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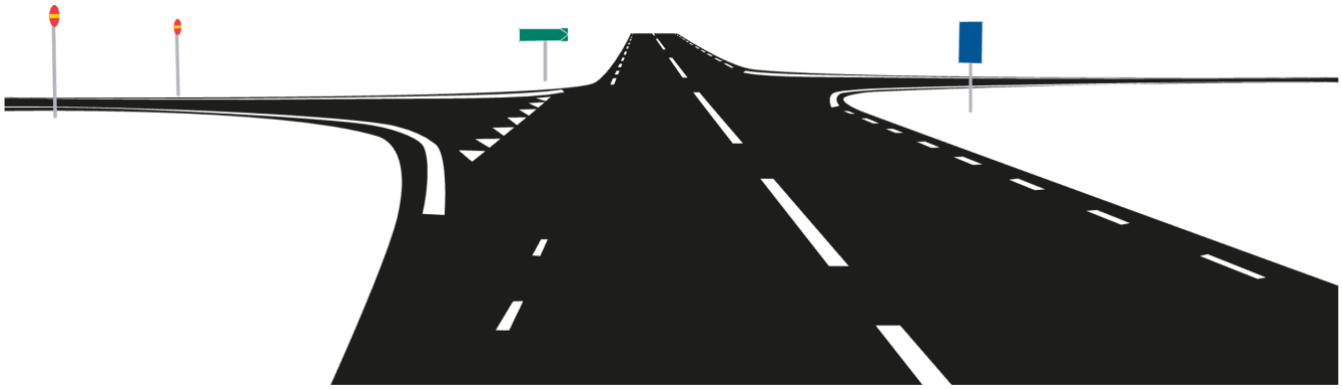

Older Drivers' Information Needs in Road Infrastructure to Prevent Wrong-Way Driving

Master's thesis in Industrial Design Engineering

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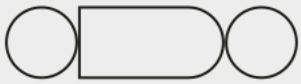

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Acknowledgments, dedications, and similar personal statements in this thesis reflect the authors' own views.

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The cover shows an illustration of an interchange.
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Abstract

Wrong-way driving (WWD) occurs when a driver starts driving in the opposite direction on the motorway, for instance by entering the motorway from an exit ramp or by making a U-turn. Older drivers are overrepresented when it comes to WWD and even though this problem is rather uncommon, it often results in severe accidents. The topic has been researched in countries such as the US, Germany and Japan but in Sweden, the knowledge about this phenomenon is still limited. The aim of this project was to investigate older drivers and their information needs in road infrastructure to design solutions that can prevent WWD. Insights from a literature review and user studies were translated through a design process into solutions and guidelines. Cognitive and physical capabilities of older drivers as well as common reasons behind WWD were explored through a literature study. User studies were also conducted with the target group. The outcome of the project was a set of guidelines for road design with a focus on older drivers and WWD as well as 9 design concepts with different approaches to prevent WWD such as improved signage, improved road geometry and reduced cognitive load. The study found that WWD is a complex issue that cannot be solved in the same way in all locations and for every situation. The study also found that older adults generally are experienced and safe drivers. Although there are some general tendencies of aging, there can be large individual differences. However, making alterations such as providing clear and repeated information as well as minimising cognitive load and time pressure could make the road infrastructure more adapted to older drivers and thereby prevent the risk of WWD.

Keywords: older drivers, wrong-way driving, signage, road design, cognitive ergonomics, human factors, industrial design

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Word list

C1-sign: A “No entry”-sign (A picture of the sign can be seen in Figure 24).

Information system: Elements, road signs and directions.

Motorways: A collective term including motorways, highways and other types of roads with separate roadways.

Trafikverket: The Swedish Transport Administration.

WWD: Wrong-way driving. (See more in Chapter 4)

WW-driver: Wrong-way-driver.

Contents

1 Introduction

1.1 Background

Wrong-way driving is a seldom, but dangerous type of traffic occurrence caused by driving a vehicle against the direction of traffic on roads with separated roadways (Rømming, 2003). This problem becomes increasingly urgent as the motorway net is developing both in Sweden and other countries all over the world. Even though serious accidents caused by WWD are uncommon, the risk of serious injury or death is relatively high compared to other accidents in road traffic (Rømming, 2003). The phenomenon of WWD have been researched in countries such as Germany, Japan and the US, but in Sweden it is a quite new topic of investigation.

