people moving close to the front of the bus, that the bus is leaving. Thereby the VRUs have the information to make better decisions, rethinking decisions such as running in front of the bus to catch it or cutting corners to more quickly cross the street.

In comparison to the approach of the bus stop, the frequency of the motion is higher to illustrate the increased hazard. The movement of the lines is intended to generate a greater call for attention, with the benefit of having a quicker response time. Additionally, the expected actions of the VRUs are indicated, with the windshield wiper-motions guiding them back and away from the front of the bus.



When in a driving state, the concept displays the direction of the vehicles using two lines starting at the base of the bus. As the bus moves in a straight forward direction, the lines are in the corresponding position. However, when the turn signal is activated and the bus is about to turn the lines are angled towards that direction. This enables surrounding VRUs to clearly perceive the intentions of the driver. Thereby, bicyclists can be alerted when a bus is closing in on or entering their bike lane and take cautionary action. Similarly, the cyclist can act accordingly when a bus is leaving a bus stop as they are overtaking the bus.

Furthermore, the direction markings also function as a preparatory signal that indicates the approach of the bus. This supports the VRUs' perception of the bus, if hidden by other vehicles or the environment. Similarly, it also alerts VRUs when quickly turning into the street at a VRU crossing as it is visible on the ground along the sidewalk. To support the hesitant individuals and aid pedestrians with visual impairments that leads to difficulties with discerning the facial expression of the driver, the projection is turned off to indicate the inactive state of the bus.

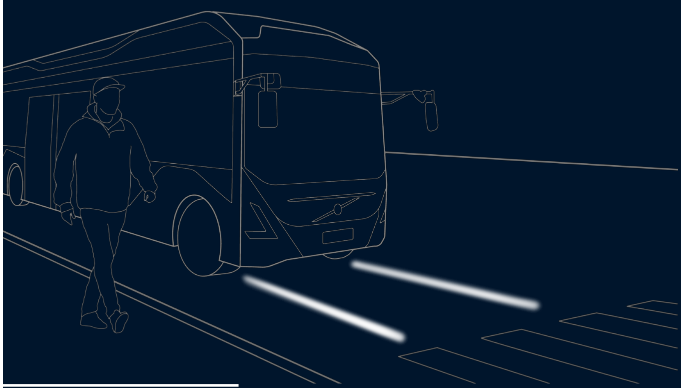
Additionally, the direction markings function as a way of alerting the approach of the bus for individuals looking down on their phone when moving in traffic. As the lines are projected forward the pedestrian has a greater response time and thus longer time to act. They can also support the discovery of the approaching bus for individuals with hearing impairment, who can more easily perceive the light signals and connect them to the specific bus.

WHO

The Risk Taker
The Inattentive
The Nonchalant
The Dedicated

SCENARIOS

Personal Distractions
External Distractions
Running late
Imposed on



BUS STOPS

APPROACH:
Rotational lines

IDLE:
Rear stop line

LEAVE:
Rotational lines

INTERMEDIATE DISTANCES

TURN:
Direction markings

DRIVE:
Direction markings

ABRUPT DECELERATION:
Rotational lines

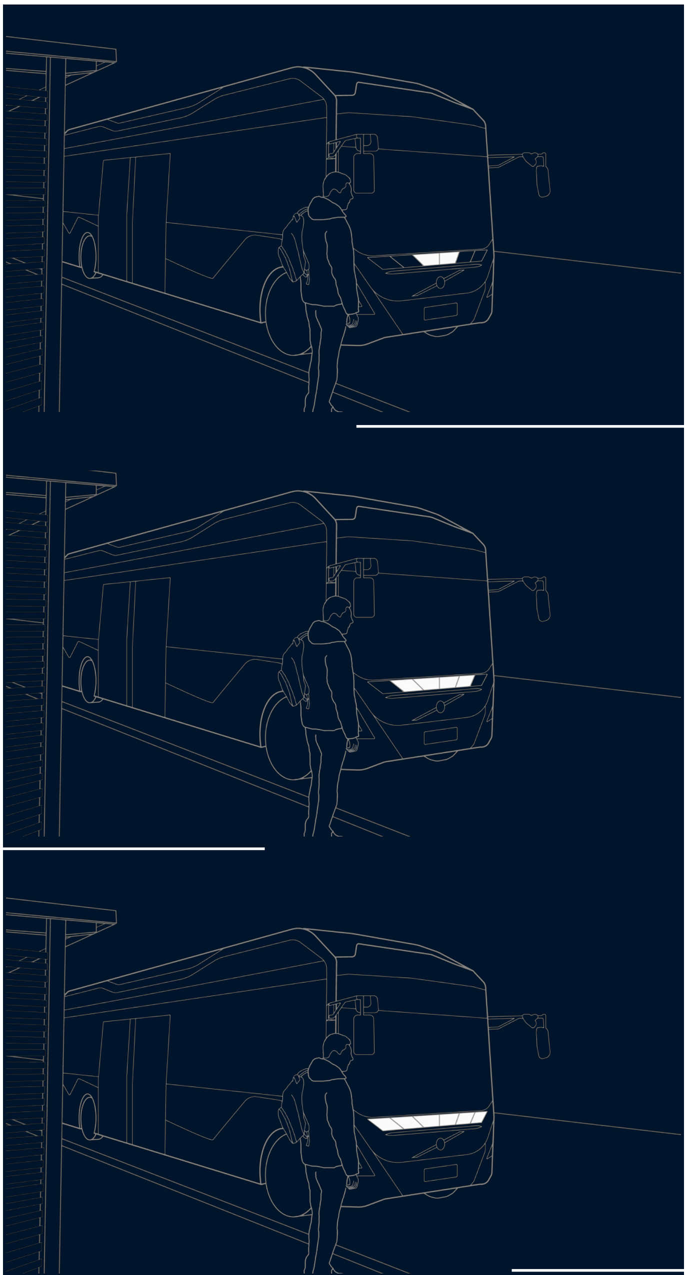
CROSSINGS

APPROACH:
Direction markings

IDLE:
Off

PASS:
Direction markings

3 CONCEPT GENERATION PHASE 2
SWEEPING SECTIONS



The concept of sweeping sections aims to alert and inform VRUs when the situation calls for it. Therefore, the concept features a progress bar on the front of the bus which provides VRUs with an approximation of how soon the bus will leave the bus stop. The sections of the bar light up in pairs as the bus goes through the procedure for bus stops, and when the driver starts to accelerate, the bar sections light up in a sweeping motion.

This signals, with a clear direction, that VRUs should move out of the bus's way. It can therefore help avoid situations where pedestrians run in front of the bus hoping to catch it or simply making it to the other side of the road before the bus leaves. With a clear signal for the departure of the bus, pedestrians are less likely to maintain the hope of having time to cross the road before the bus leaves. Seeing as the bus emits no light signals when it is idle, the progress bar indicates clearly that the bus will transition to a new phase.

The concept functions in a similar manner at VRU crossings; by making the sweeping motion when accelerating after stopping at a VRU crossing, it clarifies when it is unsafe to cross. This decreases the risk of misunderstandings as to who should go first.

WHO

The Risk Taker
The Inattentive
The Hesitant
The Dedicated

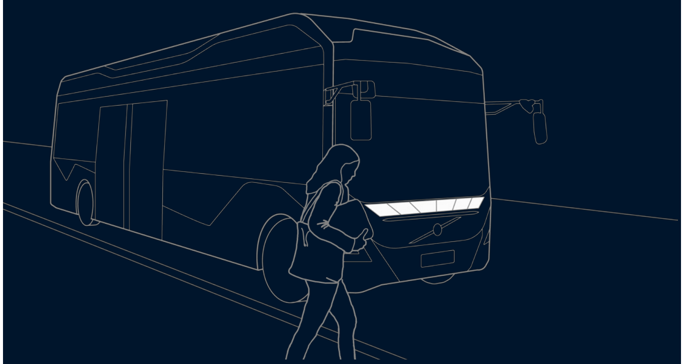
SCENARIOS

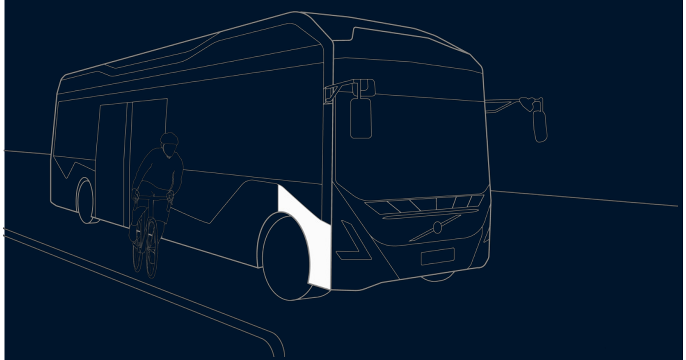
Personal Distractions
Running late
Following the crowd
Imposed on

Furthermore, the progress bar has the possibility to light up in the sweeping motion whenever it is necessary to alert VRUs in front of the bus, thereby catching the attention of the VRUs and indicate that they should let the bus pass. For critical situations, the entire progress bar lights up and pulsates to catch the attention of VRUs, accompanied by a sound warning. This way, the light reinforces the warning and facilitates for VRUs to determine from where the signal originated.

In addition to the progress bar, the bus conveys information and guidance through enlightened sections on the sides of the bus. These sections light up when the bus is about to make a turn, pull over to a bus stop or leave one. This with the intention of warning bicyclists along the side of the bus, providing a clearer indication of the bus's route.

Thereby, the sections mark out dangerous sections which one should keep a distance to, and the concept can hence prevent situations where bicyclists come too close to the bus and subsequently become surprised by its maneuvers.





BUS STOPS

APPROACH:
Off

IDLE:
Off

LEAVE:
Progress bar to sweep formation

INTERMEDIATE DISTANCES

TURN:
Side light sections

DRIVE:
Off

ABRUPT DECELERATION:
Sweep formation

CROSSINGS

APPROACH:
Off

IDLE:
Off

PASS:
Sweep formation

4

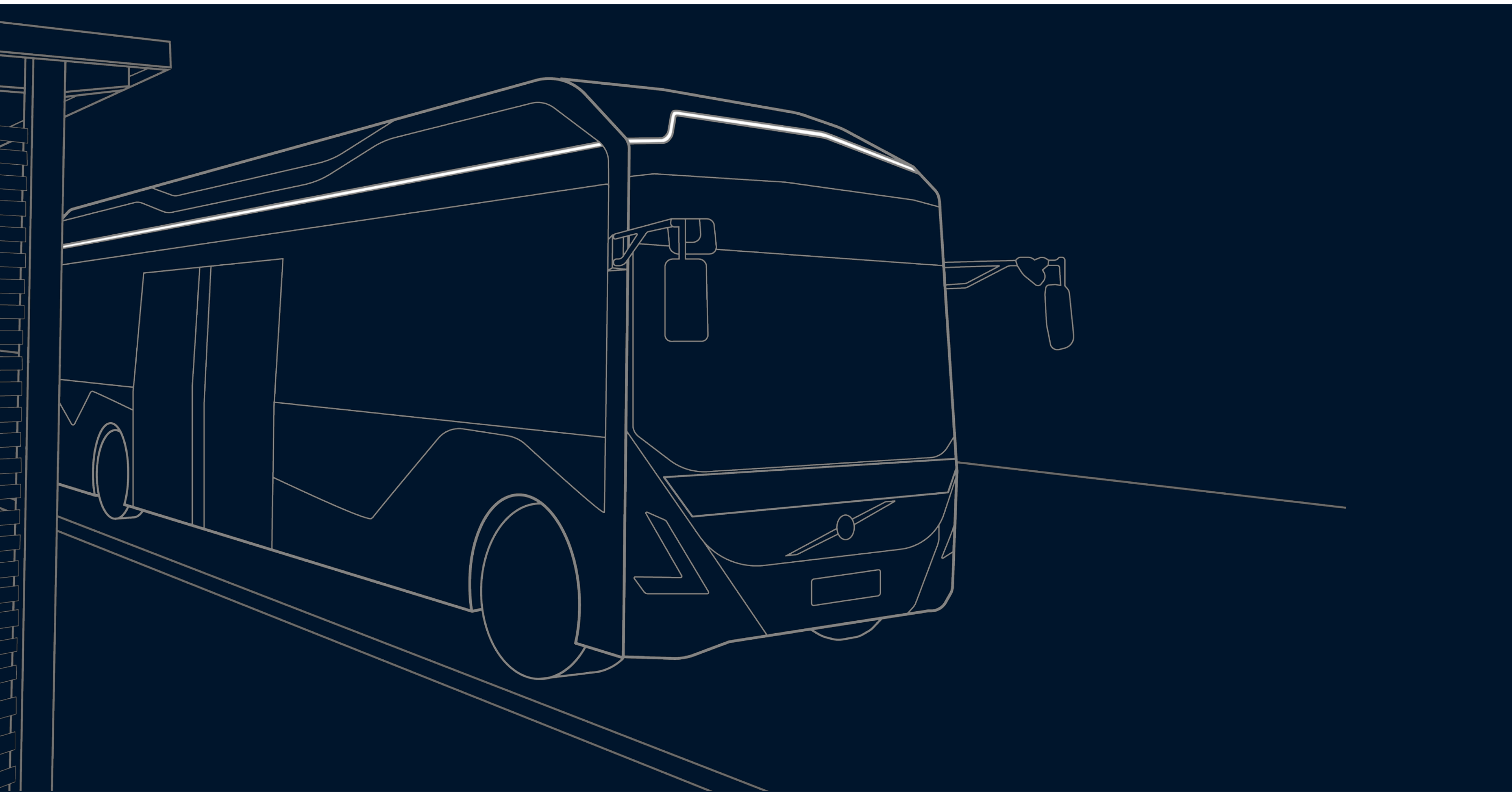
CONCEPT GENERATION PHASE 2

INFORMATIVE STRANDS

This concept focuses on informing the VRUs about the bus driver's intentions early on so as to facilitate the decision making for them. Therefore, when the bus is about to leave a bus stop, a LED light strand at the top starts pulsating intensely, signalling that it is too late to pass in front of it.

As the light strand reaches all the way around the bus, it is visible from all directions, thereby avoiding situations where pedestrians try to cross the road in front of the bus. Furthermore, as the light strand signals in all directions about the departure of the bus, it also minimizes the risk of misunderstandings for bicyclists who are unsure of whether they have time to overtake the bus at a bus stop.

The light strand also provides pedestrians with information at the bus terminus, where the bus might stand for a few minutes before leaving. Through slow pulsations of the light strand the bus signals that it will leave in one minute, and when it is nearing the departure time, the light strand follows the regular pattern of pulsating intensely and thereafter fading away as the bus leaves. It is hence easier for pedestrians hoping to catch the bus to determine the amount of time before the bus leaves, which could minimize the risk of pedestrians running to the bus when it is not necessary.



WHO

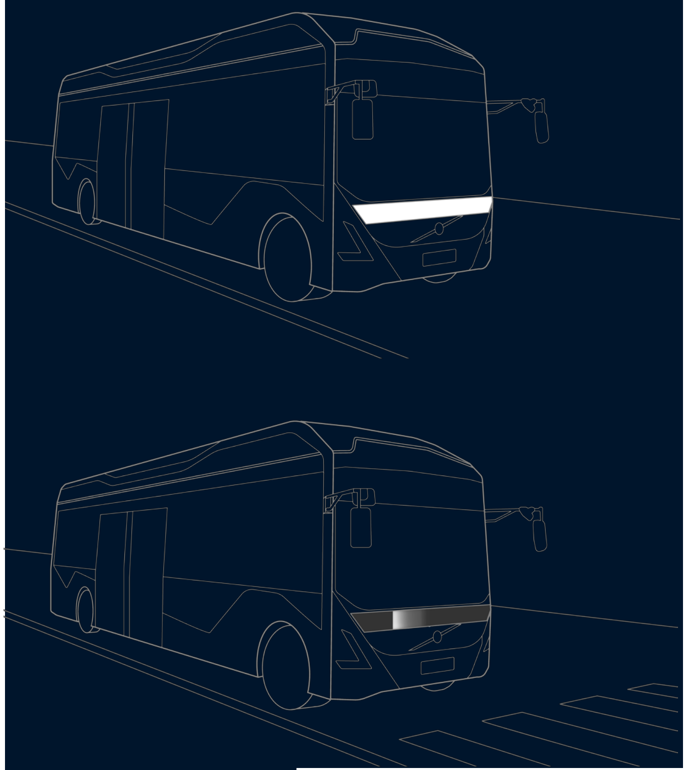
The Risk Taker
The Hesitant
The Dedicated

SCENARIOS

Running late
Following the crowd
Miscommunication
Timing

To provide further information to VRUs, a broad light strand on the front of the bus gives a signal at VRU crossings, when the bus driver wants to indicate that it is safe to cross the road. At the driver's signal, the light strand is enlightened to catch the attention of the VRU convey that the VRU has been noticed and is allowed to pass.

Thereafter, the light creates a sweeping motion on the strand, so as to indicate the passage past the bus, as well as the idle state which the bus is in. This makes the crossing more time efficient as the bus might not need to come to a full stop to signal that pedestrians and bicyclists can pass. Less time is devoted to waiting and reaching a mutual understanding, leaving the VRUs feeling more confident in their decisions. This would be especially advantageous in those situations where VRUs want to cross the road but feel uncertain as to whether the bus will stop for them.



BUS STOPS

APPROACH:
Off

IDLE:
Off

LEAVE:
Pulsating top strand

INTERMEDIATE DISTANCES

TURN:
Off

DRIVE:
Off

ABRUPT DECELERATION:
Off

CROSSINGS

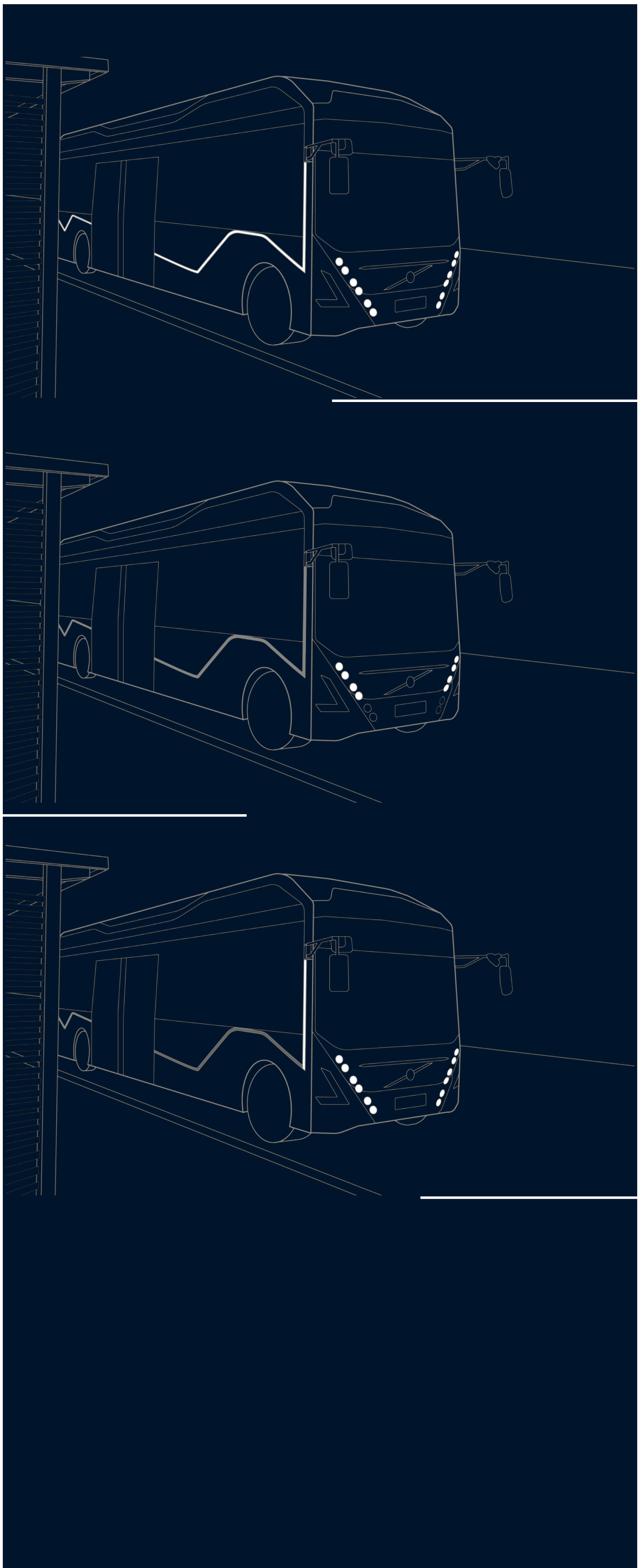
APPROACH:
Activated front strand

IDLE:
Dynamic front strand

PASS:
Off

CONCEPT GENERATION PHASE 2

5 PULSATING SIGNALS



This concept uses pulsating signals to alert and inform surrounding VRUs. As the bus arrives at a bus stop, a number of lights on the front of the bus pulsates slowly in unison with a LED light strand on the sides and rear of the bus, so as to alert the individuals waiting at the bus stop and direct their attention towards the bus. Hence, they are discouraged from standing too close to the kerb when the bus arrives, leaving enough space for the bus to pull over safely.

As the bus is idle at the bus stop, no signal is conveyed in order to create a greater difference to the situation when the bus is about to leave. When the driver is preparing to drive off, the lamps on the front light up in pairs to create a progress bar, and when the bus accelerates, the lamps pulsate intensely. This way, they clearly signal that the bus will leave and that it is not allowed to pass in front of it, hence preventing situations where pedestrians take a chance and run in front of the bus just as it drives off.

In order for the signal to be seen from the sides of the bus, a LED light strand at the front corner lights up in a manner similar to the lights on the front. This prevents recently disembarked passengers from taking a chance and brushing against the bus's front corner on their way toward the opposite side of the street just as the bus is leaving.

WHO

The Risk Taker
The Inattentive
The Hesitant
The Dedicated

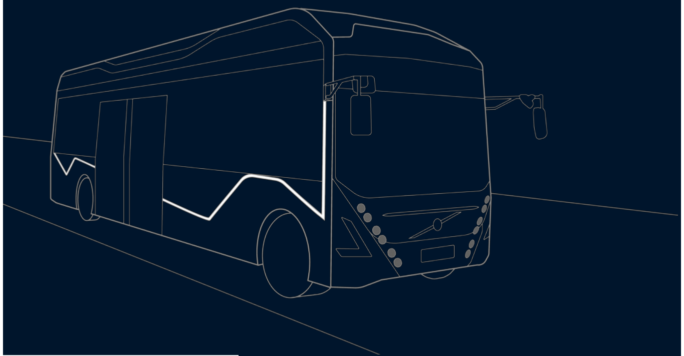
SCENARIOS

Personal Distractions
Close Proximity
Running late
Cutting corners
Following the crowd
Imposed on

The lights function in a similar way when the bus starts to accelerate after stopping at a VRU crossing, so as to alert individuals nearby that the bus is leaving and that it is therefore too late to cross. Through this, accidents stemming from certain misunderstandings as to who should give way could be avoided.

Furthermore, the LED strand on the sides and rear of the bus can prevent misunderstandings regarding the intended route of the bus. When the bus is about to make a turn, the LED strand lights up and alerts bicyclists of the planned maneuver, thereby preventing situations where bicyclists realize too late that the bus will cross their path.

In addition to the previously mentioned alerts, the concept also sends out an alert when a VRU is in front of a moving bus. In these situations, the lamps on the bus front pulsate intensely so as to call for the VRU's attention. In critical cases when VRUs should be warned, the pulsating lamps could be combined with a sound signal in order to make the warning more available and highlight the source of the auditory signal.



BUS STOPS

APPROACH:
Pulsating lights

IDLE:
Off

LEAVE:
Progress bar to pulsating

INTERMEDIATE DISTANCES

TURN:
Activated side strand

DRIVE:
Off

ABRUPT DECELERATION:
Intensely pulsating front lights

CROSSINGS

APPROACH:
Off

IDLE:
Off

PASS:
Pulsating front lights

9.3 EVALUATION

Similar to the first ideation phase, the five concepts were evaluated with a modified Pugh matrix. The results can be viewed in figure 9.3. In spite of the varying principles of the concepts, the final scores were quite even, ranging from 15 to 20, where Zone Markings and Pulsating Signals received the highest rating of 20 points.

In general, the concepts which were considered to match many of the scenarios received a high score in total. However, certain scenarios bring up similar issues, so if a concept solves one of those issues it is likely to solve the similar ones as well, which can create an imbalance in the rating.

It is also important to remember that the concepts involved many different lighting principles aimed at solving different problems, which means that a low score in general does not necessarily entail that all of the principles within the concept are incapable of solving a specific issue. This means that certain aspects of a concept can be superior and should be further developed even though it belonged to a concept with a lower score. An example of this is the sweeping light on the front of the bus, which emits a very clear signal, with the additional function of a progress bar. Despite this, the concept it was a part of received the second lowest score, as the concept did not solve as many scenarios in general.

It is therefore relevant to highlight the features which contributed the most in the different scenarios. In Zone Markings, the repelling lines and the triangle marking lead to a high rating in scenario three and nine. As previously mentioned, the sweep signal resulted in a high

	1	2	3	4	5	6	7	8	9	10	11	12	Feasibility	Result
Zone markings	2	2	3	2	2	1	1	1	3	1	1		1	**20**
Guiding lines	2	2	1	1	2	1	1	1	2	1	1		1	**16**
Sweeping lights	2		1	1	3		3		2	1	1		2	**16**
Informative strands	1			1	2	1	2	1		3	1	3	3	**18**
Pulsating signals	2		2	1	3	2	3		2	1	1		3	**20**

FIGURE 9.3 Evaluation against scenarios

score in scenario five and seven, while the top LED strand in Informative Strands received the highest score for scenario number twelve.

The front strand in that concept proved to also be the best for scenario number ten. In Pulsating Signals, the pulsating lights on the front reached the highest rating for the fifth and seventh scenario. These components are hence the ones with the most potential for further development.

Regarding the short user evaluation, the test participant was able to interpret nearly all of the signals correctly. The signals which resulted in hesitant or incorrect answers were one signal from Guiding Lines, one from Pulsating Signals and a few from Informative Strands. The lines moving in the pattern of a windshield wiper on the ground in front of the bus, belonging to Guiding Lines, was considered more unclear than the repelling lines from Zone Markings. Furthermore, the pulsating strand on the side of the bus in Pulsating Signals was thought of as difficult to interpret as well.

When it comes to Informative Strands, the test participant pointed out that it is not intuitive to look up at the top strand. Moreover, the signal given when the bus approaches a VRU crossing was interpreted as either conveying that the bus will decelerate, or that it will not slow down.

Similarly, the signal emitted when the bus has stopped at the crossing rendered the test subject very uncertain, however a guess was ventured, suggesting that the signal conveyed that the bus was aware of the pedestrian's presence. The most preferred signals overall were the repelling lines and the turn triangle from Zone Markings, the rear stop line from Guiding Lines, as well as the progress bars and alert signals from Sweeping Sections and Pulsating Signals.