Apart from making a U-turn on the motorway or confusing entrance ramps with exit ramps, WWD can also occur at one-way roads, exits from rest areas or parts of a road where lanes are being added or removed, e.g. 2+1 roads (Rømming, 2003). The reasons behind WWD driving are many and they usually appear simultaneously – some of them depend on infrastructure and weather conditions while other on the drivers themselves. Confusion, unclear signage and drunk driving are one of the most common reasons why WWD is happening (Sørensen, n.d.).

Despite that older drivers are overrepresented when it comes to wrong-way driving, studies have shown that older drivers only have a slightly increased risk of being involved in traffic accidents in general (Helmers et al., 2004). According to (Helmers et al., 2004), this might partly be due to driving adjustments made by the older drivers to compensate for their changed abilities. For instance, many older drivers tend to avoid driving at night or in stressful situations (Selander & Sandin, 2021). Older drivers are

generally also experienced and tend to have more of a “safety mindset” compared to younger drivers by for instance not driving above speed limits (Selander & Sandin, 2021).

Due to an aging population in Sweden, there is an increased number of older drivers (Selander & Sandin, 2021). The authors also mention that driving can be of big importance for older adults when it comes to mobility and independence as well as to be able to socialize and perform daily tasks such as grocery shopping (Selander & Sandin, 2021). Adjusting road infrastructure for older drivers, such as re-designing entrance and exit ramps of motorways to avoid WWD is thereby important for an inclusive society.

Avoiding serious traffic accidents, for instance from WWD, is also important for “Vision zero” (“Nollvisionen” in Swedish), a vision admitted by the Swedish parliament in 1997 with the goal to completely eliminate deaths or serious injuries within the Swedish road transport system (Trafikverket, 2024). Although all road users have a mutual responsibility to drive safely, the stakeholders responsible for designing, building and maintaining Swedish road infrastructure, such as The Swedish Transport Administration, have the ultimate responsibility for traffic safety in the entire system (Trafikverket, 2024). Designing road infrastructure to avoid WWD is therefore one part that can help fulfil “Vision zero”.

In this project, current public road infrastructure (both in Sweden and in other countries) with a focus on motorway interchanges, was studied. Furthermore, reasons behind WWD were analysed along with older drivers’ perception of road elements such as signage, road markings and general road geometry. Parts of roads in Sweden where WWD occurs or are more likely to occur was analysed with a perspective of interaction between drivers and road infrastructure. The understanding of WWD and older drivers needs was the basis for generation of design concepts and guidelines.

1.2 Aim and Objectives

The aim of this thesis work is to develop solutions that can prevent wrong-way driving on Swedish roads with a special recognition of older drivers' information needs.

The goal with this project is to develop several design concepts, both within and outside current public road regulations, that can prevent wrong-way driving. In addition, research findings from literature and user studies will be formulated as a set of design guidelines containing general recommendations about how road infrastructure should be developed to accommodate older drivers' information needs and prevent wrong-way driving.

1.3 Research Questions

Following questions will be answered in order to address the problem described in the project aim:

- What are the needs of older drivers regarding their driving habits and cognitive abilities in the traffic environment?
- How are the decisions made by older drivers impacted by the road infrastructure, signage, surroundings, other road users and weather conditions?
- How are current roads, with a focus on parts interacting with the road user, designed?
- What could be the course of events for WWD?
- How can roads be designed to prevent WWD?

1.4 Limitations

Due to the limited time and resources, following aspects on this topic will be excluded from the project scope:

- Analysing the consequences of the WWD phenomenon for the road safety and traffic flow efficiency.
- Construction and technical parameters of roadway elements below the surface course.
- Car construction and technical parameters and their effect on road safety.
- WWD caused by use of drugs or alcohol.
- Roads with allowed speed lower than 80 km/h (except from motorways in urban areas where allowed speed may be lower than 80 km/h).
- Roads that are outside The Swedish Transport Administration's jurisdiction e.g. one-way roads in cities, private roads or service roads.

1.5 Target Group – Older Adults

In this study, the group in focus was older adults and older drivers. The important aspect is not a specific age but rather it is a general description of individuals who are affected by aging in such a way that it is affecting their driving habits and abilities.

1.6 Sustainability and Ethics

In this section, both the sustainability and ethical aspects of the project will be presented, followed by how the project can be related to UN Sustainable Development Goals.

1.6.1 Sustainability Concerns

Construction and usage of motorways might be seen as problematic from the environmental point of view due to several reasons: land use, excessive noise pollution, poor air quality, emissions related to concrete and steel used in construction and creating barriers for wildlife and people (Vijayakumar et al., 2024). Motorways can also lead to increased traffic of fossil private transportation and compete with railways when it comes to freight operations, especially on so-called "last mile".