9.4 DESIGN TRADEOFFS

The development of these concepts highlighted certain issues and tradeoffs which are necessary to consider in the continued work. Firstly, there is the issue with the visibility of the lighting solutions in different levels of environmental light. The projections, in particular, will be less visible in daylight. However, they are easily visible in the dark, and have the immense benefit of reaching outside of the space which the bus normally occupies. This means that they could be spotted earlier on, and for example when looking down at a phone. As for the other light solutions, the luminous intensity and other lighting parameters must be chosen with care in order for them to be clearly visible in daylight, which is feasible considering current usage of light signals on vehicles.

Another aspect which is necessary to take into account is the consistency within the concepts, especially in the following phases of further development. Ideas and solutions will be combined in order to create a concept which fulfills as many of the needs as possible, leading to compromises and trade-offs that have to be considered. Regarding the consistency, the idea of giving a signal when it is safe to pass at a VRU crossing might be somewhat contradictory when paired with emitting a signal as the bus is leaving. The first needs a clear signal which catches the attention of VRUs and conveys the message that it is safe to cross the road, while the latter requires a conspicuous signal indicating that it is not safe to cross. Seeing as the messages of the respective signals are the absolute opposite of each other, and as it is very important that they are not confused with each other, it can be considered as quite a challenge to combine them in a consistent concept. A potential combination puts a great demand on the signals being possible to clearly distinguish from each other.

Furthermore, this raises the question as to whether one can ever signal that it is safe to cross the road, as the traffic interaction is quite complex with many parties involved. A signal of this type would therefore require a great reliability which can be challenging to achieve, both for an automated function and a human operator. On the other hand, it is as of today quite common for drivers to signal with hand gestures that they will give way for a VRU, so an exterior version of this would simply be an enhancement of already existing communication.

9.5 CONCLUSIONS

In this chapter, the second phase of ideation was described. This phase started with the definition of the stages which the bus goes through during its route. The stages were categorized according to the types of locations where they take place, namely bus stops, VRU crossings and intermediate driving. This last category was further divided into regular driving, turning and critical situations.

Thereafter, the second round of ideation began, where the previous ideas were combined in different constellations in order to develop the ideas. This lead to some new additions as well as adjustments of the original ideas, which were combined into five concepts having different areas of main focus.

The Pugh evaluation matrix showed that the concepts were quite equal when compared with the scenarios, with scores ranging from fifteen to twenty points. When diving further into the reasoning behind the scores, however, a few of the features stood out as the main contributors of the high scores. These were therefore kept for further development in the next phase.

Additionally, a number of tradeoffs were brought up, as they were considered to influence the continued direction of the project. Among these, the possibilities and flaws of projections were discussed, along with the potential of lights on the bus. Lastly, the application of a signal conveying that VRUs are allowed to cross the street was deliberated on.

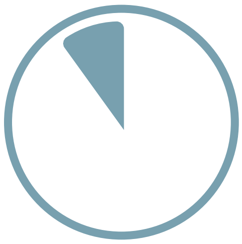
10

PHASE 3 - SYSTEMS

The following chapter presents the results of the third ideation phase. Firstly, five key features deriving from the previous ideation and evaluation are introduced. These are the foundation for the ideation that was conducted, of which the results are displayed and described in this chapter. Finally, information gained through user tests with VRUs and interviews with bus drivers are presented.

10.1 KEY FEATURES

In the third phase of ideation, a number of lighting principles were kept and developed from phase two. These lighting principles were categorised in five key features, comprising of progress bars, dynamic alert signals, terminus departure signals, zone alerts and preparatory lights. Where the dynamic alert signal encompass all signals with the purpose of alerting the VRUs of the approaching bus, while the zone alert includes the signals given to mark out hazardous areas.



ZONE ALERTS

Zone alerts are a light signal that is used to highlight hazardous areas around the bus. With different zones being marked out according to the level of safety, the signals encourage VRUs to maintain a distance to the bus or to other potential hazardous areas. The signal is conveyed through projection, enabling a visual representation of the actual outlines of the areas that should be avoided. It is intended to activate in the specific situation to catch the attention of the VRUs, making them aware of the danger and have them consider what actions they should take. The zone alerts function in many different situations, where the hazards often derive from blind spots, overhang, hidden dangers and the bus's acceleration.

TERMINUS DEPARTURE SIGNAL

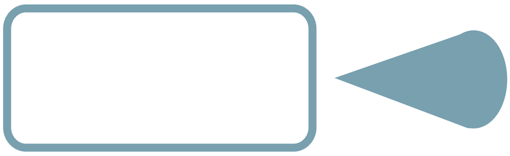
The terminus departure signal is based on the idea of indicating the status of vehicles stationed at a terminus. By allowing a signal to be sent through light sources, potential passengers are presented with more information to determine the state of the bus and thus their need to hurry. This would facilitate the passengers' decision making and instill a sense of confidence in the same. Additionally, the solution could also contribute to a reduced risk of accidents as the number of reckless running has the potential to decrease. The signal is presented in a pulsating format, commonly used to display an awaiting status, reflecting the pending state of the bus.

DEPARTURE ALERT SIGNAL

The occurrence of VRUs passing in front of the bus and thereby hindering it from leaving the bus stop can be decreased through giving clear indications regarding when the bus is nearing its departure. This can be achieved with a progress bar on the bus which communicates the status of the bus. The sections light up as the bus goes through specific phases at the bus stop, for example opening and closing the doors.

Therefore, the status of the bus is made more easily visible from more directions and longer distances, which could decrease the number of people running to catch the bus or simply trying to make it across the street before the bus leaves. The VRUs are provided with more information in order to be able to make better decisions and experience a greater certainty as to the correctness of their decisions. This is especially beneficial for individuals with impaired hearing or vision, who are presented with more cues.

A series of light sections make up the progress bar, where the section in the center lights up first so as to not indicate a specific direction and be clear from both directions. The level of acuteness can be further conveyed through the usage of different colors for the different sections, where the outer sections should be orange, thereby signalling that the situation is more critical.



PREPARATORY LIGHT

The preparatory light functions as a way to inform VRUs about the approach of a bus. By projecting shapes on the ground in front of the bus, an early detection of the vehicle is enabled. On smaller, less busy streets where VRUs commonly walk into the road, not expecting a bus, the signal allows people to be alerted about the presence of the bus. Similarly, the signal can also contribute to a better communication and reduced risk when the bus approaches a VRU crossing. With its early onset, the projection can alert VRUs that are about to suddenly turn into the street, providing them with the opportunity to reassess the situation and their decision to cross based on the speed of the bus. Additionally, this communication is further improved with the projection being adjusted in accordance with the speed of the bus. By displaying the state of the bus, the VRU receives more cues to make a more informed and confident decision to cross, whilst also potentially eliminating the need for the bus to make a full stop.

Furthermore, the preparatory light functions as a warning when the view of the pedestrian is hindered by other vehicles or objects in the surroundings. As it is projected on the ground, the signal is also more likely to be detected by individuals looking down on their phones. The preparatory line also minimizes the need for using the horn as it alerts before a critical signal is needed, thus creating a calmer traffic environment as well as facilitating for individuals with hearing impairments.

DYNAMIC ALERT SIGNAL

As the bus is leaving the bus stop, or when a VRU is obstructing the path of the bus, an eye catching light signal is required to call for the attention of VRUs and signal that they should move away. In these cases, movement is likely to be noticed, even in the peripheral field of vision. The alert signal conveys the acuteness of the situation as well as the increased hazard, similar to the trams in Gothenburg which signal their departure with a sound. This creates a consistency for when alerts are given which makes the signal easier to understand.

As the signal is given only when the bus is leaving, it provides a clear contrast towards less critical situations, and the dynamic aspect of the signal makes it more conspicuous. The dynamic factor also makes the signal intense and more urging, which is required when the bus is about to leave. Its point of origin at the front of the bus directs the signal mainly towards those who are close to the front and thereby likely to be affected by the continued path of the bus. In critical situations when the bus is approaching a VRU obstructing its path, the signal can be used as a clear warning when combined with a sound.

10.2 IDEATION

From the five key features, two concepts were created. The concepts were further developed with the aim of investigating solutions where projections and lighting fixtures on the bus are combined. This way, the benefits from both manners of communication can be preserved. Projections are easily discovered on the ground even by individuals who are not facing the bus, and can clearly show areas which VRUs should avoid. Lights on the bus, on the other hand, are more reliable in different conditions and can present information and alerts clearly where it is relevant and where VRUs would seek information.

The two concepts which were created had the five key features in common, although in different variants. The first concept, named Parallel after its projected lines which run parallel to the bus, is constituted by solutions from the earlier ideation phases. These solutions were strong in the previous evaluations and were therefore not in need of any adjustments. They were combined together as they were considered to complement each other, with the additional purpose of investigating the impression of projections combined with lights on the bus.

As for the second concept, Perpendicular, named after the projected lines being perpendicular to the bus, the aim was to find new variants of some of the key features. This aim was set as it was relevant to investigate whether there were even stronger variants than the ones previously designed.

Therefore, the turn triangle and the preparatory light were adjusted in order to create new variants for evaluation and comparison with the other concept. Thereby, the perpendicular lines in the turn triangle were designed, with matching strands on the bus, connecting the lights on the bus with the projections in a clear way. For the perpendicular lines in the preparatory light, the goal was to find a solution that appears to be moving like in the Parallel concept, but with included pulsating features as they can catch VRUs' attention.

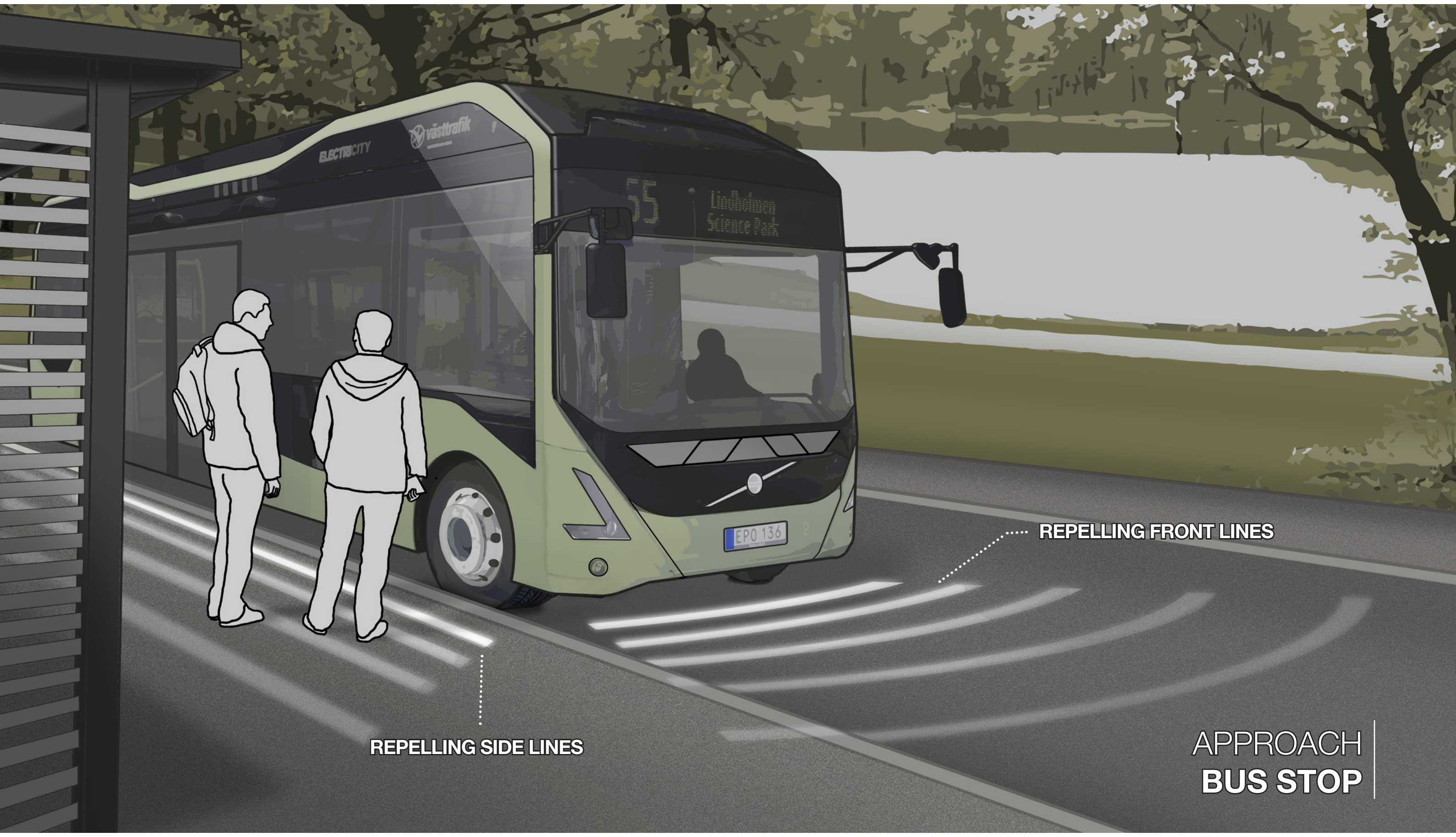


FIGURE 10.1 Display of signals during the approach of a bus stop

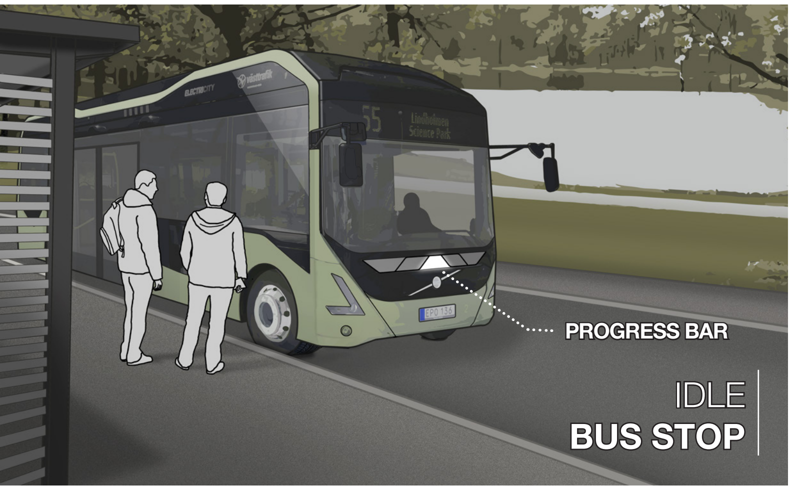


FIGURE 10.2 Signals when idle at bus stop

FIGURE 10.3 Signals on back of bus when idle at bus stop

CONCEPT 1 - PARALLEL

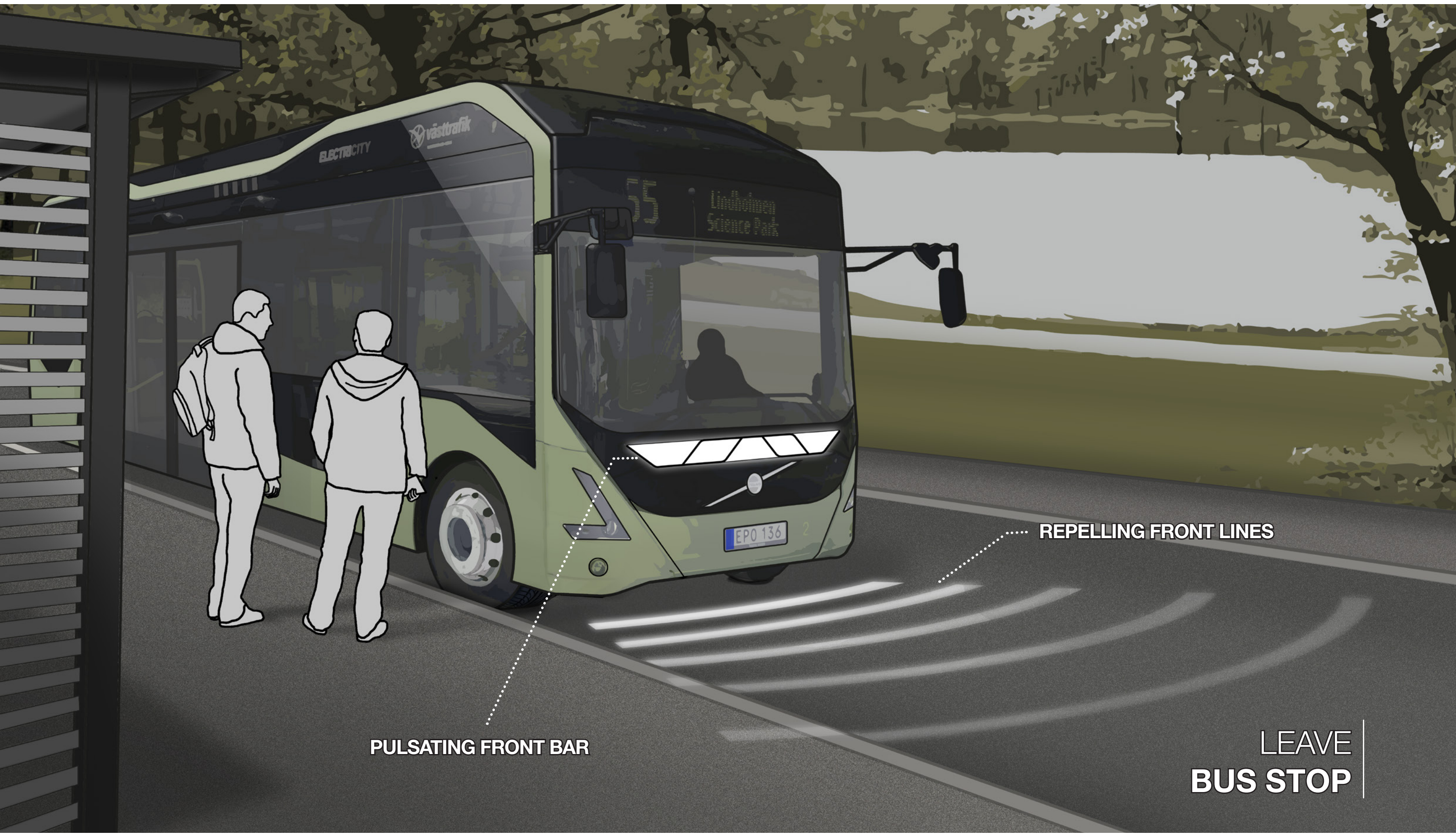


FIGURE 10.4 Given signals during departure from bus stop

FIGURE 10.5 Signal presented when at terminus

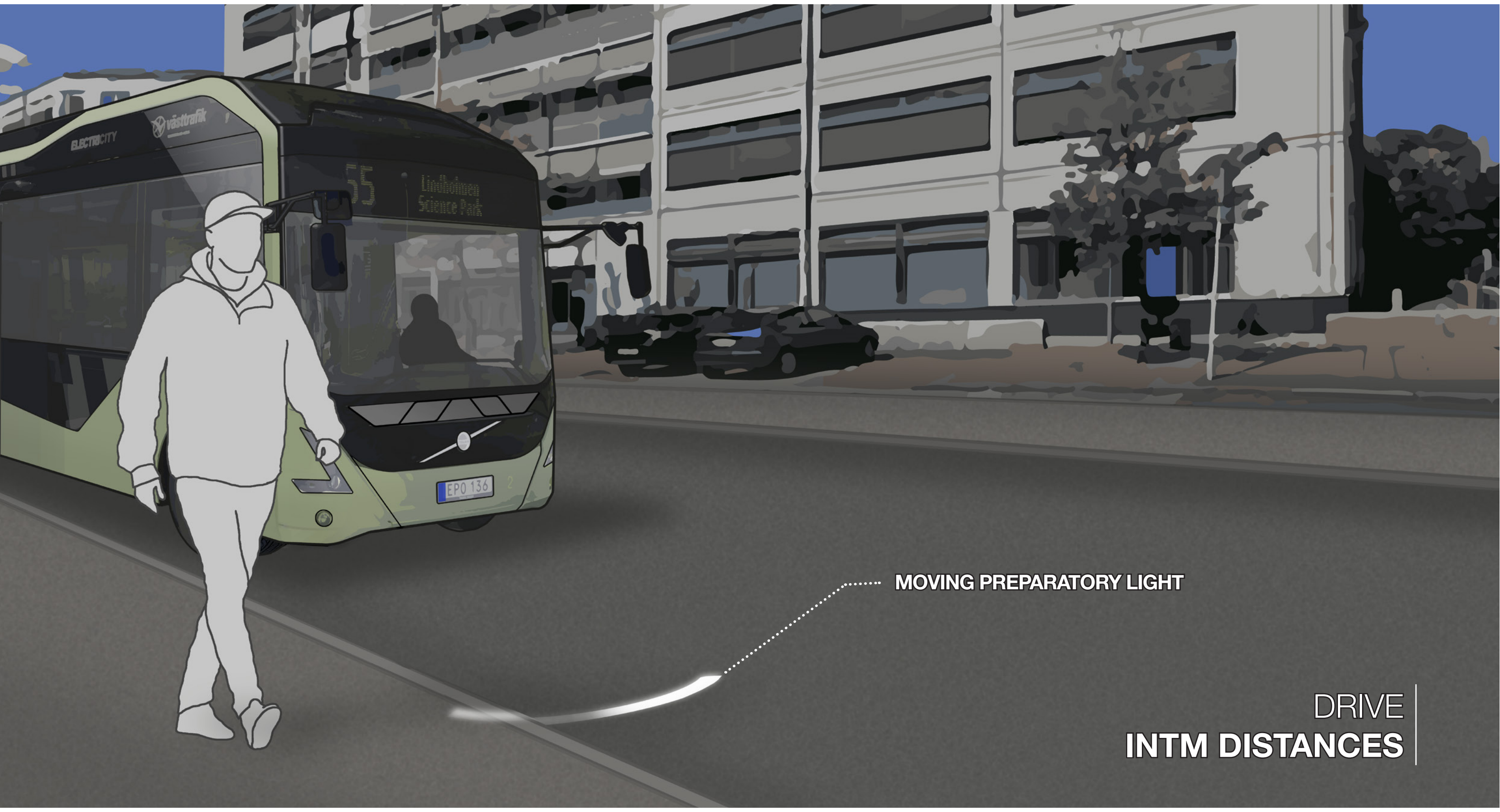
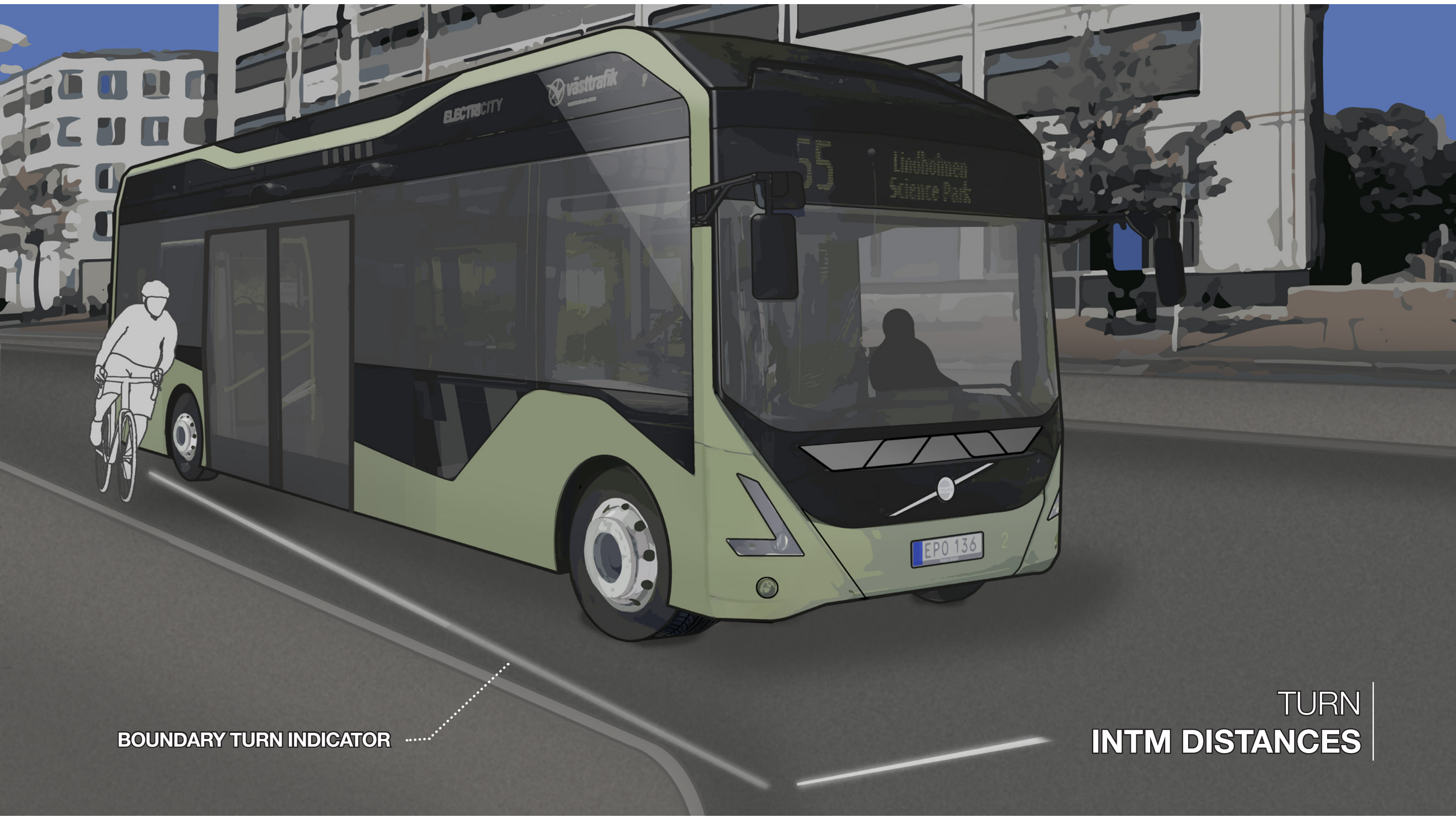


FIGURE 10.6 Preparatory light used during regular driving

FIGURE 10.7 Signals activated when turning



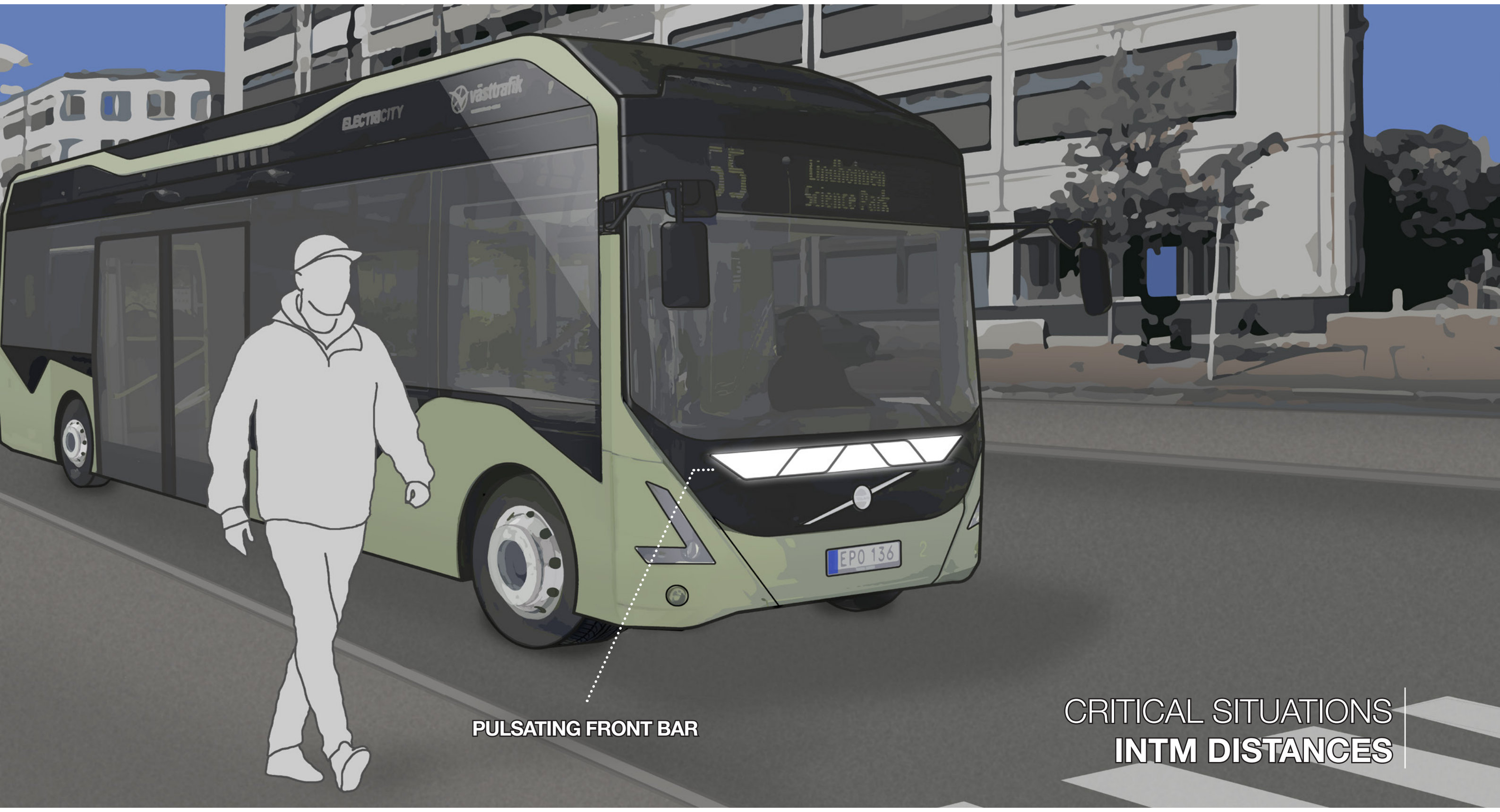


FIGURE 10.8 Signal indicating critical situations

FIGURE 10.9 Signal used to indicate speed at VRU crossings

FIGURE 10.10 Signal activated when VRUs pass behind an idle bus at bus stop

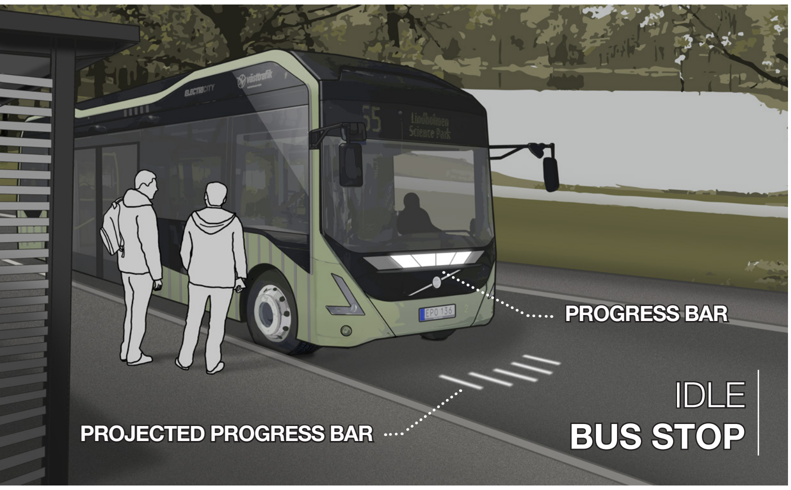


FIGURE 10.11 Signals when idle at bus stop

FIGURE 10.12 Signals on back of bus when idle at bus stop

CONCEPT 2 - PERPENDICULAR

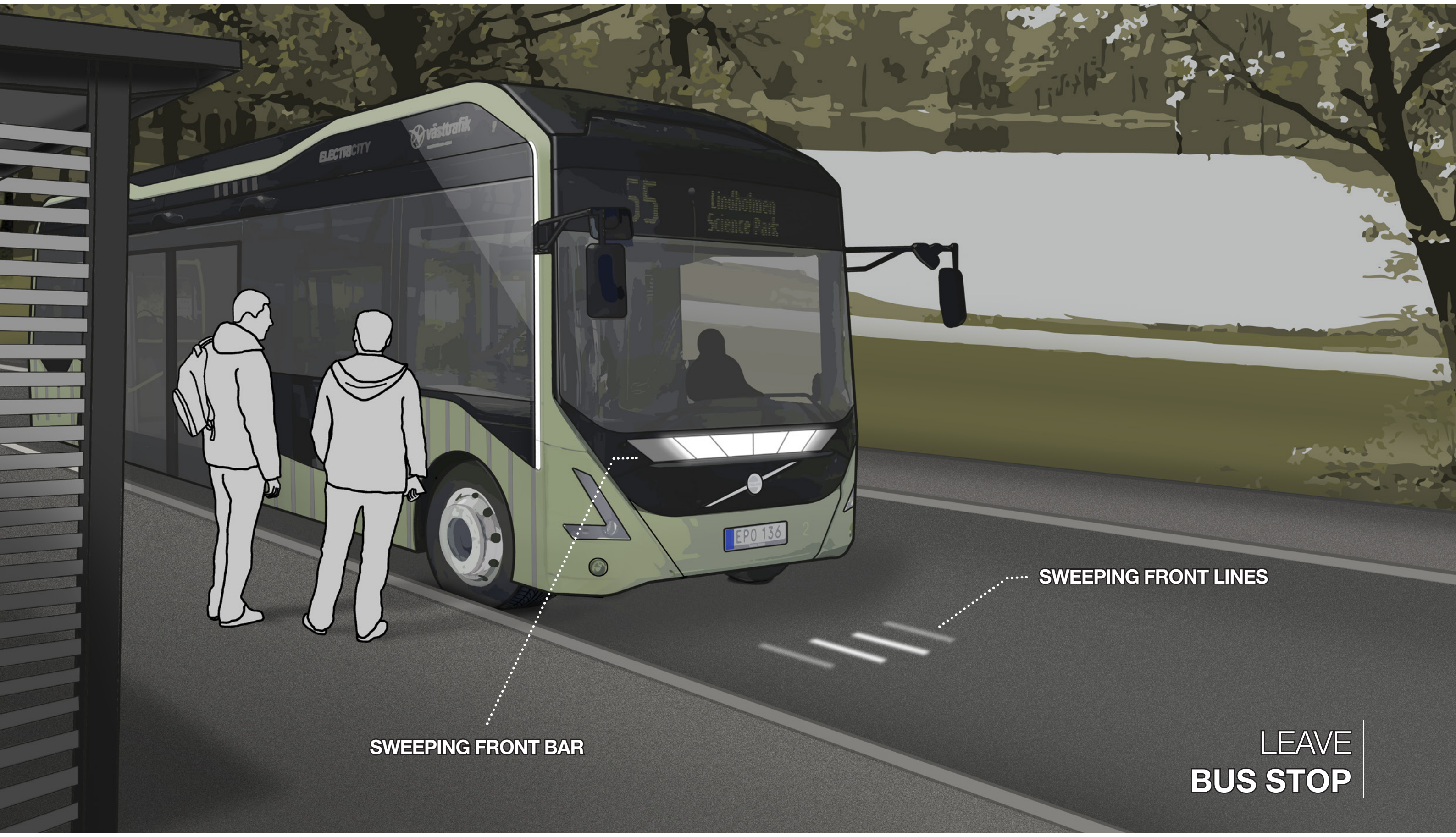


FIGURE 10.13 Given signals during departure from bus stop

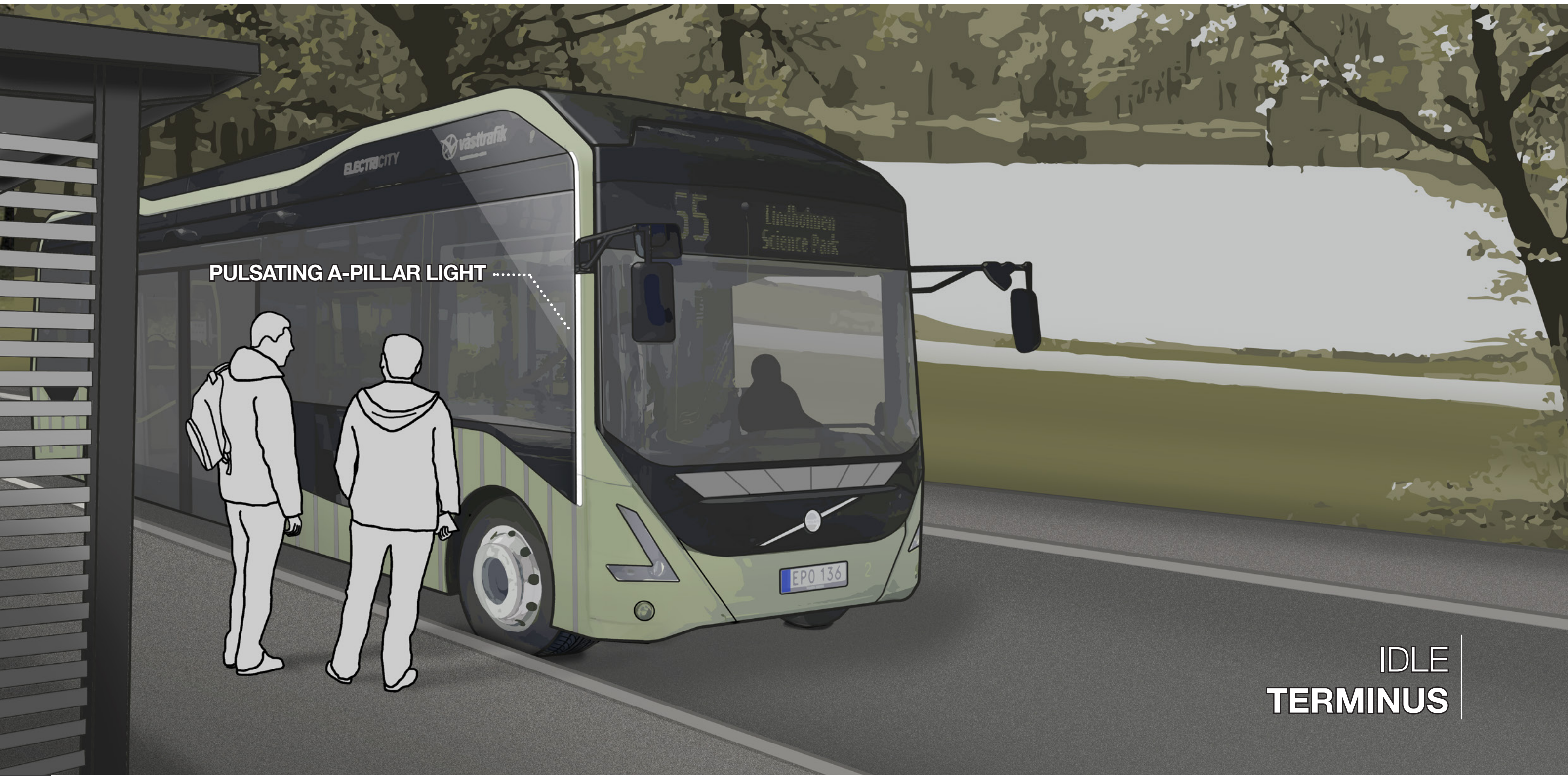


FIGURE 10.14 Signal presented when at terminus

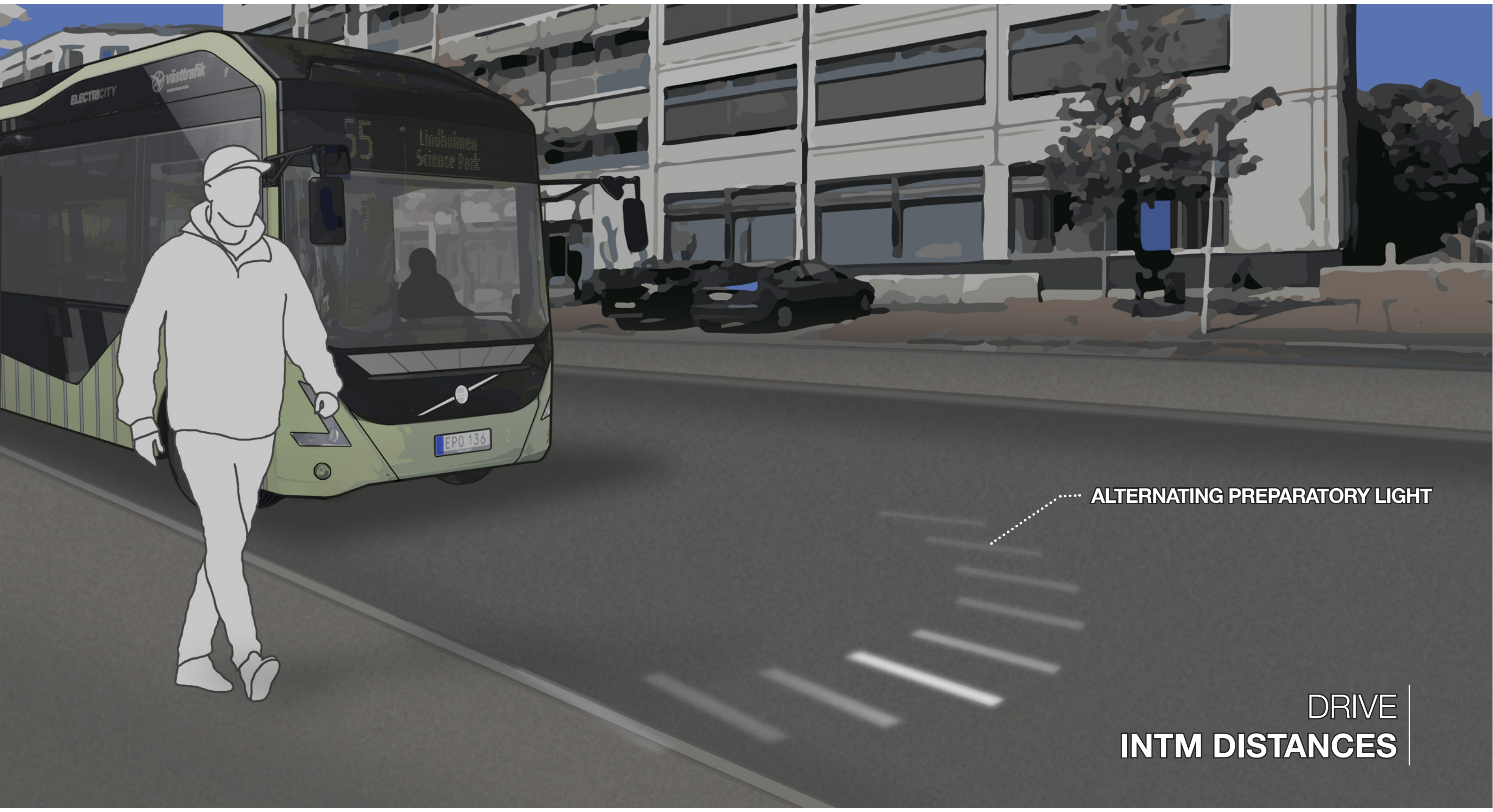
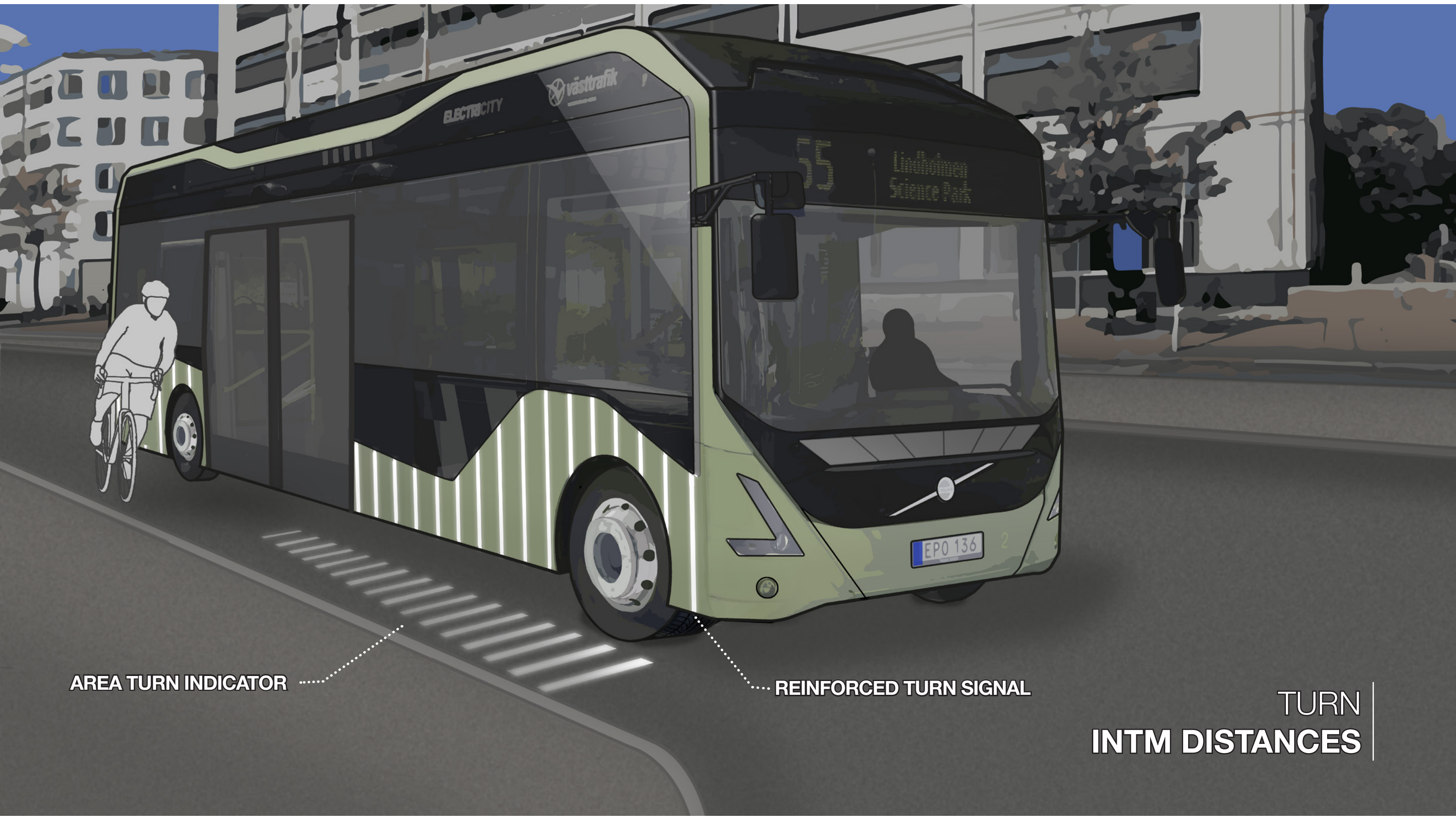


FIGURE 10.15 Preparatory light used during regular driving

FIGURE 10.16 Signals activated when turning



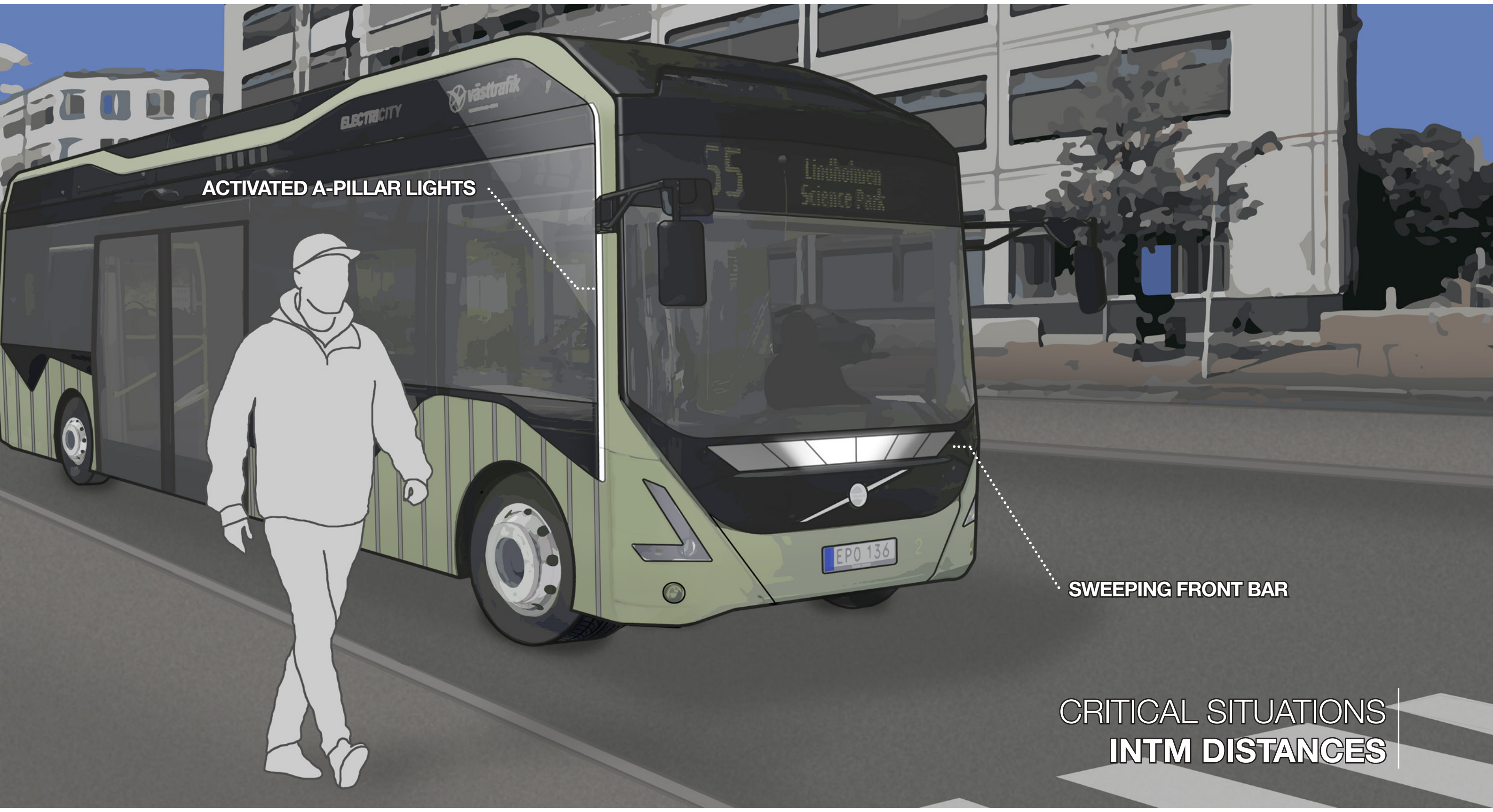


FIGURE 10.17 Signal indicating critical situations

FIGURE 10.18 Signal used to indicate speed at VRU crossings

10.3 USER TESTS

The user tests that were performed with VRUs revealed the positive and negative aspects within the different solutions as well as within the two concepts. These aspects are presented below together with the general opinions given about the concepts in whole. Each of the signals were evaluated in the order of the different stages of the bus, therefore the results are processed in the same order.

REAR STOP LINE

Regarding the rear stop line of the Perpendicular concept, eight of the participants interpreted the line to have the intended function. Some referred to the commonly used road marking of a solid line, which under regulation is not permitted to cross. Others simply stated that it intended to raise the pedestrian's awareness before he or she crossed the street, warning for oncoming traffic. Contrasting to the other participants, one individual perceived the line to indicate that the bus was going to reverse.

Nonetheless, all of the participants claimed to either carefully look before moving into the other lane or return to the sidewalk and let the bus leave the bus stop before crossing. The distinctness of the signal was also reflected in the semantic word scale where many rated the clarity high, and even more so on the feeling of safety.

In regards to the forcefulness of the signal, the participants were more divided and the average ended up slightly towards the guiding direction. A conclusion can therefore be drawn that the rear stop line is accepted by the VRUs, but might need to be reinforced to strengthen the clarity and forcefulness of the signal.

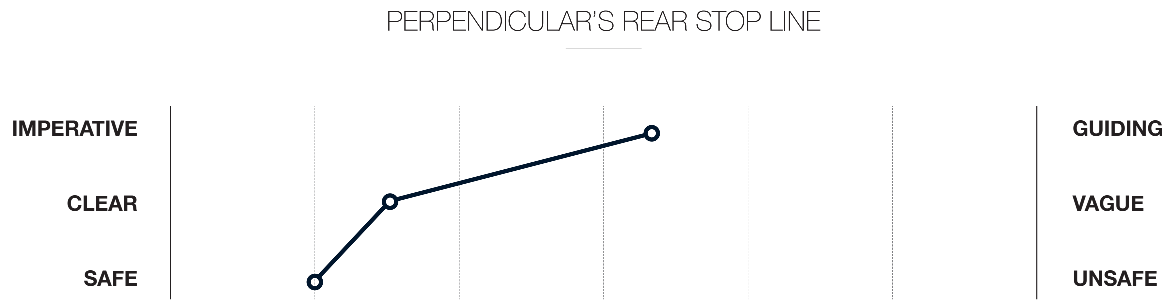


FIGURE 10.19 Diagram of the result from evaluation of Perpendicular's rear stop line

REPELLING FRONT AND SIDE LINES

When entering the bus stop, the Parallel concept signals to the surrounding VRUs to maintain a distance to the bus through light projections of repelling lines. This was understood by seven of the participants, who stated that it indicated that one was expected to step back and leave room for the bus to pass when it entered the bus stop.

The other two individuals connected the function to the unloading of passengers due to the lines projected along the side of the bus. However, the action taken was the same amongst all of the participants.

Furthermore, some added that the signal might surprise them if they had never seen it before, which was also the reason for them to lower the rate on the level of safety they experienced in relation to the signal. This was considered to be caused by the projected lines along the sides which intruded the personal space of the individuals at the bus stop.

However, the result still indicated that the signal was considered to be on the safer side, but should nevertheless be reconsidered in the development of the final concept. The participants were split on the forcefulness, making the average neutral.

Some considered the solid lines as a strong indicator to follow, whilst others thought of it more as a kind reminder to stay at a safe distance and let the bus pass. Regardless of the interpretation of the signal, a clear majority of the participants marked it to have great clarity in its purpose.