On the other hand, sustainable road infrastructure can be significant for developing the country's economy allowing people to transport labour and goods which can possibly contribute to reducing poverty and providing better life-quality (Vijayakumar et al., 2024). Motorways allow people to find employment in other cities, to commute and to access public services.

1.6.2 Ethics

An important ethical aspect related to the user group is how to accommodate the needs of older adults that might conflict with the needs of other car drivers. Designing public infrastructure is about being able to compromise different needs in order to develop safe, accessible and high-quality spaces and services. However, even if the focus of this project is to study and answer the older driver's information needs the question if the designed solutions will be well-balanced and prevent WWD among other car drivers will remain relevant.

There are also ethical concerns related to the design process itself, especially when it comes to user studies. Participants of such studies should be informed about the goals and extent of the study as well as how and in which matter the data will be used. Ethicality of a user study can be guaranteed by e.g. agreements where the participants will confirm that they are willing to participate in the project and that they are conscious about the subject of the study. A specific aspect related to recruiting older adults to the user studies is to ensure that they understand how their data is analysed, especially if its saved and used in digital forms. It is also important to ensure them that data is anonymised and will not be shared with any other third parties, which means that there is no risk of their driving license being revoked due to the answers they could give during the study.

1.6.3 UN Sustainable Development Goals

Improving and sustaining motorways can fit into UN 2030 Agenda that focuses on preventing negative effects of climate change and increasing life quality for all people using resources within the planetary boundaries. There are two UN Sustainable Development Goals related to this project (See Figure 1).

Figure 1 UN Sustainable Development Goals 3 and 10

Goal 3

Preventing injuries and deaths related to road traffic accidents is one of the targets of *Goal 3: Good health and well-being*. The aim of this project is to prevent accidents caused by WWD and to make road infrastructure safer for older drivers by adjusting it to their cognitive needs.

Goal 10

Increasing accessibility for people with different needs and preventing isolation of older adults is included in *Goal 10: Reduced inequalities.* As society is getting older, including older adults to the labour market or providing an equal access to public services is getting more challenging. One of the solutions is to improve accessibility of the transportation sector by e.g. adjusting the road infrastructure to the older adults' needs.

2 Process, procedure and methods

The procedure as well as the used methods with their general definitions will be described in this chapter in order to illustrate how the process was carried out chronologically.

2.1 General Process Description

This project was carried out in three different main phases: *Problem understanding*, *Idea creation* and *Concept finalisation*. The focus of the first phase was to gain an understanding of the problem and situation while the second and third focused on designing solutions. Different phases were generally carried out in chronological order, however, the work was iterative and some steps in the different phases overlapped. A visualisation of the process of the project can be seen in Figure 2. The outcome of the project was a set of guidelines for road design with focus on older drivers and WWD as well as 9 final concepts for road infrastructure to prevent WWD.

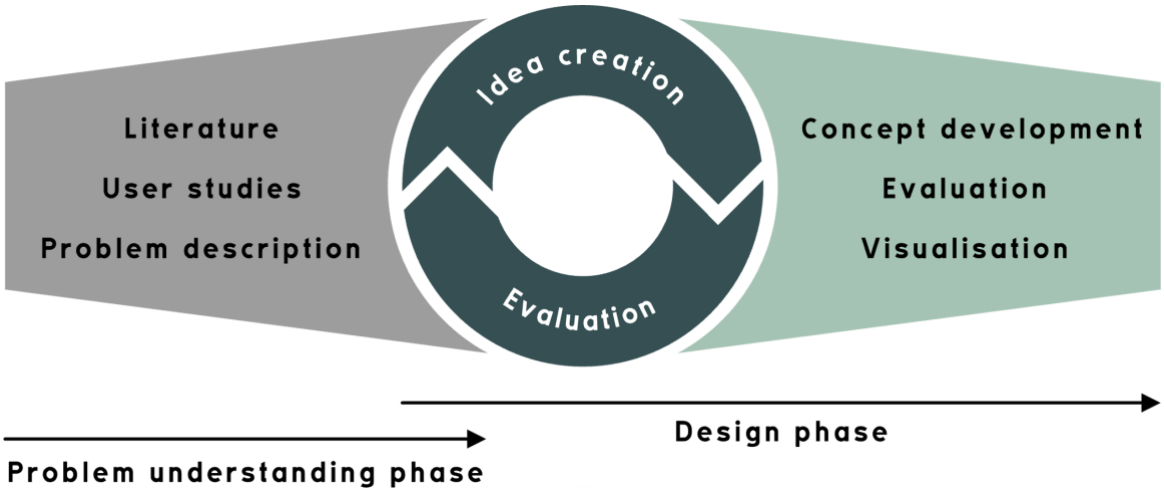


Figure 2 Visualisation of the process of the project.