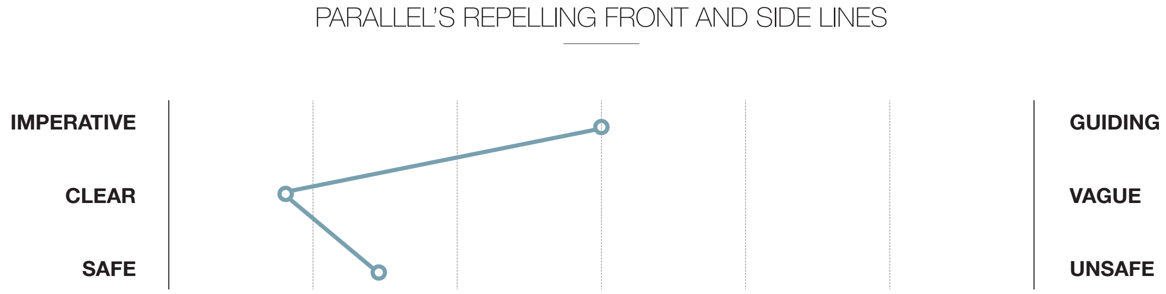


FIGURE 10.20 Diagram of the result from evaluation of Parallel's repelling front and side lines

PROGRESS BAR

When the bus is approaching its departure from the bus stop, both concepts are equipped with a progress bar which indicates the status of the bus. Parallel's progress bar, which only shows on the bus, was believed to display that the bus is preparing to leave, alternatively that it showed that the doors were closing. Both answers were close to the intended purpose of the solution. Similarly, certain participants said that is was a warning indicating that the bus was leaving the stop and therefore one should not pass in front of it.

Others interpreted the signal's meaning as a clarification that the bus was standing still or waiting at the bus stop. The semantic word scale indicated that the signal made them feel quite safe, and that the signal was equally clear in its function. In relation to the forcefulness, the signals were perceived as guiding by a majority of the participants which is appropriate with regards to its more informative purpose.

In the Perpendicular concept the progress bar was reinforced with projections on the ground, which confused some participants. They resembled the perpendicular projected lines to a crosswalk, meaning that one was allowed to pass in front of the bus. Five of the individuals believed the signal to mean that the bus was about to leave the bus stop, indicating that the VRUs should stay on the sidewalk. An individual interpreted the progress bar as a way of showing that the bus was standing still to load and unload passengers.

Many of the participants were unsure about their answer which was also reflected in the semantic word scale where the ratings were more divided, and the average was a bit lower in the levels of clarity and safety. Some rated the concept high on these scales, with confidence in their interpretation which unfortunately was not as it was intended. Similarly to the other scales, the level of forcefulness was divided resulting in an average slightly towards guiding. This indicated that the projections, especially those with an inherent dynamism, contributes to an interpretation that the signal is more forceful and imperative.

A conclusion that can be drawn from a comparison of the two concepts is that the projected lines of Perpendicular did not contribute positively to the understanding of the signal. With this being the main difference between the two, and the lower result on the scale, the added projected function did not have a positive response amongst the participants. For both of the concepts, the signal was considered to be guiding, but to lower the experienced forcefulness the design should be revised.

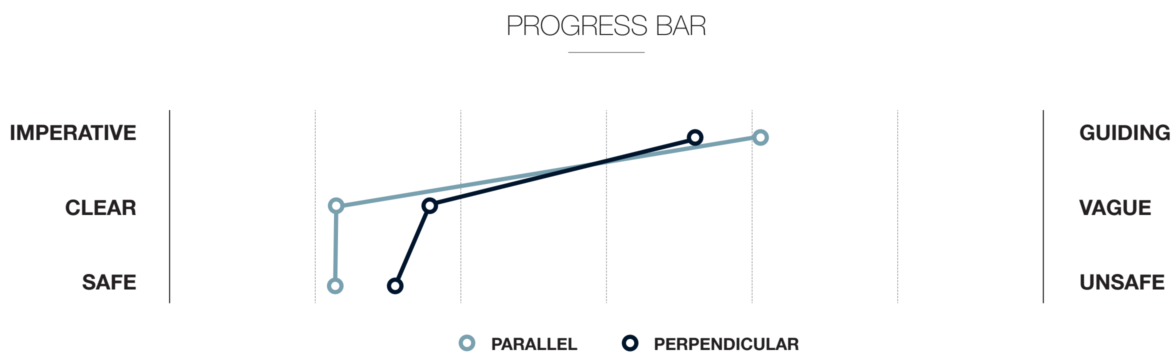


FIGURE 10.21 Diagram of the result from evaluation of the concepts' progress bars

DEPARTURE ALERT SIGNAL

A dynamic alert signal is activated when the bus starts to accelerate to leave the bus stop. The front repelling lines of the concept Parallel proved to have a clear function for eight of the nine participants. They stated that the signal indicated that the bus was about to leave the bus stop. Some adding that one should leave room for the bus, alternatively that the VRUs are meant to be attentive as the front of the bus will become a hazardous zone when the bus accelerates. One of the participants also explained that they perhaps would have crossed the street during the progress bar signal, had they been aware of this signal. Contrasting, one of the individuals interpreted the signal to mean that the bus was standing still.

The semantic word scale showed that the emotional response to the signal was significantly leaning towards the safe side. An even higher rating was reached on the level of clarity, indicating that the signal had an evident purpose to the participants. Regarding the forcefulness, the participants marked it in a varied fashion where some viewed it as imperative whereas others turned more towards the guiding side. These responses demonstrate that the forcefulness of the signal could be reinforced as it is intended for use in rather critical situations.

In the Perpendicular concept, the dynamic alert signal was bestowed with a sweeping motion on the lines that were activated during the previous step. Similarly to the Parallel concept, the signal was interpreted to indicate that the bus was about to leave the bus stop, and that it was appropriate to let it pass before crossing the street. The individuals that had interpreted the projected lines of the progress bar as a crosswalk, remained on the same track and described the signal as the time to cross was over and that is one is no longer allowed to pass closely in front of the bus. The crosswalk was moved forward, which was said to reflect the safe distance to pass.

Nevertheless, all of the participants had the same conclusion that it is not permitted to walk in front of the bus. Many of the participants did not notice the A-pillar light that was placed on the side of the bus, which indicates that a stronger signal is needed to warn the pedestrians to not hug the corner of the bus when passing it. The experience of the signal was marked by the participants as relatively safe but the clarity varied. Some rated it as vague whereas others considered it to be very distinct, leading to an average more on the side of clarity. The forcefulness was almost neutral, with highly varied answers, suggesting that the signal needs to be displayed in a more urgent manner to reflect the severity of the situation that could occur.

When comparing the concepts, the semantic word scale proved to favour the Parallel concept on the levels of clarity as well as safety. However, the Perpendicular concept was experienced as slightly more imperative, which is desired as the signal is intended for more critical situations. As none of the signals was rated high in this area, both concepts require further work to reinforce the forcefulness.

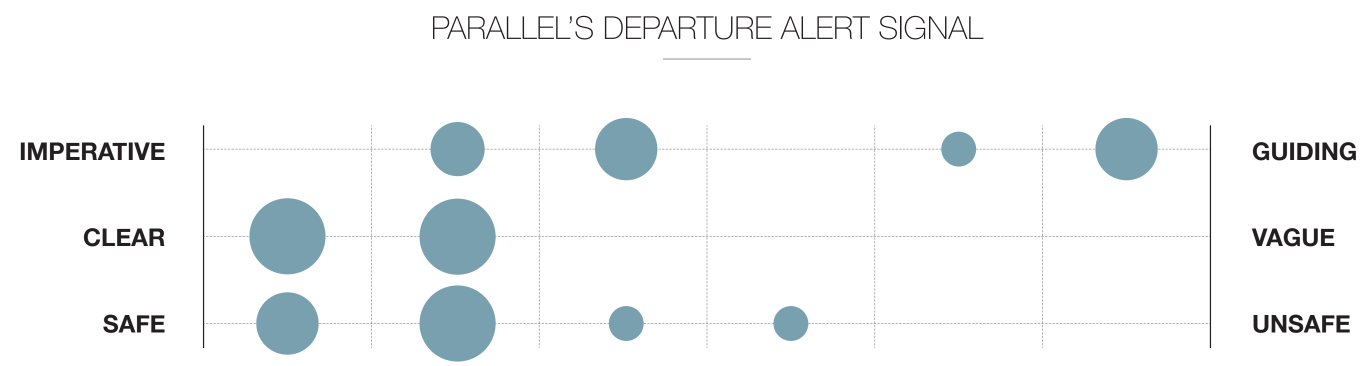


FIGURE 10.22 Diagram of the spread of answers from evaluation of the Parallel's departure alert signal

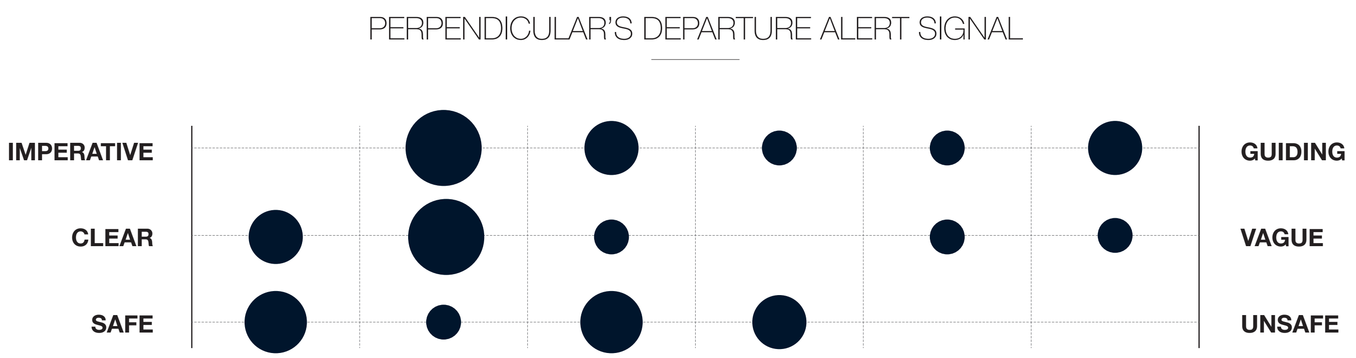


FIGURE 10.23 Diagram of the spread of answers from evaluation of the Perpendicular's departure alert signal

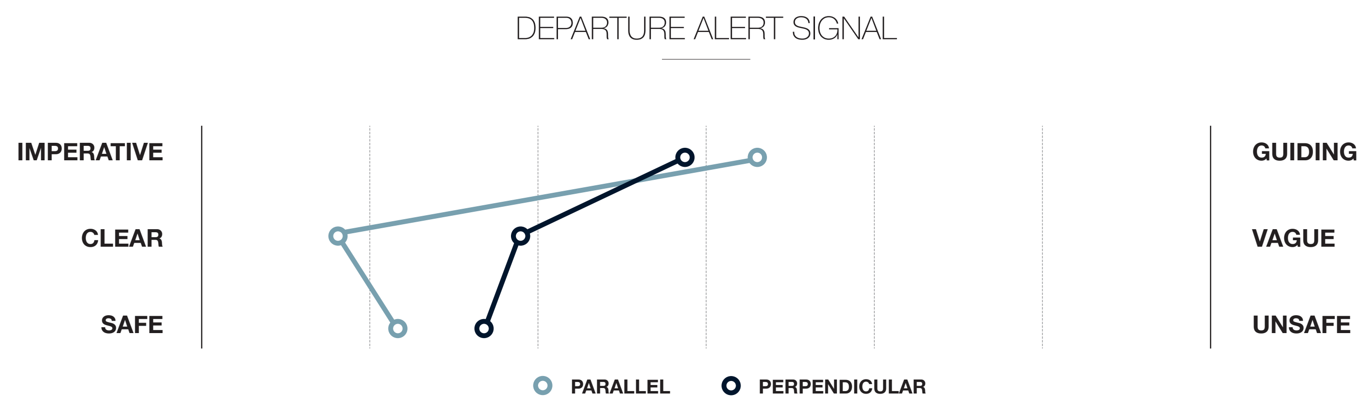


FIGURE 10.24 Diagram of the results from evaluation of the concepts' departure alert signal

TERMINUS DEPARTURE SIGNAL

At the terminus a signal is given in order to, from afar, inform potential passengers that the bus is soon leaving. The Parallel concept's pulsating top strand was difficult for many of the participants to interpret. Some speculated that it indicated that the bus was in a waiting state or possibly charging in the case of an electric bus. Others were on the fence if it meant that the bus was about to leave, or that it was clear to board the bus.

Two of the participants stated that the signal related to the bus's impending departure from the terminus and expressed a need for them to hurry up in order to make it to the bus in time. In the semantic word scale the participants rated the signal to be guiding and safe due to the less urgent qualities of the light. However, the results of the clarity showed a spread amongst the participants and the average barely reached the clear side of the scale. This indicated that the signal has a low level of guessability and needs to be altered in order for its purpose to be understood by VRUs.

Perpendicular was provided with A-pillar lights which pulsated to indicate the impending departure of the bus. Due to the placement of the lights, many of the participants interpreted the signal as something related to the doors and therefore stated that it meant that it was time to board the bus. Some added that one needs to enter the bus soon as it was about to leave. Similarly to the Parallel concept, some connected the slow pulse to a signal for a waiting or charging state of the bus.

One of the participants thought it resembled giant blinkers but was unsure of its purpose. An additional two individuals were unsure of the signal's function and were unable to guess. This was also reflected in the semantic word scale where many participants rated it as slightly vague. However, due to the slow pulsating the signal was interpreted as very guiding and safe, being mainly considered to be informative and not reflecting any urgence.

Both concepts proved to cause confusion amongst the participants. The signal was hard to interpret regardless of the placement and form of the light source, which indicates that the level of guessability is low. Although the Perpendicular concept showed greater potential with regards to the response of the participants, the semantic word scale suggested otherwise with low rating on the clarity of the signal. The overall result proved that the design of the signal was not sufficient and therefore needs to be completely reconsidered.

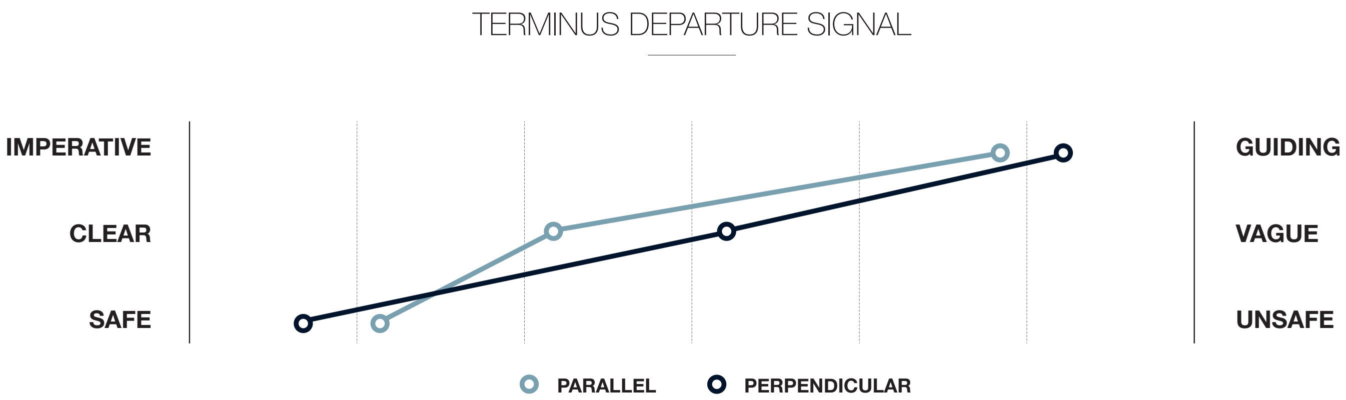


FIGURE 10.25 Diagram of the results from evaluation of the concepts' terminus departure signal

PREPARATORY LIGHT

When the bus is in a driving state, a preparatory light is intended to function as an early indication for VRUs of the approaching bus. In the Parallel concept, this function seemed hard to interpret for the participants, where many expressed a lack of clarity and a subsequent feeling of confusion. Many contemplated whether it signaled that the bus was going to turn following the movement of the moving line, alternatively leave a bus stop. Others saw two different options, either the bus driver wanted to clear the area in front of the bus or it indicated that it would yield and let VRUs pass. Which one of these was more likely, they did not know and added that another sign of clearance would be needed for them to cross the road in that situation.

Three of the participants were more in line with the intended function of the signal, stating that it was a premonition of the approaching bus and that you should not cross the street between the projection and the bus. Nevertheless, all of the participants marked the signal to be safe. The level of clarity was also marked as high, however since the answers varied the results have to be assessed with care. Similarly to the informative function of the signal, the participants rated the signal as guiding. With the variation of interpretations, the signal has to be considered in its appearance and qualities.

The Perpendicular concept's preparatory light separated the participants in their interpretations. About half of the participants described that signal as intended, that it indicated the approach of the bus and signaled that one should not do something unexpected in the vicinity of the bus. One added that it would be appropriate to use on narrow streets, like Vasastan in Gothenburg. Similarly, there was one individual that interpreted it as the bus was scanning the street to make sure that it would not hit someone. The movement of the signal lead some of the participants to think that it showed the driver's intention to turn or leave a bus stop, one exclaiming that the bus could not possibly do that all the time while driving.

Some were confused about the purpose of the signal and why it would signal when the pedestrian was walking on the sidewalk. This was reinforced in one individual who again referred to the signal as a crossing. With varying answers and some confusion, the semantic word scales showed a mixed result across the board. Due to this the clarity of the signal averaged in a relatively neutral location, likewise the safety level was varied but slightly on the safe side. The forcefulness was however more alike amongst the participants, where the average was leaning towards guiding. Similarly to the previous concept, the signal should be revised to have more distinct qualities that reflect the purpose of the signal.

For both of the concepts, the interpretation of the signal varied amongst the participants. As the movement of the light projection was believed to be an indication that the bus is about turn or leave a bus stop, this part of the signal should be reconsidered and altered. The semantic word scale indicated that the level of clarity and safety was viewed as higher in the Parallel concept, but due to the many deviating answers the result is considered to be misleading. With the responses in mind, the qualities and functionality of the signal should be revised to clarify the purpose and expected reaction to the signal.

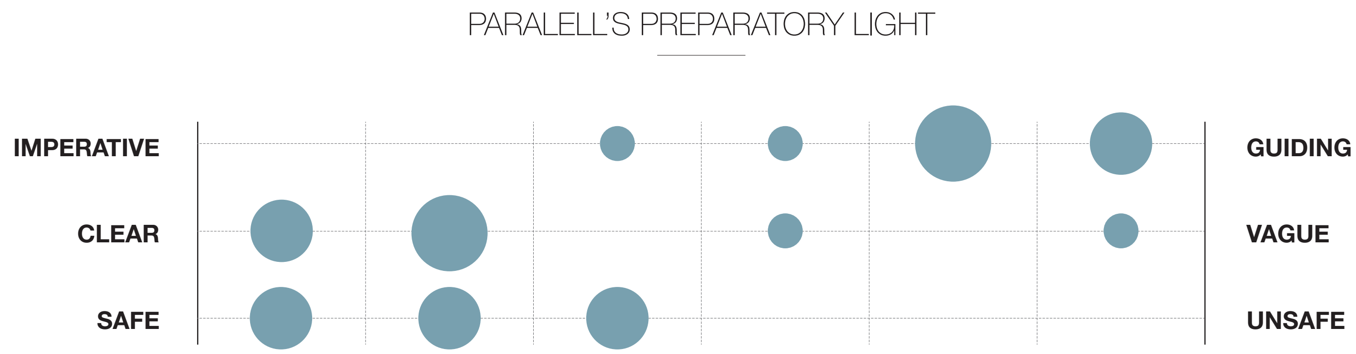


FIGURE 10.26 Diagram of the spread of answers from evaluation of the Parallel's preparatory light

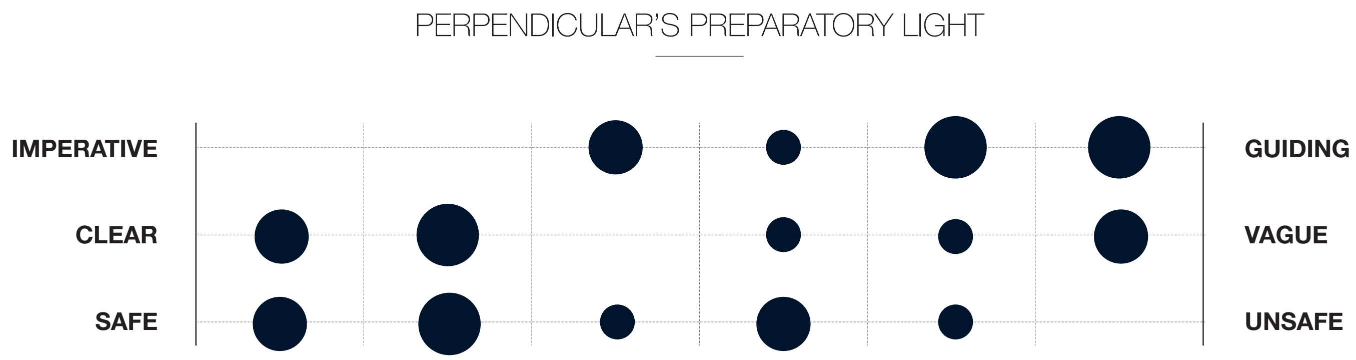


FIGURE 10.27 Diagram of the spread of answers from evaluation of the Perpendicular's preparatory light

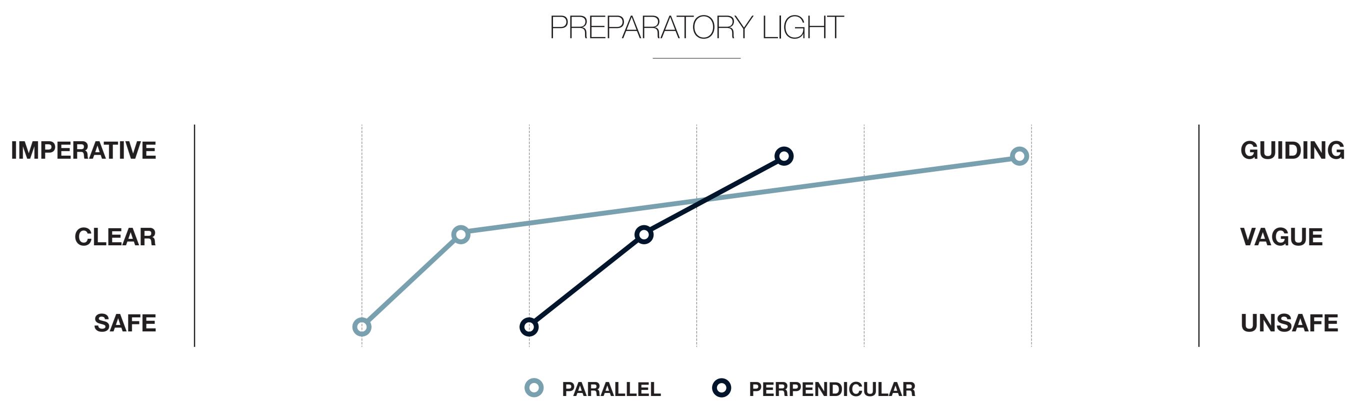


FIGURE 10.28 Diagram of the results from evaluation of the concepts' preparatory lights

TURN TRIANGLE

When the bus is about to turn, a signal is given, marking out the hazardous area on the side of the bus. The Parallel's boundary creating lines were clear to all of the pedestrians, who stated that it signaled that the bus is about to turn and that one should maintain a safe distance to the bus. Furthermore, some added that it displayed an oncoming collision path and reflected the decreasing space for the cyclist.

Many expressed an opinion that the front line of the triangle was especially effectful, having a clear connection to the function of a stop line. Some suggested that the signal perhaps should be reinforced by giving the triangle a similar appearance to blocked zones in traffic. The semantic word scale indicated that the level of safety and clarity was considered to be high amongst the participants. In contrast, the level of forcefulness varied and the average became almost neutral. As the signal is intended to be slightly more imperative, the qualities of the signal need to be altered to reinforce this aspect.

In the case of the Perpendicular concept, with a more emphasized area rather than boundaries, the participants were divided. Some praised the solution as a clear marking of the hazardous zone at turns whilst others interpreted it as the bus driver leaving way for the cyclist and that there was no intention for the bus to turn. The perpendicular lines were either perceived to be clear stop lines or some sort of crosswalk for the cyclist. Amongst the pedestrians, the experience of the signal was clear and safe. The forcefulness was more on the guiding side, suggesting that adjustments need to be made if the signal is to be more imperative towards the cyclists.

In a comparison, the two concepts have different advantages as well as disadvantages. The Parallel concept proved to have a greater clarity in its function since the projected lines were easily understood as a boundary by many of the participants. It was also considered to be more imperative, which is important due to the critical situations that can occur during a turn. Perpendicular was on the other hand believed to be more easily noticed, regardless of the contextual conditions. It was also stated that the lit area should be marked more clearly that it is a hazardous zone and not simply a restricted space. In theory, an optimal solution would therefore be reached when combining the positive elements of the two.

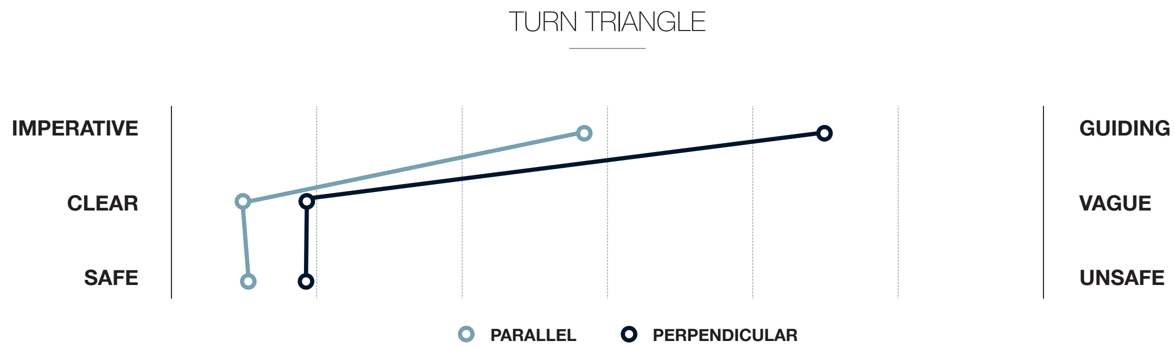


FIGURE 10.29 Diagram of the results from evaluation of the concepts' turn triangle

CRITICAL ALERT SIGNAL

The alert signal is intended to be activated in critical situations. The pulsating signal that is used in the Parallel concept was connected to this function by all of the participants. It stood clear that the pulsating light meant that they should be aware and return to the side walk. Some associated the light signal with other warning signals that they have experienced before such as train warning systems, warning blinkers on cars and the horn.

Certain VRUs also mentioned that the horn or a sound signal would have been more forceful and direct. The semantic word scale indicated that the level of safety and clarity was rated relatively high whereas the forcefulness was divided. On average, the rating became neutral. As the signal is designed to be used in a critical situation, it needs to be revised to be perceived as more imperative.

Regarding the sweeping motion of the Perpendicular concept, the answers of the participants were split. A majority considered the signal to be a warning directed towards them, but some were unsure regarding why it had a sweeping motion. These individuals claimed that it was the frequency of the motion that made them interpret it as an alert or warning.

Nevertheless, all of the participants understood that they were meant to move out of the way of the bus. For one of the individuals the signal was stressful but clearly marked that they were in a dangerous situation. The experience of the signal was considered to be very clear to the participants and also quite safe. However, the level of forcefulness was similar to the previous concept and should be altered to become more imperative.

The alert signal of the two concepts proved to be easily understood for the majority of the participants. In the semantic word scale the Perpendicular's sweeping motion was rated as more clear whereas the free interpretations indicated that the pulsating light of the Parallel concept seemed more easily understood.

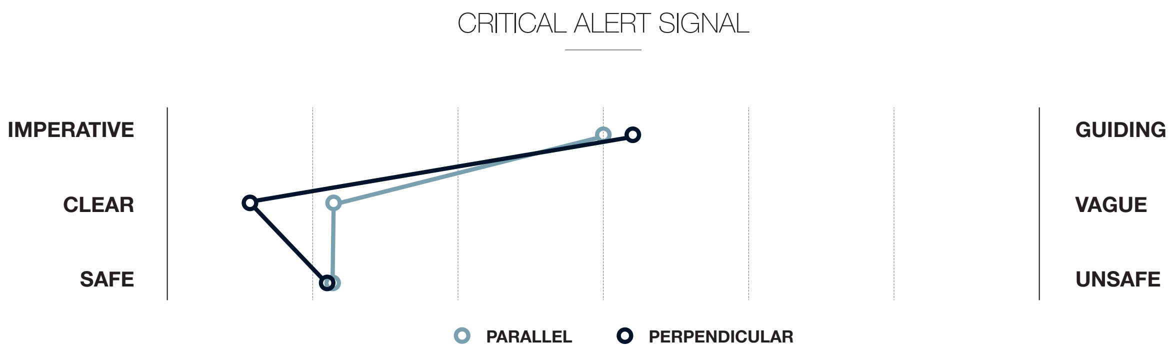


FIGURE 10.30 Diagram of the results from evaluation of the concepts' critical alert signal

DECELERATION SIGNAL

When the bus is approaching a VRU crossing, a signal is given to clarify for VRUs that the driver is going to leave way for them. In the Parallel concept, the interpretations were divided amongst the participants. Many saw it as a way for the bus driver to communicate that he was slowing down to let them pass but one individual was confused as to why the bus was signaling as it is supposed to stop. In contrast, one participant interpreted it as a warning to not cross the street. Another individual was on the fence between the two answers given.

This uncertainty was also reflected in the semantic word scale, where the level of clarity and safety was rated relatively low, yet on the positive side. The forcefulness was quite centred in the scale, resulting in an average around neutral but slightly on the guiding side. As the signal is more informative and affirmative, this must be considered in the final design.

For the variant of the signal used in the perpendicular concept, all of the pedestrians interpreted the signal as the bus intended to stop and yield for the VRU. Some were a bit unsure and claimed that they would wait until being fully confident in the fact that the bus would stop. Again, many saw the perpendicular lines as a crosswalk meaning that they could cross closer to the bus.

Additionally, many put emphasis on the altering shape of the line formation which in its reversed form clearly reflected the deceleration of the bus. This resulted in the experience of the signal being rated high on the clarity scale. Due to the functionality and qualities of the light, it was also considered to be safe by the participants. A majority also felt that the signal was more guiding in its forcefulness, which correlates well with the function of the light.

The two concepts shared many similarities in this signal, but this was not evident in the response of the participants. Many of the individuals interpreted the signals' function as they were intended, but the Perpendicular had the upper edge with regards to both the level of safety as well as of the clarity. The main difference between the concepts was the reversed formation of the Perpendicular concept, indicating that this element is a clear cue for the VRUs.

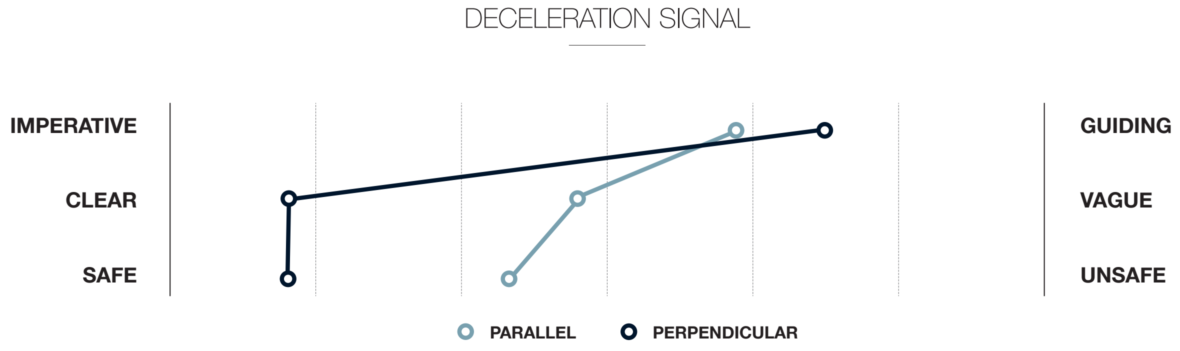


FIGURE 10.31 Diagram of the results from evaluation of the concepts' deceleration signal

ACCELERATION SIGNAL

As the bus is accelerating after stopping at a crosswalk, a signal is displayed to reflect the increased speed of the bus. All of the participants had a similar interpretation of the situation, that the bus was about start driving and that it was no longer safe to cross the street. Some added that the signal was doing the same thing as the bus, that is accelerating forwards. The answers were very alike for the perpendicular concept, with the exception of the reference to the crosswalk but the response and functionality remained the same.

The unison amongst the participants' view was also reflected in the semantic word scales, where both concepts received scores highly rated as safe and clear. However, the perpendicular concept was experienced as more guiding in comparison. With both signals having similar responses from the participants, the decision between the two is better to base on the preparatory light that is the foundation for this signal.

GENERAL OPINIONS

In general, the response to the light signals of the concept was positive amongst the participants. Some participants mentioned that there were a lot of signals to take in, where a similarity amongst them would be facilitating. A majority also stated that the signals would be more easily interpreted if they had seen them before and in the actual situation and environment.

One participant expressed an appreciation for the use of projections as it was believed to be a good call for attention, especially in combination with the lights on the bus, which was considered to be a better carrier of information. This was suggested to be further reinforced, making more information available on the bus. The movement of the projected lines was also discussed in a positive manner, where the motion reinforced the conveyed message and made it easier to notice.

Three of the individuals particularly mentioned the line usage in the concept Parallel, which many had strong associations to, due to the use of solid lines in traffic. It was considered to be more clear in many of the situations, with a distinct indication of the bus driver's intentions. Moreover, the rear stop line from Perpendicular was highlighted as very positive for many of the participants.

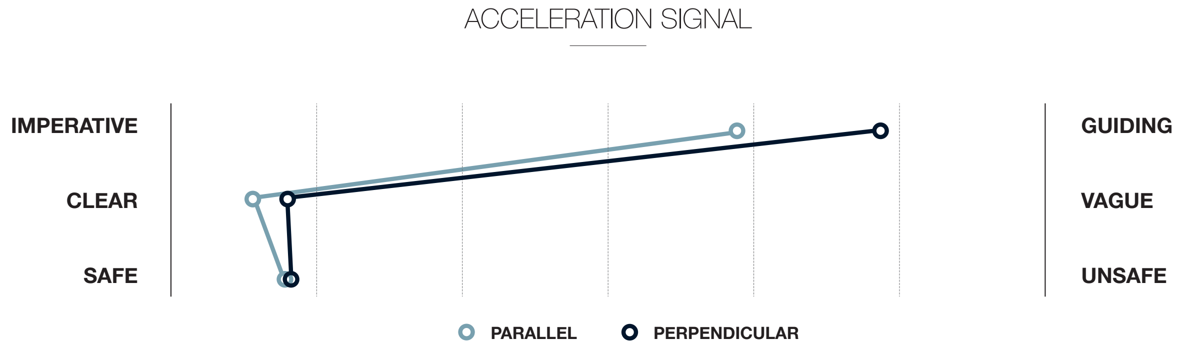


FIGURE 10.32 Diagram of the results from evaluation of the concepts' acceleration signal

10.4 EVALUATION WITH DRIVERS

In order to gain all possible perspectives on the concepts, the ideas were evaluated by bus drivers who operate the electric bus line. The results from these interviews are presented in categories relating to the situations and signals that the interviewees were introduced to, followed by a section describing general opinions expressed by the drivers.

REAR STOP LINE

The rear stop line was considered as very positive by all of the bus drivers. They recognized the issue with VRUs crossing the street as the bus obstructs their view, and some drivers claimed that they sometimes have to use the horn to warn VRUs of approaching vehicles. Therefore, they considered the purpose of the signal to be very important, and some added that the same signal should be activated on the front of the bus when someone crosses the street there. Furthermore, one driver stated that the signal should be combined with an auditory component in order to catch the attention of VRUs more easily. Another driver also requested the signal to be activated when the bus is going in reverse, as that is also a hazardous situation for VRUs behind the bus.

REPELLING FRONT AND SIDE LINES

The reception of this signal was overall positive, and most of the bus drivers saw a clear purpose with it, as they recognized the issue with crowded bus stops and VRUs coming too close to the bus. A few drivers compared the idea of the signal to the warning signals that accompany approaching trams, which they considered a positive feature. However, one of the drivers mentioned that perhaps there should be a light signal on the bus instead, in order to clarify its meaning and increase its chance of being discovered.

PROGRESS BAR AND ALERT

Most of the drivers found the progress bar and dynamic alert signal for leaving bus stops to be useful and a good idea. However, one driver did not see a clear purpose with the signal, as there are currently cues for determining when the bus is about to leave, for example the sound of the doors closing. One driver also doubted the positive effect of the signal, stating that pedestrians will run in front of the bus anyway. Another driver considered the signal to be a good step in the modernization of vehicles, and yet another driver stressed the importance of helping VRUs in determining whether or not they can cross the street in front of the bus. This signal was therefore considered as a positive addition.

TERMINUS DEPARTURE SIGNAL

The interviewed bus drivers were somewhat more hesitant towards this signal, as they believed that it would be very difficult to interpret for potential passengers of the bus.

However, they did not rule out the possibility of people learning the meaning of the signal, but also suggested symbols as a mean of communication in this situation. Additionally, a few drivers did recognize the need for this type of signal, but were not sure of how it should be given.

PREPARATORY LIGHT

A majority of the bus drivers were quite doubtful as to whether the preparatory light signal would give the sought after effect, and one driver stated that the signal was a positive addition. One of the bus drivers believed that the signal would not be noticed on the ground as VRUs tend not to look there, while two of the drivers were worried that it might not make VRUs keep their distance to the bus. Instead, they feared that the signal would instill curiosity within the people passing by it and encourage them to follow the signal, thereby placing themselves in the path of the bus. This concern was the strongest regarding children in the traffic environment.

TURN TRIANGLE

The turn triangle was received well by a clear majority of the drivers, however, two of them believed that the projected triangle would not be noticed, as some bicyclists do not look down on the ground, and are absorbed in their thoughts. Due to these reasons, the two drivers thought that extra lights on the bus would be easier to notice, as a way of enhancing the turn signal.

One driver was also worried that the bicyclists might not understand the meaning of the signal. However, the remaining drivers saw it as a signal that can help catch the attention of the bicyclists. It was also stated by the drivers that it is an important issue to solve, as some bicyclists do not notice the current turn signals.

CRITICAL ALERT SIGNAL

Many of the drivers commented that the alert signal should be combined with a sound signal for the optimal effect, in the most critical situations. In these situations, one driver stated that he would like to have a more friendly sound signal than the horn signal. For less critical situations, however, the drivers came to the conclusion that the light signal can stand on its own. Furthermore, one driver stated that it was important that the light blinked fast in order to convey that there is a hazard. Another driver pointed out that the light signal might not contribute that much to a warning signal, since one sees the signal when one is looking towards the bus. Other drivers, however, said that it was good to have an alert signal that is visual and can complement the alert devices directed towards the drivers, in order to ease the burden on the bus drivers and share the responsibility for a safe traffic environment with the VRUs.

CROSSING SIGNALS

These signals rendered most of the bus drivers somewhat hesitant as to the effects of the projections on VRUs. One driver questioned whether the signals will be understood by VRUs, while another stated that it might be useful if they are looking towards the bus. Yet another driver claimed that the effect of the signals might differ between different VRUs; young individuals would not care about the signals, while older VRUs would follow the guidance given by them. The remaining drivers considered the signals to be good, interesting and having a clear function, and that the signals should be automated.

GENERAL OPINIONS

On a general level, it was found that the drivers did not believe that the signals would distract them when driving. However, a majority of the drivers were doubtful of whether the projected signals would be visible in daylight, which diverted their focus somewhat from the signal's functionality and effects in the context. Moreover, some drivers stressed the importance of utilizing an appropriate colour for alerts, as the signals were all white in the images, and they did not consider white to be the optimal choice. This because it was considered to be a neutral colour, that does not convey a warning.

Furthermore, some drivers stated that many of the signals could be combined with sound in order to catch the attention of VRUs. When it comes to the clarity of the signals, one driver stressed the importance of having easily and quickly discernible signals, and suggested the usage of symbols. This driver also voiced the opinion that there are so many signals that it demands a thorough instruction of their meaning.

Moreover, one driver stated that the most important and hazardous situation is when the bus is pulling over to the bus stop, as some passengers stand too close to the kerb. This driver also emphasized the risk of colliding with the side mirrors. Another driver claimed that he experiences bicyclists as the VRUs who are the most at risk of being hit by the bus, when they approach the bus along its side.

10.5 CONCLUSIONS

As this chapter showed, there are many directions one can take when developing a light communication system between buses and VRUs. Theoretical evaluations indicated that solutions within the categories of traditional lighting, section lighting and directed lighting have the greatest potential to alert and inform VRUs with regards to the status of the bus. By combining solutions within these, a complete concept can be generated that can tackle the different stages a bus faces during a route.

From an assessment of the complete concepts, a conclusion was drawn that there were five key features which together were the most suitable to constitute the communication system. These key features comprised of dynamic alert signals, progress bars, zone alerts, terminus departure signals and preparatory lights. User tests with VRUs and interviews with bus drivers concerning the two concepts based on these five features, revealed that the terminus signal was hard to perceive.

A more suitable solution is a more clear display of the departure times on the bus stop. Additionally, there is a timing issue due to the unreliability of the buses' actual departure caused by previous delays of the bus or lateness of the driver. Another alternative is to utilize the displays on the front and back of the bus to illustrate the time left in numbers.

The evaluation also indicated that the repelling lines and rear stop line were both effective signals. However, the repelling lines on the side of the bus proved to cause unnecessary stress and was believed to be a shock to some of the participating VRUs. Therefore, this signal needs to be further developed to create a safer experience amongst the VRUs.

From the participating VRUs' hesitant response to the preparatory light and the doubt of some of the bus drivers, it is concluded that the signal needs to be further developed. When presented with an explanation of the signal, both drivers and VRUs appreciated its functionality indicating that it is nevertheless valuable to keep. In similarity with the progress bar, the functionality needs to be reinforced to have a more clear connection to the status of the bus.

Regarding the dynamic alert signal, the difference in design between critical situations and the situation when the bus leaves the bus stop needs to be overviewed to create a coherence. Additionally, the clarity of the critical signal needs to be revised. This also needs to be considered with regards to the A-pillar light of the Perpendicular concept which went unnoticed by many of the participants.

Increasing the experienced urgency of the signal could have an effect on the response to the signal. As with many of the signals, the colour of the light needs to be considered in the development of the concept. The use of colour can reinforce the forcefulness of the signal as well as the level of clarity. Furthermore, the technical specification needs to be defined in order for the light qualities to match the requests from the VRUs and the bus drivers.

Due to the difference in opinions regarding the reinforced turn signal, the design of the triangle should be revised. Both concepts have beneficial aspects as well as negative elements, therefore a combination of the two would be an alternative to consider in the developme-nt of the final concepts. The clear boundaries and strong front line should be kept from the Parallel concept whereas the coverage of the Perpendicular concept should be brought forward. Additionally, as was brought up by the bus drivers, the signal might need to be reinforced for those not paying attention to what is happening on the ground in front of them.

11

CONCEPT DEVELOPMENT

In the following chapter the development of the final concept is described. The different possibilities within the concept are explored and discussed to highlight the decisionmaking process. Subsequently, it also encompasses the changes made in the different part solutions and deliberates on the technical construction of the light signals.

11.1 PROGRESS BAR

For the progress bar, the aspects that are necessary to consider involve the events which will trigger the illumination of the sections in it. For this, there are two main paths; either the sections light up when a specific amount of time has passed, or it is triggered by something occurring on the bus.

With a time set progress bar, the signal is less dependent on the procedure performed at bus stops, but it is also less likely to be correctly timed for a specific bus stop. This means that the signal could be given at the wrong time, which might undermine the reliability of the signal, leading to it being ignored by VRUs.

A signal connected to actions performed by the bus therefore seems like the more reasonable choice. This gives some alternatives for the triggering actions. It is essential that the actions are performed at every bus stop, and in the same order, so as to make sure that the signal is given correctly.

One alternative is therefore to connect it to the turn signals, but they are sometimes not activated at bus stops and the signals would be given very early and very late in the process, thereby not giving an even representation of the progress.

Another alternative is to connect it to the doors, as they are always opened when the bus has arrived at a bus stop, and closed a few seconds before the bus leaves. This alternative is also matched with cues that pedestrians claimed to currently use for determining the time of departure, as many individuals stated that they try to see whether the doors are open or not when approaching the bus.

Another aspect which needs to be considered is the visibility of the progress bar from afar and from the side of the bus. The centred placement on the front and back of the bus is clearly visible from closer distances, but not from the far left side of the bus.

From longer distances, the light sections could more easily be hidden behind other vehicles or crowds of people. At these distances it might also be more difficult to use other cues for determining the bus's status, making the progress bar an even more important source of information. However, at a long distance, the status of the bus is of less relevance as the chance of catching it in time is smaller, and it is therefore more relevant to receive an indication of when the bus is about to leave. This can be given through the use of the enhanced turn indicators which will activate when the bus leaves the bus stop.

11.2 DYNAMIC ALERT SIGNAL

As the stage where the bus is leaving the bus stop and the stage in which a VRU runs the risk of obstructing the bus's path differ from one another, one might easily conclude that the signals given in the situations should be dissimilar in order to match the scenario at hand. However, the situations have certain similarities that are highly relevant for the design of the signal. These similarities are that they should both signal acuteness, encourage the VRUs to give way for the bus, and catch their attention. This means that the signals could be the same and yet work effectively in both stages. Using the same signal for both situations also entails a consistency within the concepts which facilitates the interpretation of the signals.

Due to the slightly negative response to the signal from a few VRUs, where the projected side lines were considered to be intrusive, some alternation is needed. If the front lines were to cover parts of the sidewalk, these would instruct VRUs to move out of the way. The lines along the side therefore do not function as a way to avoid collisions with side mirrors or the bus itself. Additionally, as the front of the bus is the most critical, the projected side lines are considered to be excessive. Therefore, only the front repelling lines will be active when the bus approaches the bus stop.

Another aspect which needs to be considered is how the preparatory light interacts with the alert signal given in critical situations. In order to achieve the greatest effect of the alert signal, the alert light on the bus should be combined with a projected signal which further conveys the acuteness of the situation and catches the attention of VRUs. As previously stated, a dynamic aspect of the signal is advantageous for this purpose.

Therefore, one alternative would be to simply let the projected straight lines start pulsating intensely, and another would be to use the repelling lines from the dynamic alert signal at bus stops. The former would make a smooth transition from the preparatory light, which could be seen as both positive and negative, as it is aesthetically pleasing, but also perhaps less likely to be noticed when the alert signal is activated.

The repelling lines, on the other hand, create a far more noticeable transition from the preparatory light, and also achieve a consistency within the concept, as they are used to signal that the situation is acute when the leave bus stop signal is given. This is of course advantageous, as was found in the literature studies, and means that the signals will be easier to interpret and distinguish from each other.

As for the light signal emitted from the bus, the two previous concepts suggested two variants, namely the pulsating signal and the sweeping signal. Both of these had strengths in different areas. The sweeping signal indicates a direction towards the side of the bus, intended to encourage the VRUs to move away from the path of the bus. Regarding the pulsating signal, it is closely connected with other warning signals which often blink, making it very quick to interpret.

Furthermore, the user evaluation showed that the sweeping signal in the alert stage was considered somewhat more clear than the pulsating signal, but the sweeping signal was also seen as a bit more guiding. In a critical situation, it is more beneficial if the signal is more forceful, since it is very important that the VRUs give way for the bus. Moreover, in the stage for leaving the bus stop, the pulsating signal was considered a bit more clear, however, in this scenario it was accompanied by different projections, which makes a comparison less accurate. Therefore, the signals appear as quite equal.

However, when looking further into the qualitative data from the evaluations, a few participants claimed to be confused by the sweeping signal as it showed a direction of which they did not understand the purpose. In addition to this, when considering that the signal will be combined with the projected repelling lines which shows a clear direction forward away from the bus, the sweeping signal with a direction pointed towards the sides might only add to the confusion. It is hence more reasonable to use the pulsating signal.

As the pedestrians had a hard time noticing the A-pillar light placed on the front corner of the bus, the signal needs to be reinforced. By adding a dynamic feature to the light, not simply activating it when the bus is about to leave, the signal is more likely to be noticed. Therefore, the light is bestowed with a pulsating characteristic which activates in accordance with the pulsating front bar.

11.3 ZONE ALERTS

As two of the bus drivers stated, the projected triangle could perhaps be less noticeable if one is not looking down towards the ground. Therefore, a signal emitted from the bus which enhances the turn indicators used today would be beneficial. Previous concepts have suggested to place lights at a quite low position on the bus, either on the green section below the windows, or in the split line between the green and the black sections. However, these are quite far from being near the average eye level of VRUs, decreasing their chance of being noticed.

The lights should hence be placed further up, but as the windows are placed there, the alternatives are either to put a horizontal light strand above the windows, or vertical strands at the bars separating the windows. The placement above the windows might however be too high for being noticed easily, which leaves the vertical placement. This placement is advantageous, as the vertical A pillar strand at the front for the dynamic alert signal can also be used for indicating a turn. These strands are also in eye level for VRUs.

As the user tests showed that the two variants of the turn triangles had different pros and cons, some adjustments and compromises will have to be made for the final concept. The continuously drawn straight lines from the parallel concept seemed to indicate for the VRUs that one should not cross these lines. It was made clear that the area within the lines should be avoided. The perpendicular lines of the second concept, on the other hand, marked out the zone more visibly as it was almost filled and also created a pattern which is easier to see on uneven ground surfaces. However, the perpendicular lines were by some test participants interpreted as the markings of a VRU crossing, signalling that the bus would give way for the bicyclist.

Therefore, a combination of the two variants would probably be most beneficial. A clearly marked boundary created by projected straight lines will indicate where the bus will move when turning. Furthermore, a covered area within the outer lines will be more easily perceived and clearly signal that the zone is restricted.

There are two directions to take in the design, either to cover the full area in light or use lines to fill the zone. The use of lines drawn diagonally across the triangle can reinforce the connotations with road markings showing restricted zones. However, the use of lines are also heavily associated with crosswalks which is highly unsuitable for the purpose of the signal. Therefore, a fully covered triangle with marked out boundaries is considered to be the best option. As a reinforcement of the signal, a dynamic feature could be added.

Regarding the measurements of the projected triangle, the dimensions were tested in relation to the size of the bus (see figure 11.1 and 11.2). By using tape and measuring out the full length of the bus, different measurements of the projected area were tested and compared to the size of a bike. Additionally, this allowed the experience of the signal to be partly assessed in terms of the scale. Thereby it stood clear that the width of the outer lines must be considered to reinforce the boundary of the hazardous zone. Furthermore, it allowed the front area of the projection to be evaluated with regards to its dimension, proving insight into the size of the zone to avoid the blind spots of the bus.

Lastly, as the design of bus stops might vary with regards to how many lanes it has and whether it is passed by other vehicles, the turn signal might not always be used when the bus is leaving. At certain bus stops, there is only one lane meaning that other vehicles cannot overtake the bus, which renders the turn signal less relevant in the situation. Therefore, the projected turn triangle would not appear on the ground when the bus leaves a bus stop with only one lane, as the signal would be superfluous in the context.

FIGURE 11.1 Size test of turn triangle

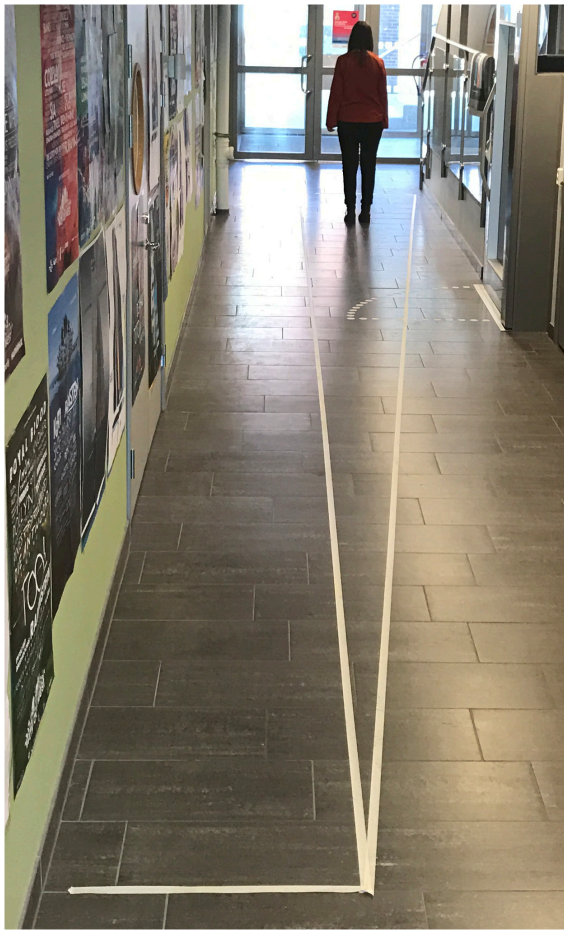


FIGURE 11.2 Turn triangle with size reference

11.4 PREPARATORY LIGHT

With the preparatory light, there are certain aspects which need to be considered and decided upon. Firstly, the projected light needs to be clearly originating from the bus in order to clarify from where the signal is coming and why. A possible solution to this is having two lines emitted from the corners of the bus straight ahead, like the idea direction markings from the first ideation phase. However, a con with this is that it is more challenging to combine it with other projections, such as the turn triangle, and make it discernible and not increase the risk of misunderstandings as to the meaning of the signals.

As previously stated the pros, on the other hand, is that it has a clear connection to the bus and as it is not a short line or a simple spot, it is less likely to be missed. The bigger area of the projections also generates the benefit of decreasing the negative impact of an uneven ground surface for the visibility of the projections.

In addition to this, as the projected light originates from two different sources with a distance between them, it is likely to have at least one line shining if the other is obstructed. It is also consistent with other road markings, where a continuous drawn line means that one should not cross it.

Furthermore, there is the tradeoff regarding the dynamics of the preparatory light. In both of the two previous concepts, the preparatory light was moving from side to side as the bus drove the intermediate distances. This was considered to be a way of increasing the likelihood of the projection being noticed by VRUs. However, the user evaluation showed that the side movement could be interpreted as if the bus would soon make a turn, or that the driver wanted to signal that VRUs could pass in front of it.

The many short lines in the perpendicular version could also be interpreted as a marked out pedestrian crossing, which could be very dangerous. It is also likely that a moving projection could distract the bus drivers as well as other drivers.