2.2 Problem Understanding Phase

The purpose of the *Problem understanding* phase was to gain an understanding of older drivers, WWD and road infrastructure. In this phase, information was gathered from literature search, data and literature provided by The Swedish Transport Administration and through user studies. Findings and useful citations from the literature studies were gathered in one document and categorised which gave the basis for the analysis made in this report. In addition, a systems analysis, a function analysis and a list of requirements was made.

2.2.1 Literature Search

Literature was gathered in three different areas: *older adults and cognitive ergonomics*, *WWD* and *road infrastructure*. While reading literature, relevant information was annotated.

Literature on older adults and cognitive ergonomics:

The purpose of researching older adults and cognitive ergonomics was to get an understanding of effects of aging as well as older drivers and their interaction with road infrastructure.

- Searching for academic papers and government reports were made using Google Scholar and Chalmers Library. All digital and physical material that could be useful for the study was gathered in Mendeley Reference Manager.
- Search words: “older adults”, “elderly”, “seniors”, “cognitive aging” and “geriatrics” alone or in different combinations with “cognitive ergonomics”, “cognitive tunnelling”, “design”, “distractibility”, “information processing” and “ergonomics”.

Literature on WWD:

The purpose of researching WWD was to get an understanding of WWD, the reasons behind it and existing preventative measures.

- Academic reports and government reports were searched using Google Scholar, Ecosia and Chalmers Library and then gathered in Mendeley Reference Manager.
- Search words: ”wrong way driving” and “wrong-way driving in Europe”.

Literature on road infrastructure:

The purpose of researching road infrastructure was to get an understanding of how it is structured. Also to know what parts could be altered with the upcoming design solutions.

- Literature was searched using Google, Ecosia, the Swedish Government's website, the European Commission's website and Transportstyrelsen's website and then gathered in Mendeley Reference Manager.
- Search words: "riktlinjer vägutformning" (*eng. road design guidelines*), "regelverk placering vägmärken" (*eng. regulations, placement of road signs*), "vägmärken" (*eng. road signs*), "vägtyper i Sverige" (*eng. types of roads in Sweden*) and "types of traffic junction".

2.2.2 User Studies

The purpose of the user studies was to study driving habits, driving characteristics of older adults and their understanding of road infrastructure which would help build an understanding of challenges older drivers need to face. Additionally, the user studies aimed at getting a Swedish perspective of older drivers and WWD since the literature research showed that there is a lack of studies and data on this topic in Sweden.

The user studies were conducted in two parts: a digital survey which was mostly quantitative and interviews which were qualitative. Two semi-structured group interviews, one longer and one shorter, were held as a part of the qualitative study.

A semi-structured interview is a qualitative method and is organised by topics and sometimes questions in an interview guide but is flexible in how the questions are asked and the order of the topics as well as allows for adding of spontaneous topics. This type of interview can be shaped dependent on the respondent and their answers (S.Lewis-Beck et al., 2004).

Target group for the user study:

The participants of the user studies consisted of older adults, around 65 years or older, that have had a current experience of driving a vehicle both regularly and more occasionally. They preferably live in smaller cities and villages of south-western Sweden which would allow an easy access to the participants if they would agree on

taking part in the interviews in person. To target the older adults that have the relevant driving experience an assumption was made that there are more older adults outside of big cities, who are regularly driving since there are often less public transport available and often longer distances to travel. Also, since the project focused on motorway driving, an assumption was made that living close to a motorway makes it more likely to use that type of road more regularly compared to living far away from a motorway. Locations adjacent to Gothenburg were selected to simplify studies on site.

Recruitment via e-mail:

Mainly local branches of the associations *SPF Seniorerna* and *Pensionärernas riksorganisation (PRO)* in regions of Halland and Västra Götaland were contacted since they are general senior associations with many members and therefore had potential of reaching out to many older drivers.

20 associations were contacted by e-mail regarding handing out the survey to their members. Out of those, 4 responded but none of them were interested.

15 associations were also contacted by e-email with goal to invite their members to participate in the qualitative study. None of them responded.

Recruitment via phone calls:

5 out of the 20 associations were also contacted by phone and 2 out of those agreed to forward the survey to their members by e-mail (in total around 550 individuals were supposed to have been reached by the survey).

1 of the associations was also contacted by phone and invited to the qualitative study but was not interested in participating.

Recruitment via social media:

A copy of the online survey was also sent out in a private Swedish Facebook group for people born during the 1940s and 50s. The Facebook group had around 72700 members.

Spontaneous recruitment on site:

Final recruitment was made at Träffpunkten Simonsland, a place where senior associations organise their activities and where many older adults in Borås spend their free time. Guests of cafeteria at Träffpunkten were invited to participate in study the same day and if they could not attend, they were asked to fill in the questionnaire instead.

Participants of the study:

The number of participants for each part of the study, along with the distribution of gender and age (in those cases the age was known) can be seen in Table 1.

Table 1 Participants of the study as well as distribution of age and gender.

	Nr. of participants	Men/Women	Age of participants			
			60-64	65-74	75-84	85-94
Survey (senior associations)	29	14/15	2	14	13	-
Survey (Facebook)	52	14/38	-	16	33	3
Long group interview	2	2/0	-	-	-	-
Short group interview	8	2/6	-	-	-	-

Mediating objects:

One of the prerequisites for the study was to give the participants an opportunity to understand the topic and share their opinions about different parts of road infrastructure without putting their safety and comfort out for risks. Therefore, conducting the study while driving a car was not possible, and usage of different mediating objects was necessary. In order to spark the discussions and give an impression of interacting with real road elements following objects were used in the qualitative study:

- Pictures of road signs used on motorways and junctions.
- Pictures of different navigation tools.
- Maps of motorway junctions both in rural and urban areas.

Pilot interview:

A pilot test of the group interview was held prior to the actual interview with two design students. During the pilot test, the procedure of the interview as well as the formulation of questions were tested to see if the questions were interpreted as intended and if additional guiding questions or background information was needed. The participants of the pilot study were aware of the purpose of the pilot test and could therefore give feedback on its procedure. The pilot test was held in Swedish.

After the pilot interview, the question about different driving habits was improved with different examples of how these habits might have changed over the years. That improvement was made in order to make it easier for the potential participants to come up with different ideas. The question about preparations before longer trips was expanded since participants in the pilot interview perceived it as interesting for the target group.

Some improvement was also made regarding the mediating object: some pictures of navigation tools were replaced since they did not represent a GPS or a navigating passenger good enough. All pictures also got assigned a number so the participants in future studies could refer to them in discussions more easily.

Procedure of the group interviews:

The group interviews were held at two different meeting points for seniors. Both interviews were held in Swedish. The longer group interview lasted approximately 45 minutes, and the shorter group interview lasted approximately 10 minutes. The longer group interview touched the topics: *driving habits*, *changes of the traffic environment during their time as drivers*, *challenges*, *trips and navigation*, *different parts of the road infrastructure* and *WWD*. The interview guide can be seen in Appendix A. For the shorter group interview, no specific questions were asked, but different topics were introduced based on the interview guide. The topics were as follows: *trips and navigation*, *WWD* and *changes of the traffic environment during their time as drivers*. The shorter group interview was more unstructured to allow for conversation between respondents rather than steering them with specific questions.

Analysis:

Notes from interviews as well as survey responses were analysed with the help of a KJ-analysis to find patterns and themes regarding older drivers' experiences and opinions.

> *A KJ-analysis is a method for analysing and grouping data from User studies or ideation sessions. The KJ-analysis is designed to challenge pre-set ideas or assumptions and to find meaning and patterns in unstructured data (Cuba Czubajewski, 2023).*

This method was selected for analysing the data since the user studies mainly were qualitative and subjective with few objectively measurable data. Although an interview guide was used during the interviews, answers from respondents could differ and additional questions could be asked dependent on responses during the interview.

First, quotes were written on post it-notes and different colours were used for quotes from the different interviews and the survey. Then the post it-notes were one by one grouped together by trying to find relationships between them and some re-arrangement of the groups and division into main- and sub-groups was made. Lastly, the groups were defined into themes. The main themes were covering *navigation*, *challenges for older drivers*, *driving behaviour of older drivers* and *external factors*. Since the KJ-analysis is designed to challenge assumptions no categories or themes were decided in advance. The analysis can be seen in

Appendix B.

2.2.3 Analysis of Gathered Information

The information gathered from literature was summarised and categorised in a mind map in the software Figma into the main categories *Older adults*, *Older drivers*, *WWD*, *Existing measures against WWD*, *Types of roads* and *Laws and regulations*. In addition, findings from the user studies were added to the mind map.

The information was also summarised and categorised in a document into the main categories *WWD*, *Existing measures against WWD* and *Older drivers and cognitive ergonomics*. Based on the summary, conclusions were also made. These conclusions also helped the forming of the final guidelines. After the structuring in the document, also some re-arrangements were made and conclusions added in the mind map.