Therefore, a static pair of lines is the better option, meaning that the intended direction of the bus cannot be misinterpreted. As for the aim of making the signal stand out by moving, this will still be fulfilled as the projections move forwards when the bus does. This is believed to create a noticeable but yet collected impression, compared to the projections moving from side to side, indicating multiple directions.

Furthermore, the transition from the preparatory light to the repelling lines when the bus is pulling over to a bus stop also needs to be defined. As the lines are perpendicular to each other, the lines directed forward are not easily transformed into the repelling lines. Therefore, a transition where both signals to a certain extent exist simultaneously is probably the best solution. This means that the repelling lines will appear and push away the preparatory light lines, thereby deleting them and replacing them with the repelling lines.

At VRU crossings, a transition also needs to be made for the preparatory light in order to show the change of speed that the bus goes through. As the user evaluations showed that it was quite easy to interpret the projections coming closer to the bus as if the bus is decelerating, it is considered advantageous to keep this feature. However, what happens when the bus actually stops at the VRU crossing is less straightforward. For this situation, there are a number of alternatives.

Firstly, the lines of the preparatory light could become increasingly shorter with the deceleration until they are simply two small squares just in front of the bus when it has stopped. This would provide a clear transition from one stage to another, although the stage where the squares are in front of the bus might be difficult to interpret if one missed the lines transforming into the squares. Another alternative would be to let the lines become shorter and add a stop line for the bus between them in order to signal that the bus will not move and cross the line in front of it. However, this might also be difficult to interpret if one did not see the transition to it.

Yet another alternative would be that the lines of the preparatory light become shorter and then folds out towards the sides of the bus, thereby clearly indicating that the path is free in front of the bus. On the other hand, it might be unwise to give a specific signal that it is safe to cross, as the VRUs are still required to also scan the surroundings for approaching vehicles, and it could be hazardous to present a signal that they would trust blindly. The last, and strongest, alternative is that the lines simply fade out when the bus has come to a stop at a VRU crossing, in order to signal that the bus is temporarily inactive. The VRUs will hence receive an indication of the bus's status, but still be encouraged to check the surroundings themselves before crossing the road.

Regarding the continuous usage of the preparatory light, there are certain contexts where it will be unnecessary as it is directed only towards VRUs. Hence, in environments where VRUs are very unlikely to appear, the preparatory light can be off. Examples of these environments are large roads where motor traffic is separated from VRUs and where VRUs rarely cross.

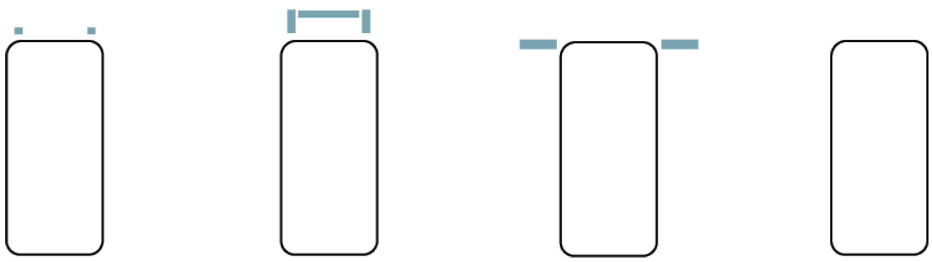


FIGURE 11.3 Different versions of preparatory light when idle at VRU crossing

11.5 TECHNICAL SPECIFICATIONS

The technical aspects of the final concept are also important to consider, as they affect the final result. In this section, the foundation for decisions regarding technical specifications will be presented. Firstly, light technology will be brought up, followed by the placement of the light fixtures. Thereafter, how the lights are activated and controlled will be described, and lastly, the reasoning behind the choice of colour for the signals will be described.

LIGHT TECHNOLOGY

The most reasonable light technology for the signals is LED technology in different variants, as it has a low energy consumption as well as a long lifespan, it is flexible and can come in many different variants. It is also a light and compact light source, which is advantageous for a vehicle when it comes to its energy consumption. Therefore, the progress bars and the vertical light strands should be constituted of regular and commonly used LED lights, as they fulfill the purpose and are relatively cheap.

However, the projections are more complex to create and require therefore more advanced LED lights in order to function as suggested. Hence, a solution similar to the digital lights created by Mercedes Benz described in chapter five, would be the optimal choice in order to achieve the sought after functions. The light contains over one million micromirrors per lamp, creating projected light on the road, making it possible to adjust each micromirror to change the brightness level of a specific point similar to a pixel in photographs. This enables the light source to direct light towards a certain point or project detailed images.

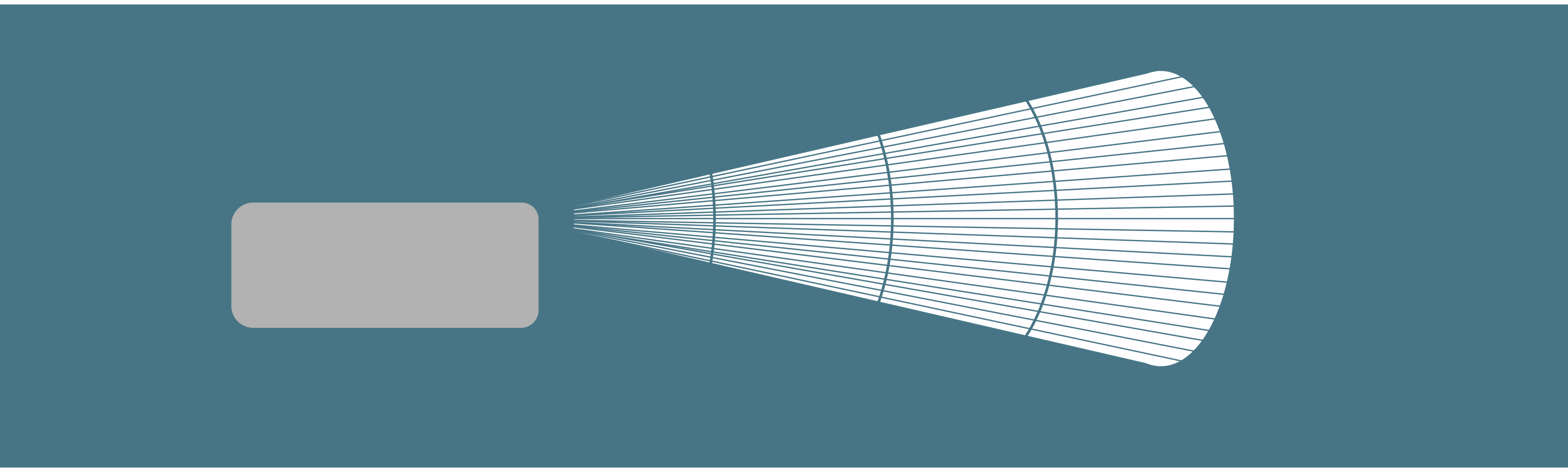


FIGURE 11.4 Illustration of LED projection functionality

These lights are of course more expensive, but as they are the light sources that are best suited for creating the projections, the functions are prioritized. Moreover, as these lights become more commonly applied, the cost is destined to decrease.

PLACEMENT

When it comes to the placement of the light sources, it is of course important that they are not positioned at a spot which creates a glare that reaches individuals around the bus. The lights which are the most likely to create glares are the ones generating the projections as they need to have a higher intensity, therefore, they must not be placed at a too high position. On the other hand, they should not be placed too low either, as that would limit the possible projection area. Furthermore, these lights should be shielded as much as possible in order to avoid a too wide spread outside of the relevant direction.

Moreover, it is important to minimize the number of light sources and group them together in order to optimize the number of components used. Through this, costs and energy consumption can be minimized, as well as environmental impact. It is also a matter of keeping the weight down, as that also affects the energy consumption of the bus. In addition, it is also advantageous for spatial aspects to use as few components as possible.

In some cases, different light signals can originate from the same light source or at least share certain components with each other. An example of the latter is the progress bar which can be grouped together with the light source creating the repelling lines in front of the bus. They can most likely share components for controlling the signals as well as providing them with electricity. The progress bar should only be visible on the bus, while the projections must be visible on the ground, which demands a much stronger lamp.

The light source creating the direction markings could similarly be incorporated in close relation to the headlights, as they are supposed to cover the same area in front of the bus. When it comes to the rear stop line, the projection device for it should be placed by the brake lights on the back of the bus, but the two different lights should not originate from the same source as their functions differ from each other. Lastly, the vertical light strands on the side of the bus are not possible to group with any projection sources on the side as they are placed quite high up, which the projection device should not be.

Additional lamps have to be added to create the triangle shaped projection that is activated when the bus is about to turn. To generate the correct light casts, the light sources are placed along the sides of the bus. The longer, front facing signal derives from a LED system placed in the rear of the bus. A light source is also placed in the middle of the front half of the bus to generate the smaller back facing triangle.

As the hybrid and the fully electric bus have different appearances, with three and one door respectively, the placement has to be considered. However, there is an area between the middle and front door of the hybrid and the front and only door of the electric bus which is shared by the two models. Therefore, this area is the suggested placement for the light source.

Regarding the available space on the bus, the front allows for a progress bar to be placed below the windshield and between the wiper attachments. This leaves an area of 150x1300 millimeters that can be used for mounting the light source. With this placement the progress bar would be located at a height of 1000 mm, meaning it would clearly be within the vertical field of view as this is approximately 134 degrees. On the back of the bus, the potential placement area covers a width of 1500x550 mm. The highest possible placement is a height of 1500 mm, which is sought after due to a greater visibility as it surpasses the height of most cars. Additionally, a higher placement also avoids the individuals in vehicles behind the bus being forced to look straight into the light.

CONTROL

Regarding the triggering factors of the signals, the different situations demand individual solutions. The turn triangle and the vertical light strands on the side of the bus work together with the turn indicators, and should therefore be activated when the turn indicators are switched on by the drivers. However, in certain situations, the turn triangle is quite superfluous, for example when the bus is pulling over or leaving a bus stop, without having to switch lanes. Therefore, a position system needs to be connected to the signal in order to keep it in its off mode at certain places even when the turn indicator is activated.

The same principle applies for the repelling lines which should be activated as the bus approaches a bus stop; the position system should activate the signal at the relevant places. Furthermore, during regular driving the preparatory light could also be controlled by this system in order to enable the direction markings to be in off mode in areas where they are not useful.

At crossings, however, the direction markings are regulated through the acceleration of the bus in order to reflect its speed. This means that the direction markings will follow the same pattern when slowing down or moving faster in areas where there are no crossings as well. As previously stated, the progress bars should be controlled by the status of the doors, while the pulsating signal should be triggered by the acceleration of the bus.

Lastly, the alert signal in critical situations could either be controlled by the drivers or automated with the help of future pedestrian detection systems. As of today, the most reasonable alternative is to let the drivers control the signal, as they do with the horn, since there is currently no fully established system for

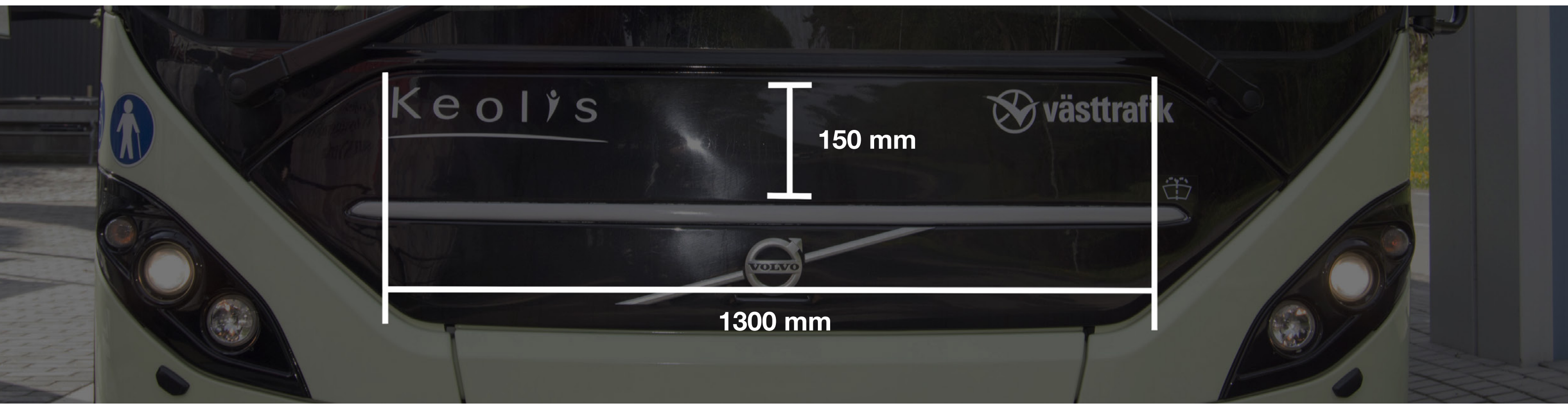


FIGURE 11.5 Measurements for progress bar at the front of the bus

pedestrian detection. However, in the future, an automated signal could be beneficial for both the drivers and the VRUs, as the workload for the drivers would decrease, while VRUs would always receive a signal when they are too close to the bus.

As many of the bus drivers mentioned in the interviews about the concepts, the visibility of the signals will decrease in strong daylight. To combat this issue the intensity of the light should be maximized in order for it to be perceived by the VRUs. However, when the environmental lighting becomes dimmer the signal must not cause glare to individuals in the surroundings. Therefore, the intensity of the light should be adapted according to the amount of daylight, with lower candela levels during the early and late hours of the day.

COLOUR

Regarding the colour usage for the signals, the alternatives that are currently legal to use on vehicles are quite few. Depending on the direction in which the light will shine, the options are white, orange, red and green. Green light is not suitable as it signals that everything is alright, and in a traffic context, that it is safe to cross the road. As there are no signals aiming to convey that message within the concept, green light should be avoided.

Furthermore, red light can only be emitted from the back of vehicles, meaning that the only signals that can be red are the back progress bar and the rear stop line. A red progress bar could be interpreted as a brake signal, which is the opposite of what it means. Therefore, red is ruled out. As for the rear stop line, red colour might be too much connected with an urging to stop, when the signal is only intended to encourage the VRUs to be careful and attentive when passing behind the bus. Therefore, the red light would perhaps make them stop and stand waiting behind the bus, which would not be safe either. White light, on the other hand, should only be emitted from the front, and does not carry a meaning as the other colours do. There is also a risk of confusing the projections with white road markings, which would only contribute to a less safe and more complex traffic environment. Hence, the best option is orange light, which is allowed to be emitted from all sides of the bus. Orange also has a clear connection to warning signals that is suitable for the projections and the lights on the bus.

This means that the progress bars will be orange. Although, the middle section of the progress bar should not be orange as that section is not intended to convey a warning. When only that section is illuminated, it is allowed to cross the street in front of the bus. Therefore, the middle section on the front bar will be white when it is the only illuminated section, and as the second part lights up, it will turn orange in order to be more easily interpreted. As it is a signal which one should be able to interpret quickly, the differently coloured illuminated blocks are less suitable as they might appear as though they carry a more complex meaning than they really are. The three sections together should signal that when all sections are activated, there is no time to cross the road. A monochrome bar is therefore easier to interpret quickly. Similarly, the A-pillar lights along the side of the bus would appropriately be provided with an orange colour. This to reinforce their function as emphasized blinkers, which commonly are orange.

11.6 CONCLUSIONS

This chapter described the reasoning behind the decisions regarding the final concept. A few parts were eliminated and others were adjusted, while some parts were found to work best when they remained as they were in the previous concepts. The function of the progress bar will be connected to the status of the bus doors, and the principle of the feature will remain the same. However, its aesthetic features need to be investigated and adjusted in order for it to match the rest of the exterior and at the same time clearly show the signal.

Furthermore, it was determined how the dynamic alert signal will interact with the preparatory light. A compromise was also reached for the turn triangle in order to include the positive features from both of the previous variants. Moreover, the preparatory light was redesigned into a solution resembling the older concept direction markings so as to fulfill all demands which were put on it.

These concept definitions thereafter lead to the technical specifications being made, amongst these were colour, placement and light technology. As this is a conceptual solution, these factors will of course have to be tested in models and prototypes, but currently seem to be the most reasonable choices. How these factors and parts of the concepts all fit together will be presented in the following chapter, where the concept will be summarized, explained and visualized.

12

FINAL DESIGN

This chapter describes and explains the final concept in its entirety. The final concept is a set of signals tailored for the different stages of the bus. The signals allocate a part of the responsibility to the VRUs by keeping them in the loop regarding the status of the bus in all situations, improving the possibility of a safe and smooth traffic flow. Firstly, the signals for each stage in the route of the bus is presented, followed by more detailed descriptions of the four key features the concept includes. After this specification, the effect the concept will have on the different stakeholders will be discussed, followed by an evaluation of the concept against the guidelines.

12.1 STAGES

This section describes the concept with the stages of the bus as points of reference, in order to place all signals in their true context. The stages are categorized under three headlines, namely bus stops, intermediate driving and VRU crossings.

BUS STOPS

As the bus is approaching the bus stop, a signal is emitted from the front of the bus in the form of projected lines. The lines move outwards one by one, as new lines appear along the ground at the front of the bus. This gives a clear indication to VRUs moving in the vicinity of the bus to maintain a distance to the bus as it approaches the bus stop. It alerts the VRUs of the collision path of the bus with regards to the side mirrors, the front corner and the bus as a whole. Subsequently, the bus also has a free passage to enter the bus stop, thus facilitating for the drivers to maintain their time schedule. Additionally, the need for the drivers to devote a great amount of attention to the individuals on the platform is reduced and the cognitive burden is therefore decreased.

FIGURE 12.1 Dynamic alert signal when approaching bus stop

The signal is intended to ensure the safety of the VRUs on the platform and emphasize the expected behaviour from them. This particularly directed towards individuals with a lack of attention to their surroundings, as well as those who wish to be considerate of the needs of the driver and those on the bus but is missing proper guidelines to follow. Additionally, with the signal's distinct indication, which marks out individuals in the wrong place to all VRUs in the surroundings, the nonchalant personas are targeted.

Foremost, the signal takes on the issues with VRUs occupying the space close to the kerb and running the risk of being hit by the bus or the side mirrors. Due to the visual aspect of the signal, the problems with missed warnings are also decreased, facilitating for individuals with hearing impairments as well as for those using headphones. Similarly, the moving repelling lines projected on the ground can alert VRUs that are preoccupied by their cell phones and therefore tackle some of the problems caused by personal distractions. It also functions as a way of breaking up crowds that cross the street in front of the approaching bus, not letting it enter the bus stop.

When the bus is idle at the bus stop, the projections from the front are inactivated. As the doors open for boarding and disembarking, progress bars on the front and back of the bus are instead activated. The bars light up step by step, from the middle and moving outward, to display the status of the bus and the procedure it is performing. By providing this information, VRUs in the vicinity of the bus have a foundation for making better decisions with regards to the state of the bus. This especially for the individuals who seek information before making their decisions, namely, the personas defined as the Hesitant and the Considerate. Similarly, the Risk Taker would also be assisted with more guidance to compare the gains to the potential consequences.

FIGURE 12.2 Progress bar when idle at bus stop with open doors

FIGURE 12.3 Progress bar when idle at bus stop with doors closing

FIGURE 12.4 Progress bar when idle at bus stop with doors closed

The first section is lit, indicating that the bus has opened the doors. In this stage, there is a chance for the individuals who want to board the bus to pass in front of it and likewise for those who simply want to cross the street. As the doors are about to close and the second level of light is activated on the progress bar, the VRUs are made aware of the fact that there is no longer a window of time to make the bus. The VRUs are therefore provided with information that can prevent them from exposing themselves to unnecessary risks. With the last set of lights being lit and the final step having been performed at the bus stop, the surroundings are notified that the bus's procedure at the bus stop is completed.

The signal is targeted towards individuals seeking to make it to the bus from the opposite side of the street as well as people simply wanting to cross in front of the bus. Beyond hindering them from passing before the bus at unsuitable times and informing them when they do have the time, the signal aims to prevent VRUs from following others before them and encourage them to instead attend to the information displayed on the bus. Thereby the signal can counteract the problem with individuals following groups, regardless of their surrounding preconditions.

Regarding the progress bar on the back, a different yet similar purpose is intended. By displaying the status of the bus to those behind it, better decisions can be made with regards to the overtaking of the bus. Bicyclists are more aware of the time slot that they have to pass a bus at the bus stop, and the signal can therefore assist in the assessment of whether to overtake the bus or not. Similarly, the rear progress bar can also support car drivers to make the same judgement call.

FIGURE 12.5 Progress bar when idle at bus stop with doors closed from rear view

FIGURE 12.6 Rear stop line activated when a pedestrian walks behind bus at bus stop

When the bus is idle at the bus stop, another signal is also emitted if a pedestrian moves behind the bus. A line is projected on the left side of the vehicle to alert the individuals and make them consider the decision they are making. It is intended to prevent VRUs from crossing the street and walk into oncoming traffic that is hidden behind the idle bus. As the signal is activated when the pedestrian is moving in close proximity to the bus's rear, the signal is meant to be more easily perceived and less likely to be ignored.

In addition to the external distraction that the bus constitutes in relation to the oncoming traffic, the signal tackles personal distractions such as the use of a mobile phone. This by enabling the signal to be noticed while looking down. Naturally, the signal targets the personas described as inattentive and also the Risk Taker. By giving the signal, the Risk Taker can be impeded in his or her actions and be slightly more cautionary when crossing.

To alert that the bus is leaving the bus stop a signal is emitted, indicating the bus's intention to accelerate and the need for VRUs to stay clear of its path. This signal is similar to the repelling lines used when approaching the bus stop, but is combined with a pulsating front bar. The repelling lines mark out the hazardous zone and indicate the direction of the bus, whereas the pulsating light is intended to reinforce the warning element and the sense of urgency. Together the two light types compose a clear indication that it is too late to make the bus or cross the street.

The signal's main purpose is to prevent people from rushing in front of the moving bus, but it also functions as a way of breaking up crowds in front of the bus. With the group mentality that exists amongst VRUs in traffic, the forcefulness of the signal can impose the pedestrians to reconsider their following behaviour. The Hesitant can therefore be assisted to be confident in their decision, and not simply

FIGURE 12.7 Dynamic alert signal when leaving bus stop

do as others do. Similarly, the Considerate are made aware of the driver's intentions and are ensured in their decision to wait for the passing bus. However, the signal's main purpose is to indicate the severity of the situation in order to target the Risk Takers in traffic. The urgency of the signal together with the visibility also makes it hard for the Nonchalant to ignore. As the projection is dynamic, the concept is also more likely to be noticed by the VRUs that are of the type Inattentive.

Whilst the dynamic alert signal is activated, A-pillar lights on the front corner of the bus are also turned on. These pulsate to alert the VRUs about the dangers of moving closely to the front corner of the bus. This as it is a blind spot and due to the fact that the bus is unable to stop with a very limited distance between the bus and the VRU. Thereby, the light can make VRUs take caution of the front corner and avoid hugging the corner of the bus when quickly crossing the street after disembarking.

Whilst the main target is the Risk Taker who is made aware of the danger through the signal, the Inattentive also has use in the signal as its pulsating quality draws attention.

In order to facilitate for the individuals approaching the bus from the side, the bus is provided with vertical lights along the side of the bus similar to the A-pillar lights. These are activated together with the turn signals, to reinforce the oncoming maneuver of the bus. Due to their visibility, the approaching VRUs receive a signal when there is no longer any chance to make the bus. Thereby, they will not have to hurry unnecessarily towards the bus which minimizes the risk taking behaviour. Beyond the Risk Taker, the signal also targets the Hesitant as more information is provided to confidently make decisions. Similarly, due to the light indications the Considerate will not have to assess his or her own needs in relation to others that will be forced to wait, as the bus has already signaled that it is too late.

INTERMEDIATE DISTANCES

As the bus proceeds to leave the bus stop, the repelling lines progress and evolve into a preparatory light in the form of direction markings. With the projected lines stretching out from the front of the bus, the signal alerts VRUs about the approach of the bus. The reach of the projected light enables the VRUs to be informed about the oncoming bus even with infrastructural obstructions such as narrow streets and corners. Similarly, the preparatory light functions as a way of alerting VRUs when the bus is hidden by other objects, for example traffic in the opposite direction.

The signal also has a purpose on calmer streets, where VRUs do not expect traffic, especially not a bus. As VRUs are paying less attention in these areas, the direction markings can reveal the approach of the bus. Thus, the driver does not have to use the horn as the signal alerts before a critical warning is needed, thus also facilitating for individuals with hearing impairments. There is neither a need for the bus driver to approach the VRUs slowly, waiting until the bus is finally noticed. In general, the signal calls for attention amongst inattentive individuals and is easier to notice for individuals looking down on their phone in traffic.

The lines in the driving state also has a function at VRU crossings. With its preparatory qualities, the projection can alert VRUs that are about to suddenly turn into the street. They are made aware of the approaching vehicle and have the opportunity to reassess the situation based on the speed of the bus. It provides an early alert to VRUs moving close to the path of the vehicle and enables a longer reaction time for the VRU to act on the approach of the bus.

FIGURE 12.8 Preparatory light during regular driving

To reinforce the maneuvering of the bus and mark out the dangers that follow, the bus is provided with a signal that highlights the hazardous zones that appear when a bus is turning. Mainly this is targeted towards bicyclists, moving next to or behind the bus, due to the risks connected to blind spots and overhang. The signal comprises of a triangle that is lit along the side of the bus as the driver activates the turn signals, illustrating the area which should be avoided. Similarly, a triangle is also projected on the opposite side of the bus, to warn for the rear overhang following a turn.

The triangles are marked out with solid lines, clearly marking out the boundary of the hazardous zone. In order to reinforce the perception of the signal, the area within the projected lines is covered. To raise further attention towards the signal, the covering light increases and decreases in intensity, thus creating a pulsating signal. Similarly to when the bus is leaving the bus stop, the turn signal is also reinforced by the vertical lights on the side of the bus. This is intended for the bicyclists that do not pay attention to the ground, as well as for use in strong environmental lighting. Both the vertical light and the projected triangle pulsate in pace with the turn signal.

The signal is intended to alert the VRUs when the bus is about to turn and potentially invade the space of their path. This either when exiting or entering a bus stop, alternatively during a lane change. Due to the nature of the situations, with a position where all types of individuals can end up, the signal is designed for all the defined personality traits. The signal is meant to support the Hesitant, to raise awareness for the Risk Taker, call for attention for the Inattentive, inform the Considerate and nudge the Nonchalant to change.

FIGURE 12.9 Turn triangle activated with turn indicator

FIGURE 12.10 Turn triangle activated to alert for rear overhang

If a critical situation would occur in the interaction between a VRU and the bus, a signal is emitted to alert the pedestrian or bicyclist of the danger. Due to the similarity in expected behaviour, the signal is identical to the one used when the bus is leaving a bus stop, with repelling lines and a pulsating front bar. The dynamism of the pulsating light and the moving lines is intended to catch the attention of the VRU and reflect the urgency of the situation. With the projected lines the movement of the bus is illustrated and as they cover an area in front of the bus, the hazardous zone can easily be identified.

As the personality traits often leading to critical situations comprise of risk taking behaviour, inattention and nonchalance; these were intended to be the targets of the signal. The signal has a clear connection to warnings, thus making the Risk Takers associate their actions with consequences.

Additionally, the signal is a call for attention to raise the awareness of the Inattentive. Lastly, the signal is intrusive in order to be less easy to ignore by the Nonchalant.

FIGURE 12.11 Critical alert signal alerting for the approach of the bus

VRU CROSSINGS

When the bus approaches a VRU crossing, the preparatory light previously described is altered in accordance to the new situation. To signal the driver's intention to yield for a pedestrian or cyclist, who is also approaching the crossing, the direction markings shorten towards the bus.

This reflects the deceleration of the bus and displays the increased possible stopping distance to the VRU, letting the VRU know that it is safe to pass. The VRU receives more cues to make a more informed and confident decision, whilst it also might eliminate the need for the bus to make a full stop. Thus time and energy is saved for both the VRU as well as the bus and its passengers.

With regards to the previously created scenarios, the signal can assist individuals having difficulties with interpreting the indirect signals of the driver for example due to a loss of sight. In general, it can support individuals with personal traits defined as hesitant to become more confident in their actions and provide them with a better experience. The signal can also be beneficial for those wanting to show consideration for others in traffic by enabling them to do the expected action sooner, thus catering to the needs of themselves and others.

If the bus reaches a full stop, the lines are fully turned off to indicate the bus's temporarily inactive state. Thereby, the VRUs can be ensured that the bus will stand still until they have passed the crossing.

FIGURE 12.12 Preparatory light adapting to the deceleration of the bus

FIGURE 12.13 Preparatory light adapting to the acceleration of the bus

When the VRUs have made their way to the other side of the street, the direction markings are yet again activated and elongated in accordance with the acceleration of the bus. This to indicate the bus's passage of the crossing, with the stretching solid lines of the preparatory line illustrating that it is no longer suitable to cross.

The signal targets individuals searching for information as to whether they can pass or not, namely, the Considerate, the Hesitant and the Risk Taker. Regarding these, the signal is intended to guide their decision making process and lead them to become confident in what behaviour is expected from their side.

However, the projected lines are also meant to affect the behaviour of the Inattentive and the Nonchalant. The first of the two by drawing attention to the bus through the dynamic projected lines, the later by giving a clear signal of the driver's intentions, making it harder to ignore.

Similarly to when the bus is approaching the crossing, the signal can assist individuals with visual impairments to interpret the intentions of the driver. It can also prevent individuals from running in front of a bus that is about to accelerate, either due to stress or simply because they are not paying attention due to personal or external distractions.

12.2 PROGRESS BAR

The function of the progress bar is intended mainly for those VRUs who look towards the bus in order to seek information and search for cues revealing the status of the bus. Therefore, it is placed at a central position where it is easy to spot. The fact that the sections light up outwards from the centred symmetry line entails that the bar is not imbalanced in one direction, and it is easily interpreted from all perspectives. It also facilitates determining how many sections remain to become illuminated.

Regarding the visual features, the strong diagonal lines on the bus are reflected in the progress bar, making it harmonize with the aesthetics of the bus. The visual features of the bar are nevertheless simple in order to preserve its discernibility, as it should be possible to interpret it quickly. This quality is also enhanced by the different sizes of the sections, which create a greater difference between the phases. On a more technical level, the sections are integrated in the bus's electrical system, enabling the progress bar to be connected to the doors of the bus. The middle section lights up as the doors are opened, while the next one is illuminated when the doors start to close. Thereafter, a few seconds later when the doors are closed entirely, the outer sections light up, giving a clear signal of the bus's status.

Due to the versatility and low energy consumption, the sections are comprised of LED lights showing an orange or white colour. The middle section on the front bar is white when it is the only illuminated section, in order to signal that it is allowed to cross the street in front of the bus. When the other sections light up, the middle turns orange as well in order to convey the alert more clearly. Due to traffic regulations, the back progress bar is orange throughout the process. As the progress bar should cover a great width of the front of the bus, the upper edge is 1300 millimeters long. The height of the bar is 150 millimeters, covering the space between the windshield and the Volvo logotype.

FIGURE 12.14 Progress bar

12.3 DYNAMIC ALERT SIGNAL

In order to create a coherent city traffic, the buses of public transport should give a signal when they leave a bus stop, similarly to the trams. This way, VRUs can feel more secure, as they receive an update as to what the bus will do. It could also be helpful for VRUs with a partially impaired vision, as this signal is easier to spot than other cues.

When the bus starts to accelerate at a bus stop, the signal is therefore activated, emitting a light from the progress bar which pulsates with a five Hz frequency. This rather quick frequency clearly conveys that the signal is intended to be an alert, and the pulsating quality creates a consistency with conventional warning signals. The dynamic character also entails that it is easier to discover in the periphery. Due to the 10:1 ratio in luminous intensity for the light pulses, the signal is even easier to notice as proven by previous studies. The two light strands on the sides of the bus, reinforcing the signal, pulsate with the same frequency as the front bar and entails that the signal can reach VRUs on the sides of the bus as well.

Furthermore, the projections on the ground comprise of solid lines indicating that passage is not allowed, and increasing the chances of the signal being noticed by VRUs looking down at their phones. The signal is hence reinforced, as it utilizes both lights on the bus and projections.

The lines are also slightly curved and become wider farther away from the bus, showing clearly from where they originated. These projections reach out past the kerb, marking out the front corner of the bus and cover the area below the side mirrors. These factors make the signal forceful and convey urgency, which is necessary for an alert signal. As it is an alert, the colour of all elements is orange, establishing a consistency with other warning signals.

Since the signal should not be emitted for a longer time period than necessary, the signal is deactivated when the bus has reached a speed of five km/h, as this speed would imply that the bus's path is free. If the bus has to stop again before reaching this speed, the dynamic alert signal is turned off after five seconds.

The projected lines are also activated as the bus approaches a bus stop in order to encourage potential passengers to keep their distance to the bus. Since there could also be an issue with people crossing the road in connection with the bus stop, thereby hindering the bus from reaching its location for unloading and loading passengers, the signal should be activated a few meters before the beginning of the bus stop. This would convey to all VRUs that they should give way for the bus.

In critical situations, the alert signal that is given is identical to the one emitted when leaving bus stops, which creates a coherence within the concept and entails that there are fewer signals to learn the meaning of. The signal has two levels, since a sound component is required in the most critical situations.

As the driver can determine the most correctly whether a VRU is about to obstruct the path of the bus, this signal is activated by the driver, in similarity with the horn. In future applications, however, an automated activation could be advantageous as the pedestrian detection systems become even more exact.

FIGURE 12.15 Example of dynamic alert signal

12.4 ZONE ALERTS

The rear stop line is placed in line with the left side of the bus, placing the signal where it is relevant just before they would step into the street. In order to be clearly visible, it is two meters long and 150 millimeters wide. As it is an alert, it has an orange colour. This also signals that it is not a stop signal intended to indicate when it is safe to cross the road, but rather a reminder to be attentive when passing behind the bus. The device which emits the signal is placed together with the brake lights so that they can share components if possible. As the signal is activated when someone walks behind the bus, the device is controlled by a motion sensor.

When it comes to the turn triangle, it has solid orange lines for marking out the boundary and showing the zones exactly where they are, which makes it a very concrete signal. The solid lines also refer to restricted zones in traffic, making them easy to interpret, where the orange colour clarifies that they originate from the bus, avoiding confusion with the white permanent marks on the street. Moreover, the wider solid line at the front gives a clear indication that one should not cross it.

The line along the side of the bus should be 120 millimeters wide and end one meter from the front of the bus. At the front, the line should end 1200 millimeters from the side of the bus, and this front line should be 200 millimeters wide in order to be noticeable from a distance. The two devices required for creating the signals are placed on the sides of the bus at a low position in order to avoid causing glare. As they should not protrude from the bus, they are integrated in the body of the bus.

The projections are activated as the driver starts the turn signal, and the field within the lines is illuminated by an even light which pulsates with the blinkers, making the field easier to notice.

The signal is further reinforced by light strands on the sides of the bus, placed between the windows. Thereby, they are in the line of sight of the bicyclist and are also visible from a distance with their high placement. These strands pulsate with the frequency and colour of the turn signals, further connecting them to the blinkers.

12.5 PREPARATORY LIGHT

In order to make the approach of the bus more noticeable, for example when VRUs do not hear it, the preparatory light is projected in front of the bus. It is informative and guiding, rather than forceful, as the lines are projected with a steady and evenly shining light. From the fact that the lines start right below the front of the bus, it is clear that the signal is originating from the bus, and as it moves, the lines enhance its movement and clarify when it changes direction. Since the lines are always constant they are less likely to distract other drivers or VRUs. Furthermore, the position system of the bus ensures that the lines are not projected when the bus is in an area where VRUs are very unlikely to cross the road.

Due to the continuity of the lines, they are associated with traffic markings meaning that one should not cross them. Moreover, the lines are orange in order to avoid confusion with white road markings. The lines are twenty centimeters wide and six meters long so as to be easily noticeable. As the lines are supposed to be aligned with the sides of the bus, the projection device is positioned near the headlights, which also entails that the two light sources could share some components.

The alteration of the lines in connection to VRU crossings is controlled by the speed of the vehicle, with the lines becoming shorter when the speed decreases, and vice versa as the speed increases. Since the lines should not be too long, they will not become longer than six meters, a length that is reached at 40 km/h. This speed limit was chosen as, in city traffic, velocities below 40 km/h are the most relevant to be reflected in a projection, since the interaction with the bus often takes place at low speeds. The enhanced reflection of the bus speed makes it easier to come to a mutual agreement at VRU crossings, and should be considered as quite intuitive as the user evaluations showed that a great majority of the participants interpreted the signal correctly.

12.6 STAKEHOLDER IMPACT

The developed communication system is targeted towards increasing the safety of the pedestrians and bicyclists moving in the vicinity of the bus. Naturally, there is therefore a gain for these individuals in implementing the system. But there are also other parties that can find the light communication system beneficial.

Volvo Buses, the developer of the solution, could use the potential of a vehicle to pedestrian communication system to further establish their leading role in the forefront of the electric vehicle development by solving the problem following the silence of the vehicle type. Additionally, the solution could also strengthen the Volvo brand, being a prominent figure in the fields of active and passive safety. Due to the nature of the system that has been developed, there is an additional area of application in the development of autonomous vehicles. Similarly to silent vehicles, autonomous ones would require a communication system to indicate the intentions and actions of the car or bus. Therefore, the light signal can become a stepping stone for a new type of communication systems in self-driven vehicles as well.

As the developed concept differs from many of the existing solutions which are based on the use of auditory signals, the light communication system is a new approach to the problems. Implementing this on the electric and hybrid buses adds another quality to the already distinguished characteristics of the vehicles, therefore reinforcing the innovative nature of the technology. Subsequently, a light communication is thought to reduce the need to add sound signals that pollute the environment in cities.

For the customers of Volvo, namely companies handling the public transport service, the developed light communication system can ensure the safety of their passengers. Beyond that, the implementation also visibly displays the company's efforts to decrease the number of accidents involving buses and VRUs. It indicates that the companies are evolving and facing the issues that concern their businesses. At the same time, the signals can also minimize the idle time at bus stops and crossings, thus facilitating for the drivers to maintain the routes within the timetables.

As previously mentioned, a lot of the responsibility to ensure the safety of VRUs in the surroundings of the bus are placed on the bus drivers. The drivers also have an obligation to the passengers on the bus, whilst being expected to maneuver the bus in various states of traffic and weather conditions. With the many areas of responsibility, the drivers have a possible gain in the system as it has the potential to lower the cognitive demands put on identifying and avoiding hazards. The signals aim to shift some of the responsibility to the VRUs, to help them make better choices in the interaction with the bus. With better work conditions, the bus operators also can feel the positive effects of the drivers' reinforced wellbeing. This gain is further emphasized by the system's potential to ensure that the bus arrives on time, thus allowing the bus drivers to have their breaks whilst also keeping to the buses' timetables.

Additionally to the bus drivers and VRUs, the car drivers are also reached by the signals. Even though they are not the target of the communication system, the information it carries can be of use. Some of the signals can be equally helpful for the driver of a car when interpreting the state of the bus as it is for a VRU. Furthermore, there is also a gain for the car drivers as the VRUs can move erratically around the bus. As the VRUs are more likely to move in a less unexpected manner in the close vicinity through the regulating signals, the driver can more easily calculate risks and avoid collisions.

Lastly, there is also a gain for the city in which the system is launched. Foremost, the signals reinforce the citizens' ability to travel safely using public transport. This can also promote the general view of public transport, encouraging more individuals to leave the car at home. A light communication system also contributes to a better city environment by enabling a greater use of the electric buses without the need of a constant sound signal. Therefore, the pollution from both noise and emissions can be lowered. Additionally, the city can be the face of the new technology and be in the forefront of innovation within public transport.

12.7 EVALUATION

The evaluation showed that the concept follows many of the defined guidelines (see appedix X). The concept received high scores within the category of communication as this has been a main focus throughout the project. The scoring for the most critical situations was however lower, as the light signal alone is not enough in those situations. But, with the adding of an auditory component, the light signal will contribute in the calling for attention.

When it comes to the category for technical aspects, the lower scores were due to the uncertainty regarding the visibility of projections in bright daylight. The environmental conditions such as weather and ground surface could also affect their visibility, but the effects of these factors are difficult to estimate more exactly before testing them. The signals could however be visible to some extent, and the lights on the bus also reinforce the signals, which was why the concept still received a two for the relevant guidelines. As the signals are also given through lights on the bus, the effect of environmental conditions are lessened.

As for the emotional aspects, the evaluation shows that there is a need of balancing the friendliness with the forcefulness, although the act of inducing a sense of wrongdoing in case of faulty actions was not the focus, but rather to convey a firm message. The emotional aspects are of course also difficult to grade exactly at this stage, as the emotions the signals result in must be tested more specifically.

CATEGORIES	TOTAL
Vision and Perception	64
Technical Aspects	64
Modality	42
Emotional aspects	34
Communication	133

FIGURE 12.16 Evaluation matrix against guidelines

12.8 CONCLUSIONS

The final concept comprises a number of signals categorised under four key features, namely progress bar, dynamic alert signal, zone alerts and preparatory light. Two progress bars are placed on the front and rear of the bus, showing the progress which the bus is making at a bus stop. This facilitates determining when it will leave, avoiding scenarios where potential passengers run in front of the bus. The dynamic alert signal emits a pulsating light from the progress bar as the bus accelerates, accompanied by projected lines on the ground, thereby warning VRUs of crossing the road in front of the bus. This signal is also activated when VRUs walk in front of an approaching bus, catching their attention through the light pulses.

Furthermore, the zone alerts consist of an alert signal for when the bus is approaching a bus stop, an enhanced turn signal and a stop line at the rear of the bus. The first is a signal that is activated when a bus pulls over at a bus stop, where projected lines on the ground move outwards from the bus, signalling that VRUs should keep their distance to it. Moreover, the turn signal is emitted as the driver activates the blinkers, thereby enhancing the effect of the conventional turn indicators. A projected triangle consisting of solid edge lines beside the bus displays the area which should be avoided, and it is accompanied by four pulsating light strands between the side windows. These are intended to catch the attention of VRUs and inform them about the upcoming maneuver.

At bus stops, an orange stop line is projected from the back of the bus when VRUs walk behind it in order to warn them concerning the traffic and encourage them to be vigilant. Lastly, two lines are projected from the vehicle's front as the bus is moving so as to facilitate the discovery of the bus when the view is obstructed.

The evaluation showed that the concept follows many of the defined guidelines, while it also indicated that certain aspects need to be improved further or tested more carefully in a larger context. Amongst these, the technological solution for projections should be tested, in similarity with the emotional reactions of VRUs in a real traffic context.

13

DISCUSSION

In this chapter, the methods and process of the project as well as its result are discussed according to a number of categories. In the section for the background study, the theoretical and empirical studies are discussed. Thereafter, the evaluations are examined, followed by a discussion concerning the final result. Lastly, the measures which could be taken during a future continuation of the project are suggested in the section for further work.

13.1 PROJECT FOUNDATION

The aim of this project was to create a safer traffic environment and instill a sense of safety among VRUs. This is believed to be fulfilled as the final concept informs VRUs about the status of the bus at different stages, guides VRUs away from hazardous areas and calls for attention. It thereby creates better circumstances for a safe traffic environment.

Furthermore, the project was intended to create a more efficient traffic flow and a less stressful work environment for the bus drivers. Through the indication of the status of the bus and the elements which call for attention, one could also argue that a more efficient traffic flow could be achieved, as VRUs are assisted in their decision making, thereby decreasing the risk of them blocking the bus's path. Thus, the work environment of the bus drivers is also likely to improve and become less stressful.

As for the objectives, they concerned the creation of concepts to support the aim. In this, the different stages in which the bus interacts with VRUs were to be defined, as well as relevant scenarios and personas highlighting relevant situations and factors. When it comes to the personas, they proved to be very useful in the entire process, which might be due to the fact that they captured key behaviors. There are strong similarities between the personas defined in this project and traffic behavior profiles defined in previous studies, as described in chapter four, which implies that the personas are indeed representative.

Regarding the process as a whole, it was advantageous to work iteratively, letting the key factors of the concept evolve. It was however less beneficial to create five concepts in the second iteration as the evaluation for the project instigators became more difficult with more concepts to choose from. The number of concepts could have been limited, thereby facilitating the evaluations and enabling a more comprehensive user evaluation to be conducted at that stage. More user evaluations would most likely have given more insights into the VRUs' perception of the signals.

Furthermore, the choice to early in the project perform a quite comprehensive background study was advantageous as it facilitated the decisions concerning which direction the concept development should take. It was especially beneficial to carry out the background study iteratively, where observations of traffic and interviews with VRUs were mixed with theoretical studies and benchmarking. This way, the different types of studies enriched each other and indicated what should be more looked into theoretically and empirically.

13.2 BACKGROUND STUDY

The initial study provided a background to the topic and area of interest by involving the different key users to share their experiences and thoughts on the matter. As the interviews that were conducted with the bus drivers took place within a limited time frame, due to the time table of the bus, the number of questions was restricted. Therefore, the bus drivers kept their answers short which hindered the interviews from going in depth. A longer interview could have highlighted more detailed problems and a greater insight in the experience of the drivers. In contrast, the number of interviews with VRUs were limited but allowed for a more in depth conversation. Each of the participants could fully describe their experience and the problems they have faced in the interaction with buses. However, gaining insight from a larger number of individuals could have enabled more issues to be identified and investigated.

Due to the qualitative nature of the background study, the use of questionnaires can be debated. The method is mainly used to gain quantitative data, with closed questions as praxis to facilitate for the participants and streamline the results. In this project, many questions were however open, meaning that the participating individuals had to make the effort to put their thoughts down in writing. The objective was however to reach a more diverse group both geographically as well as societal. However, a greater number of interviews would have provided a more in-depth knowledge from each of the participants. This particularly in the case of the VRUs with hearing impairments which were only reached through the questionnaires. Individual interviews or focus groups would most likely have allowed for a greater exploration of the experience of traffic and warning signals for these individuals.

The observations that were performed during the initial phase of the project were mainly in connection to bus stops and interchange points due to the high level of interaction between VRUs and buses. However, as noted in the chapter for the contextual frame and the defined stages of the bus, there are more locations that are of interest when reviewing the interplay between VRUs and buses. Therefore, a greater range of location types could have been further investigated to gain a direct overview of the potential problems which were brought up in the interviews and questionnaires. However, this would have required a more extensive study as these locations have less frequent interactions in comparison to a larger bus stop.

13.3 EVALUATION

The outcomes of the evaluations have affected the decisions made during the course of the project, therefore, their results and the process which lead to them should be examined. In this section, the Pugh matrix evaluations are briefly discussed, before moving on to the user and bus driver evaluations.

PUGH MATRIX

The evaluations which were carried out in the first two ideation phases consisted of modified Pugh matrices where the solutions were checked against the defined scenarios. This enabled a fast evaluation which gave indications as to which concepts had the most potential. However, the fact that the solutions were not in that stage evaluated against the set guidelines entailed that some aspects might have been overlooked, as the guidelines gave a more complete picture than the scenarios. On the other hand, as the first phase resulted in 23 ideas, it would not have been feasible to check all 23 ideas against the complete list of guidelines, for an initial screening.

Furthermore, the evaluation against the scenarios turned out to be somewhat imbalanced as certain scenarios were very similar, so a feature matching one of these scenarios would automatically receive a high score on the similar situations as well. This meant that concepts which did not have features matching these scenarios got a significantly lower score, even though they received a high score in one or two other scenarios. This resulted in a less reliable final score, although it was quite even, so it was decided that each part of the concepts which contributed to high scores would be kept for the next ideation phase. This eliminated the effect of the imbalanced scoring to some extent.

USER EVALUATIONS

As for the user evaluations, a few shortcomings of the test procedure were discovered during the tests and the analysis of the results. One flaw was the fact that the context in which the showed scenarios took place was not complete, as digital images with animations, accompanied by a short oral description of the situation, were the only material presented. This lead to certain details and cues relevant for the interpretation of the situation and the light signal being missed, which most likely affected the participants' answers. However, it is fairly unlikely that these flaws in the concept representations rendered the results overly positive with regards to the clarity and meaning of the signals, as more cues would have facilitated correct interpretations of them.

Another flaw in the representation was found to be the images for the alert signals, where the pictures showed a VRU crossing. This appeared to confuse the test participants, as the description stated that the situation concerned suddenly walking in front of the bus, triggering a signal which they interpreted as a warning. Therefore, they were perplexed when they noticed the VRU crossing, since that would imply that the bus should give way for VRUs. As the purpose was to simply investigate how the test participants viewed the signal, the VRU crossing rendered the interpretation unnecessarily difficult, leading to potentially less positive ratings.

Furthermore, the situation where a progress bar lights up and subsequently begins to pulsate when the bus is leaving the bus stop was divided into two separate steps. This might also have caused a certain amount of confusion, as the completely illuminated progress bar is intended to be more or less instantly followed by the departure alert signal. Had they been more closely linked in one animated sequence, the signals might have appeared as more clear.

Moreover, the order in which the concepts were presented turned out to affect the result. The order varied between tests, and the second concept that was shown to the participants seemed to be easier to interpret for nearly all test subjects. This means that the interpretations of the second concept were influenced by their previous experiences of the first concept, making it more difficult to determine how intuitive the concepts were.

When it comes to the semantic word scale, the word pairs might have been difficult to interpret in the way the were intended, as it was not specified whether the test subjects should grade how safe they would feel in the situation or after having received the light signal. Therefore, the individuals interpreted it differently and graded it accordingly. Furthermore, the word pair for forcefulness was interpreted somewhat arbitrarily as well, as some test participants did not see the two words as opposites.

EVALUATION WITH BUS DRIVERS

As for the evaluation with the bus drivers, the results were naturally less detailed as only one of the concepts was presented to them due to time restrictions. It was therefore not possible to compare the two concepts, and their answers were in some cases probably very influenced by the one concept they did see, hindering them from giving critique on a more general level. However, this approach was beneficial as it decreased the risk of fatigue from the interview procedure, thereby resulting in more engaged and reliable answers concerning the concept that was introduced.

Additionally, similarly to the user evaluations, the presented material had a limited representation of the context for the situations and their accompanying signals. However, as the bus drivers were not supposed to guess the correct interpretation of the signals, any missing pieces of information were easier to fill in without it affecting the results of the evaluation. Another factor impacting the answers from the interviews were the bus drivers' predispositions. As they are used to being the receivers of information and alerts in a traffic situation, they occasionally found it difficult to see the situation from the perspective of a VRU and estimate to which extent the signal would help VRUs.

13.4 FINAL RESULT

With the final result defined and visualized, there still remain certain aspects to discuss. This section therefore brings up the impact the concept will have on road users, choices that were made with regards to the signals, and how well the concept follows current traffic regulations. Furthermore, the usage of projections is discussed, followed by sustainability aspects.

CONCEPT IMPACT

Firstly, the effect of the combination of the signals is difficult to foresee, as the signals could only be evaluated separately within the frames of this project. Some signals will perhaps appear less clear as they are preceded by other signals on the bus route. Furthermore, the total amount of signals is quite large, entailing that VRUs will have to learn the meaning of many signals and grow accustomed to their application in various situations. On the other hand, the signals are relevant in their context and will therefore hopefully be seen as the help they were intended to be. It is however necessary to consider the effects of too many signals, as this creates the risk of VRUs becoming used to them and stop reacting to them.

This would of course be negative, as the signals would lose their purpose. But if the signals are considered by the VRUs to be relevant for their continued journey, they are not likely to be ignored even when the novelty of the signals has faded. This becomes clear when studying signals directed towards drivers of motor vehicles, which are seldomly ignored, in spite of their frequent use.

Furthermore, the signals are necessary to consider in a larger context. If all buses were to have the signals, the city traffic environment might be experienced differently and perhaps as less structured and more confusing. The signals most at risk of creating a confusing impression with an increasing quantity of buses are probably the projections, as they affect the area outside of the bus as well. Buses do however not compose a majority of the vehicles in traffic, and at the places where many buses are likely to be at the same time, certain signals could be shut off in those specific areas if the signals would become too dominant.

When it comes to the application of the signals, the impression of having both lights on the bus and projections is difficult to foresee, as visualizations of the concept cannot convey the full scale of it, nor the complete context. Perhaps the signals will be confusing when they are composed of two different elements, or it will simply achieve an appropriate level of redundancy. Therefore, tests on a real bus are necessary.

As for the traffic context, tests are also required in order to establish how the concept functions together with road markings and other traffic signals. However, as the concept does not attempt to replace already existing signals and markings, but rather exists in new areas where there is a need for a signal, they should not lessen the effects of each other.

Another question which remains to be answered is whether the signals will be followed, which needs to be tested in a traffic context. It is however likely that the signals directed towards the information seekers will be followed, if interpreted correctly. Most of the signals were easy to interpret according to the user evaluations, but full scale tests would also have to be carried out. Additionally, the alert signals are intended to be combined with a sound component in order to use two modalities and create redundancy, which should also be tested to ensure the highest clarity.

Redundancy is naturally the most important for people with impaired vision or hearing, and it is therefore an important feature to keep. But they could also hopefully be further helped through the signals influencing other VRUs to act more sensibly, as some individuals with an impairment stated that they try to mimic the actions of others in traffic, for example crossing the street when someone else is.

SIGNAL DESIGN

Furthermore, a light signal cannot naturally stand alone in all situations as it cannot reach a person facing the other direction, which sound could. But auditory signals could on the other hand contribute to sound pollution, and light signals are more suitable for those situations where VRUs seek information from the bus. Additionally, sound signals might not reach individuals with a hearing impairment, which creates a need for redundancy in the alert signals.

Another aspect to consider is the usage of the dynamic alert signal both for leaving bus stops and alerting inattentive VRUs. The situations are indeed quite different, even though they have some similarities. There is therefore a possibility that the alert signal will be seen as unnecessarily intense for leaving bus stops, or that the signal will be associated with leaving bus stops and hence appear less forceful in critical situations. This will have to be tested in a traffic context as well.

REGULATIONS

One issue which needs to be discussed is the legal aspects of the suggested light signals. As was stated in chapter four, only certain types of lights are allowed to use on vehicles as of today, for example low and high beam headlights, turn indicators and warning lamps on road maintenance vehicles. The current variants stated by Transportstyrelsen do not leave much room for progress bars or pulsating LED strands. This is of course problematic, as the final concept should be feasible, and thereby must be allowed to exist in a traffic environment.