2.2.4 Function Analysis

To get an understanding of the purpose of different road elements within the road infrastructure, a function analysis was made.

A function analysis is a tool that can be used to understand the purpose of different products and services. Each function is described by a verb and a noun and then classified depending on type of function and on how important the function for a given product is (Johannesson et al., 2004).

The road elements that got identified in the system analysis such as road signs, ramps or crossroads were objects for the function analysis. The role of these elements in guiding the road users or maintaining functionality of the road infrastructure was analysed. Another purpose of conducting the function analysis was to link the literature findings as well as laws and regulations with the topic of the project. The identified functions also helped form requirements for the list of requirements.

Each road element of the analysis was analysed in a separate table with the following information (see Table 2):

Table 2 Information contained in the function analysis.

Function	Measurable limits	Class:	Priority:

		Main function (MF) Part function (PF) Side function (SF)	Necessary (N) Desirable (D) Worth considering (W) Unnecessary (U)
Function 1	Limit 1	MF	N
Function 2	Limit 2	PF	D

In this project, the measurable limits could be for instance existing regulations or usage of a certain road element. When it comes to the classification of functions, the main functions were central for the road element's functionality, the part functions were supporting the main functions, and side functions were extra functions that improved the functionality of the road element.

After the analysis was made, defined functions were labelled with:

- An important function, but the design of the road element could be changed.
- Important function to prevent WWD.
- No label.

The labels were used to identify important aspects to include when designing solutions as well as to identify which parts of the road infrastructure had improvement potential.

2.2.5 Systems Analysis

To get an understanding of the road infrastructure system and factors affecting the older driver, a systems analysis was made by creating a systems model. The systems model will also be used in this report to visualise important aspects of older drivers, the road infrastructure and the complexity of the research area.

A systems model is a way of describing relationships between different elements and its environment. A system has a boundary that defines what is a part of the system as well what is not. Elements in a system can be seen as systems of their own, so-called sub-systems (Flood & Carson, 1993).

Figure 3 shows an example of a systems model.

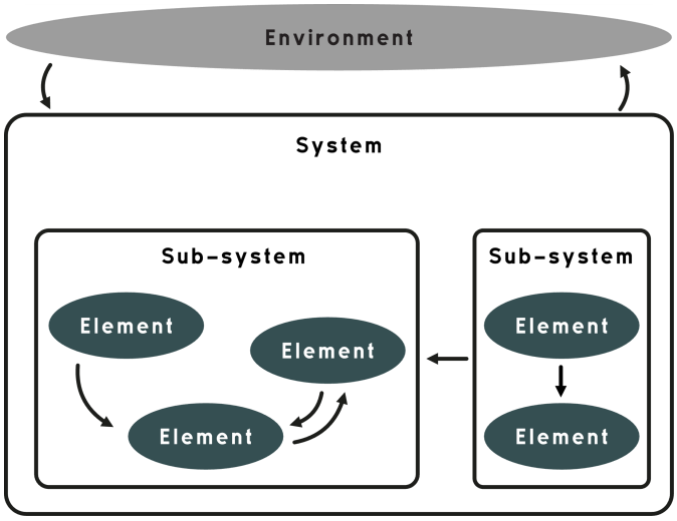


Figure 3 An example of a systems model.

In the systems model, the motorway and surrounding areas was analysed containing the sub-systems *surroundings*, *road infrastructure*, *the vehicle, the older driver* and *other road users*.

2.2.6 List of Requirements

Based on the gathered information and analysis, a list of requirements was created as a basis for concept development as well as for evaluation of concepts.

> *A list of requirements is a tool that allows to translate findings from information gathering into measurable decisions that set boundaries for solutions that will be developed* in a later state.

The list of requirements was divided into different categories (*cognitive*, *general*, *maintenance*, *older drivers*, *physical* and *sustainability*) based on their purpose and origin. These categories were used to sort the requirements, to simplify navigation through the list and to make sure that important aspects were covered.

The list contained the following information: category, description of requirement, level of priority (desirable or necessary) and possible comments. Requirements that are fundamental for the functionality of a product were classified as *necessary*, while the other ones that contribute to additional user value were described as *desirable*. An example of information in the list can be seen in in Table 3.

Table 3 Structure of the list of requirements.

Category	Description of requirement	Desirable (D) / Necessary (N)	Comments
Category A	Requirement 1	D	Comment
Category A	Requirement 2	N	
Category B	Requirement 3	N	Comment

The project aimed to develop different types of solutions, covering different parts of the road infrastructure. Therefore, not all requirements could be applicable to all solutions which had to be considered during the evaluation of the concepts at the end of the project. For instance, a requirement regarding colour contrast for visibility is not relevant for a solution that is not designed to be seen by the driver.