However, exceptions are continuously made for light signals which have a clear and important purpose that does not interfere with other regulations or create new hazards. Additionally, regulations will have to be adjusted as autonomous vehicles grow more common, hence creating a need for new signals being emitted from vehicles. As those vehicles do not have a driver to communicate with, it becomes relevant to facilitate the communication between the vehicle itself and individuals in the vicinity, possibly through the use of light signals. Therefore, the development in this area will also drive the evolution of the legal aspects for lights on vehicles.

Furthermore, the regulations for certain light signals are more difficult to determine, as they are not specifically mentioned in the publications concerning usage of lights on vehicles. An example of this are projections, which means that new regulations would have to be specified in case of a realisation of the concept. In this case, it is therefore currently only possible to verify that it does not interfere with any other essential rules that are in some way applicable to the relevant area.

PROJECTIONS

When it comes to the projections, the main concern is their visibility in daylight, which is necessary to test in the true environment. It is however likely that they will be at least partially visible, if one studies current applications of light projections. It is also a matter of how intense the lights are, as stronger lights entail more visible projections.

There is however a negative aspect with too strong lights, as the risk of glare or distracting reflections increases. Depending on the ground surface, the projection light could be reflected and cause glare. Therefore, these lights should not be too strong either. Perhaps, this will be a more easily solved tradeoff in the future, as technology constantly pushes forward.

Furthermore, it might become easier to connect lights with different functions in the future in order to let the same light source create different types of light. The possibilities for this will also increase with the change of regulations, which are likely to happen as light communication for vehicles grows more common.

SUSTAINABILITY

As the concept would add new components to the bus and increase its energy consumption, it is necessary to consider the sustainability of the suggested solution. Therefore, the benefits within the area of sustainability must exceed the environmental costs. In the case of this concept, one possible advantage is the potential of creating a smoother traffic flow where the bus drivers are seldom required to brake and accelerate alternately, thereby lowering the bus's energy consumption.

Furthermore, as the concept aims to contribute to a safer traffic environment, it also includes aspects of social sustainability. In a larger context, this concept could also further distinguish the electric buses from other vehicles and act as a positive marketing feature for electric vehicles, as well as public transport. This would in turn benefit the environment.

13.5 FURTHER WORK

As mentioned in earlier sections, the signals need to be tested in full scale in a real traffic context in order to determine their effect on VRUs and other road users. In this, the VRUs' experience of the signals should be examined as the semantic word scale in the user evaluation was quite short, and based on digitally sketched images which did not convey the complete context. How the concept is interpreted in its true context would also require testing.

In a larger context, it would also have to be confirmed that the signals are indeed interpreted similarly in different countries, to ensure that it could be utilized worldwide. Moreover, the impact on other road users was not tested during the project, and is necessary to do before the concept is accepted as a feature on buses. Additionally, the impression of multiple buses emitting the signals at once is difficult to foresee at this stage, but could possibly be evaluated with help from virtual or augmented reality.

For these tests, more detailed technical specifications regarding components, wiring and fixtures are required. Alternative solutions to LED projecting lights could furthermore be searched for, as other technologies for this purpose could be realized in the future, for example laser projection.

14

CONCLUSION

In this final chapter, the conclusions drawn from the project are presented, accompanied by a summary of the findings from the background study and the final concept. A number of issues in traffic were discovered and with these issues in mind, concepts were developed which finally lead to a system of light signals tailored to the different stages of the bus.

14.1 CONCLUSION

The user studies found that there were three main problem areas connected to certain behaviours in traffic, namely distractions and inattention, hazardous behaviour and misunderstandings. The first comprises the behaviour and situations that occur due to a lack of focus from the VRU, resulting in stress and frustration for the bus drivers, who have to be constantly vigilant in order to avoid accidents.

Included in the hazardous situations are risk taking behaviours that are considered to generate unnecessary dangers. It encompasses conscious decisions and actions, that are made due to stress, laziness or simply because the individual feels entitled to act in that manner.

The last category includes issues where road users miss warnings, and the communication is not mutually understood. Furthermore, it also encompasses problems that occur due to a lack of communication.

Many of the issues seemed to originate from, or be strengthened by, a lack of communication, as VRUs had difficulties with interpreting the intentions of the bus drivers. The VRUs tended to look for different external cues in order to determine the status of the bus, but these cues were not always discernible. Therefore, with these mentioned issues, it was decided that the solution should apply the three leading words, namely inform, guide and alert.

Furthermore, a number of personas and scenarios were defined in order to establish the problematic areas and clarify the guidelines that the concepts should follow. This lead to the definition of the stages which the bus goes through during a route. These stages concerned approaching, being idle and leaving bus stops as well as VRU crossings, and intermediate driving. This category was further divided into regular driving, turning and critical situations, consisting of alert and warn, where warnings would need to include an auditory signal.

The final concept developed through iterations included four key features, namely the progress bar, the dynamic alert signal, zone alerts and preparatory light. The signals under these categories were applied in the different stages of the bus and aimed to inform VRUs about the bus's status, guide them away from hazardous zones and alert them in critical situations. These factors can in turn decrease the stress levels of bus drivers, create a safer traffic environment and generate a smoother traffic flow, thus creating a gain for all stakeholders.

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APPENDICES

APPENDIX I

Interview Template for Bus Drivers

Erfarenhet av buss:

- Hur länge har du varit busschaufför?
- Hur länge har du kört elbuss?
- Vad är den största skillnaden mellan vanlig buss och elbuss?

Kommunikation och interaktion:

- Hur ser din interaktion/kommunikation med fotgängare och cyklister ut i trafiken?
- Tutar du på fotgängare? I vilka situationer?
- Hur reagerar fotgängarna när man tutar på dem?

Risker och faror:

- Hur upplever du att cyklister och fotgängare förhåller sig till och rör sig nära bussen?
- Upplever du något problem med hur fotgängare/cyklister beter sig runt bussen?
- Finns det någon situation som känns extra riskfylld/problematisk?
- Finns det någon plats där riskfyllda situationer oftare förekommer?
- Ser du någon speciell orsak till att de riskfyllda situationerna uppkommer?
- Upplever du att det finns någon sorts trafikant som oftare blockerar din färdväg eller bidrar till riskfyllda situationer? (Fotgängare som kollar mobilen, cyklister som inte visar vart de ska, fotgängare i grupp etc.)
- Finns det några situationer där du skulle vilja att bussen signalerade eller informerade omgivningen?

APPENDIX II

Interview Template for Pedestrians

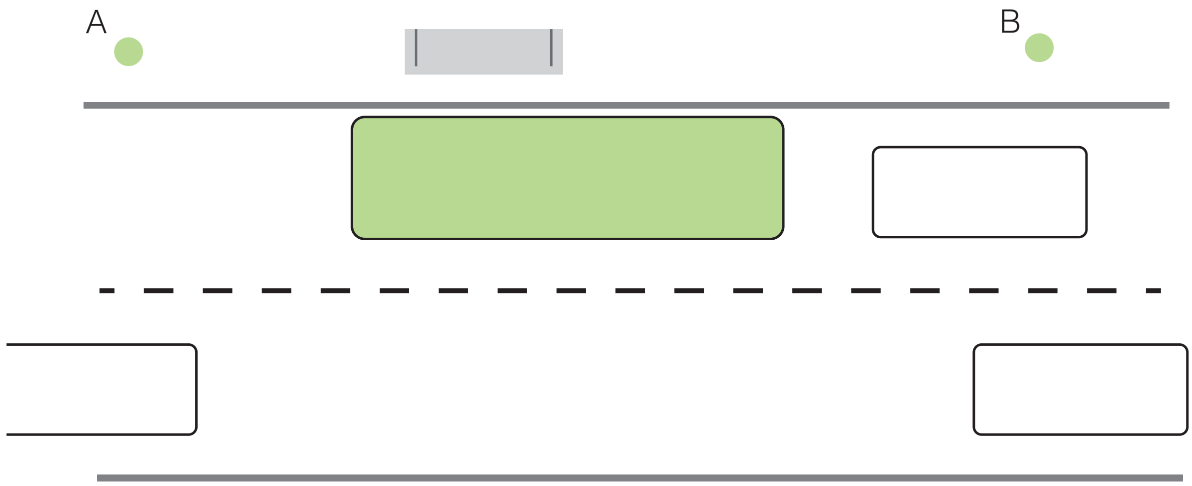
- Hur gammal är du?
- Hur ofta rör du dig som fotgängare i trafiken?
- Hur ofta åker du med kollektivtrafik?
- Finns det någon situation där du känner dig utsatt i trafiken som fotgängare?
- Kan du minnas någon gång då situationen kändes riskfylld eller att olyckan var nära?
- Brukar du ha hörlurar eller telefonen framme när du rör dig i trafiken som fotgängare?
- Har detta någon gång skapat problem? Eller har du blivit överraskad i en situation på grund av detta?

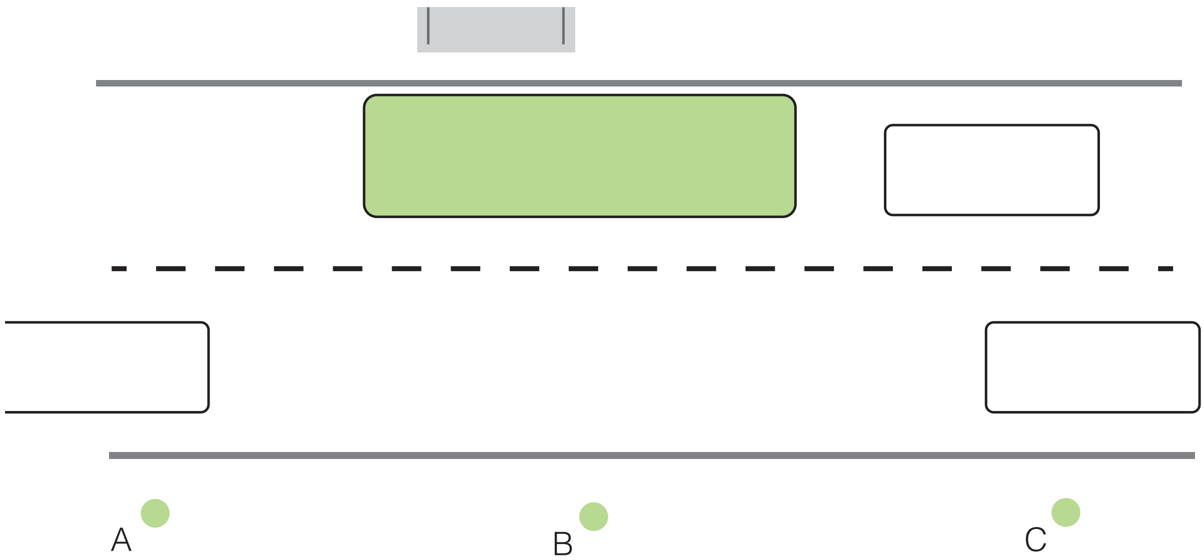
Scenarion:

- Om du ska korsa vägen
  - Hur avgör du om det är säkert att korsa vägen?
  - När kollar du? Står du still när du kollar?
  - Om fordonen står i kö, hur avgör du om du kan röra dig mellan dem?
  - Hur avgör du förarens avsikter? (skillnad mellan bil och buss)
  - Är det någon skillnad om det är vid ett övergångsställe du korsar?
  - Är det någon gång du känner dig osäker på om du kan korsa vägen?

- Om du skyndar dig för att hinna med en buss/spårvagn och du befinner dig på rätt sida vägen:
  - Hur skulle du gå till väga för att ta dig till bussen från plats A?
  - Hur skulle du gå till väga för att ta dig till bussen från plats B?
  - Vad påverkar din bedömning om du kommer hinna med eller inte?
  - Är det någon skillnad om du är på plats B?

- Om du skyndar dig för att hinna med en buss/spårvagn och du måste korsa vägen för att hinna med
  - Hur skulle du gå till väga för att ta dig till bussen från plats A?
  - Hur skulle du gå till väga för att ta dig till bussen från plats B?
  - Hur skulle du gå till väga för att ta dig till bussen från plats C?
  - Vad påverkar din bedömning om du kommer hinna med eller inte?
  - Är det någon skillnad om det är vid ett övergångsställe du korsar?


A
B


A
B
C

APPENDIX III

Interview Template for Individuals with Visual Impairments

- Skulle du kunna beskriva effekterna av din synnedsättning?
- Hur uppfattar du olika sorters ljus?
- Hur upplever du att det är att vistas i trafik?
- Finns det någon situation där du känner dig utsatt i trafiken?
- Kan du minnas någon gång då situationen kändes riskfylld eller att olyckan var nära?
- Reser du i dagsläget med kollektivtrafik?
- Hur upplever du att det är att resa med kollektivtrafik idag?
- Hur upplever du varningssignaler i trafiken?
- Finns det några exempel på bra eller dåliga varningssignaler?
- I vilka situationer vill du bli varnad/informerad?
- Vilka konsekvenser tycker du uppkommer i och med att fordon blir tystare?

APPENDIX IV

Interview Template for Evaluation with Bus Drivers

- Vad tror du om detta? Vad tror du detta skulle ha för effekt?
- Om områden på marken framför bussen skulle lysas upp, tror du att det skulle störa dig?
- Tror du att det skulle vara distraherande om ljuspunkten rörde sig eller blinkade?
- Om marken lystes upp på sidan, tror du att det skulle störa dig?
- Vilka steg genomför du vid en hållplats? (kan vi koppla något till progress bar?)
- Är det någon signal som du skulle vilja kunna styra?

APPENDIX V

Questionnaire for Bus Drivers

Säkerhet kring bussar

Vi är två studenter från Industrial Design Engineering på Chalmers Tekniska Högskola som gör ett masterexamensarbete om interaktionen och kommunikationen mellan bussar och andra medtrafikanter. Projektet genomförs i samarbete med Volvo Bussar och syftar till att skapa en säkrare trafikmiljö för fotgängare och cyklister. Enkäten innehåller 9 frågor och dina svar är anonyma. Vi uppskattar din medverkan!

1. Hur länge har du varit busschaufför?

2. I vilken sorts trafik kör du buss?

- ❑ Stadstrafik
- ❑ Landsväg
- ❑ Stadstrafik och landsväg

3. Hur kommunicerar du med fotgängare och cyklister i trafiken?

- ❑ Ljustuta (blinka med helljus)
- ❑ Tuta
- ❑ Ögonkontakt
- ❑ Hastighet
- ❑ Gester
- ❑ Övrigt

4. Brukar du känna dig tvungen att tuta på fotgängare? I så fall, i vilka situationer?

5. Vilken/vilka reaktioner uttrycker fotgängarna när man tutar på dem?

6. Upplever du något problem med hur fotgängare/cyklister rör sig eller beter sig kring bussen?

7. Finns det någon situation som känns extra riskfylld/problematisk?

8. Finns det någon typ av plats där riskfyllda situationer oftare förekommer?

9. Ser du någon speciell orsak till att de riskfyllda situationerna uppkommer?

Övriga kommentarer:

APPENDIX VI

Questionnaire for Bicyclists

Vi är två studenter från Industrial Design Engineering på Chalmers Tekniska Högskola som gör ett masterexamensarbete om interaktionen och kommunikationen mellan bussar och andra medtrafikanter. Projektet genomförs i samarbete med Volvo Bussar och syftar till att skapa en säkrare trafikmiljö för fotgängare och cyklister. Enkäten innehåller nio frågor och dina svar är anonyma. Vi uppskattar din medverkan!

1. Var god fyll i din ålder:

- ❏ Under 20 år
- ❏ 20-29 år
- ❏ 30-39 år
- ❏ 40-49 år
- ❏ 50-59 år
- ❏ 60-70 år
- ❏ Över 70 år

2. Hur upplever du din interaktion med bussar i trafiken?

3. Hur blir du uppmärksammad på att ett fordon närmar sig?

4. Hur avgör du förarens avsikter när det gäller bussens färdväg?

5. Finns det någon situation där du känner dig utsatt i trafiken?

6. Finns det någon typ av plats eller väg du upplever som osäker eller problematisk?

7. Kan du beskriva någon gång då situationen kändes riskfylld eller nära ögat?

8. Brukar du ha hörlurar på dig när du rör dig i trafiken?

- ❏ Ofta
- ❏ Sällan
- ❏ Aldrig

9. Om du använder hörlurar i trafiken, har detta någon gång skapat problem eller har du blivit överraskad i en situation på grund av detta?

Övriga kommentarer:

APPENDIX VII

Questionnaire for Pedestrians

Vi är två studenter från Industrial Design Engineering på Chalmers Tekniska Högskola som gör ett masterexamensarbete om interaktionen och kommunikationen mellan bussar och andra medtrafikanter. Projektet genomförs i samarbete med Volvo Bussar och syftar till att skapa en säkrare trafikmiljö för fotgängare och cyklister. Enkäten innehåller åtta frågor och dina svar är anonyma. Vi uppskattar din medverkan!

1. Var god fyll i din ålder:

- ❏ Under 20 år
- ❏ 20-29 år
- ❏ 30-39 år
- ❏ 40-49 år
- ❏ 50-59 år
- ❏ 60-70 år
- ❏ Över 70 år

2. Finns det någon situation där du känner dig utsatt i trafiken som fotgängare?

3. Kan du beskriva någon gång då situationen kändes riskfylld eller att olyckan var nära?

4. Brukar du ha telefonen framme när du rör dig i trafiken?

- ❏ Ofta
- ❏ Sällan
- ❏ Aldrig

5. Brukar du ha hörlurar på dig när du rör dig i trafiken?

- ❏ Ofta
- ❏ Sällan
- ❏ Aldrig

6. Om du använder hörlurar eller telefon i trafiken, har detta någon gång skapat problem eller har du blivit överraskad i en situation på grund av detta?

7. Om du ska korsa en väg framför en buss, hur avgör du om det är säkert att passera?

- ❏ Bussens hastighet
- ❏ Ögonkontakt med föraren
- ❏ Bussens inbromsning
- ❏ Väntar tills bussen stannat
- ❏ Avstånd till bussen
- ❏ Övrigt:

8. Om du skyndar dig för att hinna med en buss som står vid hållplatsen, vad hjälper dig att bedöma huruvida du kommer hinna med eller inte?

Övriga kommentarer:

APPENDIX VIII

Questionnaire for Individuals with Hearing Impairments

Vi är två studenter från masterprogrammet Industrial Design Engineering på Chalmers Tekniska Högskola som gör ett examensarbete om interaktionen och kommunikationen mellan bussar och andra medtrafikanter. Projektet genomförs i samarbete med Volvo Bussar och syftar till att skapa en säkrare och inkluderande trafikmiljö för alla fotgängare och cyklister. Enkäten innehåller elva frågor och dina svar är anonyma. Vi uppskattar din medverkan!

1. Var god fyll i din ålder:

- ❑ Under 20 år
- ❑ 20-29 år
- ❑ 30-39 år
- ❑ 40-49 år
- ❑ 50-59 år
- ❑ 60-70 år
- ❑ Över 70 år

2. Skulle du kunna beskriva effekterna av din hörselnedsättning?

3. Hur upplever du att det är att vistas i trafiken?

Otryggt = 1 Tryggt = 7

4. Finns det någon situation där du känner dig utsatt i trafiken?

5. Hur blir du uppmärksammad på att ett fordon närmar sig?

6. Skulle du kunna beskriva någon gång då situationen kändes riskfylld eller att olyckan var nära?

7. Reser du i dagsläget med kollektivtrafik?

- ❑ Dagligen
- ❑ Ofta
- ❑ Sällan
- ❑ Aldrig

8. Hur upplever du promenaden till och vistelsen kring hållplatsen?

9. Hur upplever du varningssignaler i trafiken?

Ohjälpsamma = 1 Hjälpsamma = 7

10. Enligt dig, finns det några exempel på bra eller dåliga varningssignaler?

11. I vilka trafiksituationer vill du bli varnad eller informerad?

Övriga kommentarer:

APPENDIX IX

User Evaluation Procedure

Vi undersöker hur ljussignaler på bussar kan användas för att kommunicera med fotgängare och cyklister, och detta test syftar till att utvärdera våra lösningsförslag. Du kommer att introduceras till en rad olika trafiksituationer där bussar förekommer som man som fotgängare eller cyklist kan möta. För varje situation kommer du att få svara på några frågor och fylla i en semantisk ordskala.

(Parallel) Du står vid en hållplats och väntar på bussen, när den närmar sig ser det ut så här: [bild på buss - repelling lines]

- Vad tror du att det här betyder? / Hur skulle du tolka det här?
- Vad skulle du göra om du var i den här situationen?
- Fyll i ordskala

(Perpendicular) Du har stigit av en buss och närmaste vägen är att gå bakom bussen över vägen. När du går bakom händer detta: [bild på buss - rear stop line]

- Vad tror du att det här betyder? / Hur skulle du tolka det här?
- Vad skulle du göra om du var i den här situationen?
- Fyll i ordskala

Vid en hållplats är du precis på väg att korsa en bussfålla, i den står det en buss vid sitt hållplatsläge. [bild på buss - progress bar]

- Vad tror du att det här betyder? / Hur skulle du tolka det här?
- Vad skulle du göra om du var i den här situationen?
- Fyll i ordskala

När ljusen på fronten tänts upp helt, som du precis såg på förra bilden, och bussen fortfarande står vid hållplatsen så ser det ut så här: [bild på buss - dynamic alert signal]

- Vad tror du att det här betyder? / Hur skulle du tolka det här?
- Vad skulle du göra om du var i den här situationen?
- Fyll i ordskala

Du närmar dig bussen du ska åka med som står vid sitt hållplatsläge på en ändhållplats. Bussen ser då ut så här: [bild på buss - terminus departure signal]

- Vad tror du att det här betyder? / Hur skulle du tolka det här?
- Vad skulle du göra om du var i den här situationen?
- Fyll i ordskala

Du går på en trottoar vid en väg och ser en buss komma åkandes: [bild på buss - preparatory light]

- Vad tror du att det här betyder? / Hur skulle du tolka det här?
- Vad skulle du göra om du var i den här situationen?
- Fyll i ordskala

Du cyklar bredvid en buss innan en korsning, då detta händer: [bild på buss - turn triangle]

- Vad tror du att det här betyder? / Hur skulle du tolka det här?
- Vad skulle du göra om du var i den här situationen?
- Fyll i ordskala

När du snabbt viker ut i gatan för att korsa vägen dyker en buss plötsligt upp. [bild på buss - alert signal]

- Vad tror du att det här betyder? / Hur skulle du tolka det här?
- Vad skulle du göra om du var i den här situationen?
- Fyll i ordskala

Nu ska du korsa vägen vid ett övergångsställe, där du ser en buss närma sig. Bussen ser då ut så här: [bild på buss - preparatory light closing in]

- Vad tror du att det här betyder? / Hur skulle du tolka det här?
- Vad skulle du göra om du var i den här situationen?
- Fyll i ordskala

Du är återigen på väg till ett övergångsställe, bussen har precis släppt förbi en fotgängare, du är ett par meter bort. [bild på buss - preparatory light förlängs]

- Vad tror du att det här betyder? / Hur skulle du tolka det här?
- Vad skulle du göra om du var i den här situationen?
- Fyll i ordskala

Avslutning

- Har du några ytterligare kommentarer kring hur du upplevde situationerna?
- Var det någon signal som stack ut som tydligare, bättre eller sämre?

Tack för din medverkan!

Ordskala

Tvingande							Guidande
Tydlig							Vag
Trygg							Otrygg

APPENDIX X

Evaluation Matrix Against Guidelines

	GUIDELINE - the concepts should:	EXPLANATION	WEIGHT	SCORE
Vision and Perception	not visually disturb the bus driver	The driver must have a clear view of the surroundings and not be distracted by visual elements	4	2
	not obstruct the view of the bus driver	The driver must have a clear view of the surroundings and hindered by physical objects	5	3
	not blind any road users	The concepts must not shine with an intensity or direction that creates a glare	5	2
	not distract road users	The concepts should not have an appearence that distracts road users from their main task	4	2
	not interfere with other traffic signals	The concepts should not hinder other traffic signals from being seen and perceived	4	2
	not contradict other traffic signals	Road users should not be confused by the concepts' appearence in relation to other traffic signals	5	3
Technical Aspects	be possible to add to existing buses	The concepts should be limited to installment in production	3	1
	not extensively protrude	The concepts should not hinder the bus' navigational range or risk colliding with other RU and objects	4	3
	be visible in different light conditions	The concepts should be visible in daylight and at night	3	2
	be visible in different weather conditions	The concepts should be discernable in rain, sunshine, fog and snow	3	2
	be visible with different road conditions	The concepts should be discernable with snowy, icy, wet and dirty conditions	3	2
	be visible on different ground surfaces	The concepts should be discernable independently of coarseness and colour	3	2
	abide by regulations	The concepts should abide by regulations concerning colours, direction, intensity and placement	5	2
	be conspicuous	The concepts should have a contrast and intensity that stands out from the background	5	3
Modality	minimize the dependency on sound warnings	The concepts should explore other means of alerting road users and add qualities that sound signals cannot achieve	3	2
	provide redundancy	By offering signals from sources of different modalities, the signal is more easily perceived by all road users	4	3
	not create extensive cognitive weight	The interaction should not require extensive amount of time, effort or attention from the driver	4	3
	be possible to perceive and interpret quickly and easily	The processing of the concepts should not require extensive time or effort, thus avoiding a lack of focus on other traffic elements	4	3
Emotional aspects	instill a sense of security in VRUs	The VRUs should feel safer through the interaction with the concepts	4	3
	exude a sense of safety	The concepts should be identified as a safety feature	3	2
	exude a sense of friendliness	The appearance of and interaction with the concepts should generate positive emotions	3	2
	enable VRUs to be more confident in their actions	The VRUs should be able to know what the right actions is and have the willingness to execute it	4	2
	induce a sense of wrongdoing in case of faulty actions	The VRUs should be made aware when they are acting in an incorrect manner and be discouraged from such behaviour	2	1

Communication	communicate and clarify the intentions of the driver	The intentions of the drivers should be easily perceived and interpreted by the VRUs	4	3
	communicate and clarify the status of the bus visibly from all sides	The status of the bus should be easily perceived and interpreted by the VRUs	4	3
	inform about the appropriate behaviour in the vicinity of the bus	The VRUs should be enlightened regarding the hazardous areas around the bus	4	3
	call for attention in critical situations	The VRUs should be warned when in immediate danger	3	2
	call for attention in hazardous situations	The VRUs should be alerted of dangers deriving from the bus to prevent critical situations from occuring	5	3
	prevent critical situations from occurring	The concepts should function proactively to avoid hazardous situation	5	3
	be compatible with exisiting communication signals	The function and appearance of the concepts should not divert from established norms	4	3
	minimize the amount of false alarms	The VRUs should not be warned unless there is a critical situation, in order to maintain the connection between warnings and danger	3	2
	present the warning or information at the appropriate time	For maximum effect, the signal must match the situation well	4	2
	raise awareness regarding personal risks	The VRUs need to acknowledge hazardous situation in order to make sensible decisons	3	3
	raise awareness regarding one's own actions in relation to the repercussions for others	The VRUs need to acknowledge the hazardous situations for others generated by the actions of the individual	2	1
	enable communication adapted to the situation	The drivers need to be able to communicate clearly with VRUs in different situations	4	3
	be consistent within itself	The elements of the concept should be perceived as coherent and carry a communal meaning	4	3