2.3 Idea and Concept Creation Phase

The purpose of the *Idea and concept creation phase* was to explore a wide set of possible solutions and to develop a limited number of concepts that could be further developed in the upcoming phase. In this phase of the project, ideation and evaluation of ideas was made in several iterations. Some of the ideas were selected for further development into concepts. A visualisation of the selection process can be seen in Figure 4. The ideation phase partly overlapped with the problem understanding phase. Therefore, some additional gathering of information and data was made to be able to investigate some of the ideas even further.

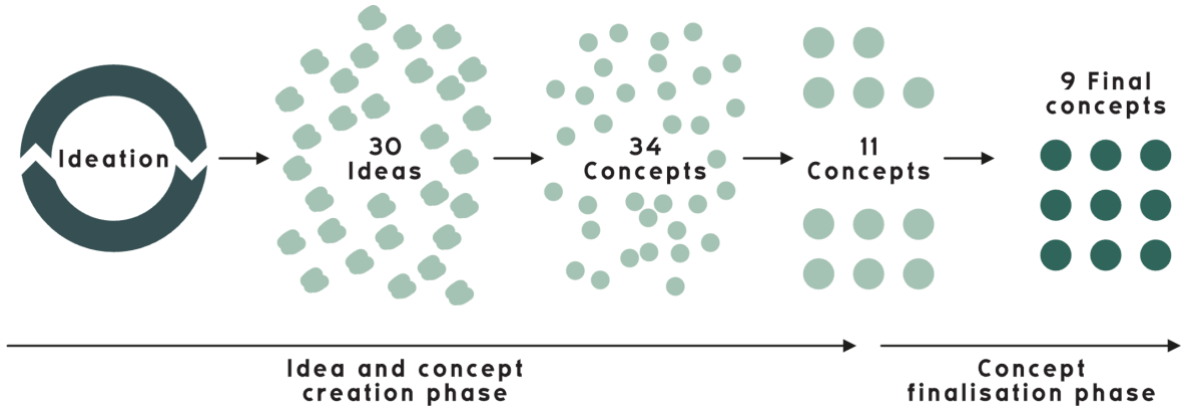


Figure 4 Visualisation of the idea and concept selection process.

2.3.1 Procedure of Ideation

Ideation was made in several sessions where each session had a different focus (different design strategies/methods, purposes and types of solutions). Some examples of the focus areas are *clarifying direction of traffic*, *new geometric design of interchanges*, *ideas based on design strategies for behaviour change* and *calling attention of distracted drivers*. The procedure of ideating based on different focus areas was selected to be able to tackle the complexity of WWD and to explore a wider range of potential solutions that could be applied on different parts of road infrastructure.

Different ideation methods were used, but all sessions started with setting a certain theme and ended with a presentation of ideas followed by a discussion regarding potential, possible improvements or new ideas. Mostly, Brainstorming was used, but also Crazy 8's and open discussions.

Brainstorming is an ideation method where quantity is more important than quality. It starts with defining a theme or a question that the session should focus on, then the participants sketch or write down ideas individually on a paper. After a set time, the ideas are presented and discussed (Wikberg Nilsson et al., 2015). Crazy 8's is an ideation method for quickly creating ideas. It starts with creating a grid with eight squares on a paper. The participants then sketch one idea in each square during eight minutes (Design Sprints, n.d.).

For one of the sessions, regarding geometric design of interchanges, different digital parts of roads were used to create collages to produce new geometric interchange designs. The notes and sketches were photographed and collected in Figma.

After the ideation sessions, the ideas were discussed and 30 ideas were selected. Their benefits/potential as well as disadvantages/challenges regarding how well they addressed the needs of older drivers and the technical aspects of installation and maintenance were listed for each idea.

2.3.2 Procedure of Concept Creation

During the conceptualisation phase, the 30 ideas from the ideation phase were developed further into concepts. Some of these ideas were combined, and some of them were split into more concepts. A total of 34 concepts were developed in this phase of the project.

Each concept was then evaluated based on how well it fulfilled eight different criteria (see Table 4) and additional comments were made in an evaluation matrix (see Appendix C). Fulfilled criteria received “+1”, non-fulfilled criteria “-1” and criteria not relevant to the solution scored “0”. The criteria were selected to cover important aspects of preventing WWD and of older drivers’ information needs in road infrastructure as well as solutions in relation to other parts of the system since these are central aspects of the project. In addition, a criterion regarding innovativeness was added to ensure the solutions would bring something new to the area of WWD.

Table 4 Evaluation criteria and their descriptions.

Criteria	Description	Motivation
Clarity	How clear and understandable is the information?	Clarity of information is important for older drivers to be able to understand the information/usage of the solution and thereby reduce cognitive load.
Visibility	How easy is it to see the solution? (E.g. font size, contrasts etc.) (*Note: not all solutions are meant to be visible by drivers*)	Solutions with good visibility can easily be spotted and read (for signage) by older drivers.

Guidance	Is the solution guiding the driver in an effective way?	Solutions with clear guidance can help minimise confusion.
Attracting attention	Does the solution contain elements that attract attention of the driver? (*Note: not all solutions are meant to attract attention of the driver*)	A solution that attracts attention can alert drivers who are not observant or make it easier to spot important information in a complex environment.
Potential cost	Resources (time, money and space) required to implement the solution.	Solutions that involve major changes or require much space or resources can be difficult to implement, especially in a near future.
Sustain-ability	Is it possible to maintain the solution? What is the potential product life cycle?	A solution that requires much maintenance or has a short life cycle could be non-effective if implemented in many places.
Other road elements	How is the solution harmonising with other road elements?	It is important to view the solution in the context of the entire road environment since it should work as a part of a system.
Innovation	Is the solution groundbreaking?	A new solution in the context of WWD can provide a new perspective.

The concepts were then categorised into groups based on the type of solution (*Improved navigation*, *Avoiding wrong turns*, *Reminding about the direction of traffic* and *Minimise risk of accidents after WWD*). Concepts with a score of five or higher were marked (in total 11 concepts). Six of these concepts were not considered to have further potential for improvements and were therefore not prioritised. In addition to the five concepts with the highest scores, six other concepts were selected for further development. These were selected due to having potential for improvement even though they did not score the highest in their current state (partly since some of the criteria was not applicable to the solutions), but also to enable for a variety of different types of solutions in the final phase of the project. In total, 11 concepts were selected for further development.

2.4 Concept Finalisation Phase

The purpose of the *Concept finalisation phase* was to develop and evaluate a limited number of concepts from the previous phase in more detail. The goal was to develop the concepts with clear visualisations and descriptions so that their potential effects on preventing WWD could be assessed. A meeting with a traffic engineer was also arranged during the development of the concepts. After the concepts were finalised, they were evaluated with expert panel, target group and against the requirements list. Suggestions for further improvement was made based on the evaluation carried out in later stages of the project.

2.4.1 Concept Development

The concepts were developed by considering different design aspects depending on the type of solution. These included factors such as colour, shape, pattern, materials, size, and placement.

Existing rules and guidelines based on the findings from the research study were used to improve the concepts regarding their coherence with other road elements and adaptation to the older drivers' needs. For instance, sizing of text on signage as well as the sizes of signage was made based on Swedish regulations.

During the phase, some of the 11 concepts were divided into several concepts, some were combined to utilise strengths from different concepts in the best way. One of the concepts were removed since it was not considered to provide any possible improvement in the road environment. In total, 9 final concepts were developed.

2.4.2 Meeting with a Traffic Engineer

A meeting with a traffic engineer was arranged to get insights and feedback regarding the concepts from an expert within road infrastructure. The traffic engineer provided a different view on the concepts, and the feedback could be used to further develop the concepts in more detail to better be applicable in practice.

Procedure

A digital meeting was arranged for a duration of approximately one hour. The meeting began with an introduction to the project and goal with the meeting, During the meeting, descriptions and visualisations of the concepts were presented one by one. Some considerations regarding the concepts were discussed and the traffic engineer was encouraged to comment and give feedback from a traffic engineer's point of view. During the meeting, relevant comments were annotated.

2.4.3 Evaluation of Concepts

Evaluation of concepts was made to get an idea of expected effects, investigate advantages and possible improvements as well as to ensure that the concepts fulfilled the complete list of requirements. Theoretical evaluation with a panel of experts was made to support the evaluation with expertise from different academic fields. An interview with an older driver was also conducted to control whether the solutions were understandable for target group and if the design choices that was taken resulted in better visibility och perception of the road elements. Finally, a list of requirements was used to control some technical issues of the concepts such as their sustainability, resilience to the weather conditions or their coherence with other road elements. More details about each type of evaluations are presented below.

2.4.3.1 Evaluation with Panel of Experts

The purpose of the evaluation panel with experts was to get insights from experts within different relevant fields outside of the project (Table 5). A meeting with all experts was arranged on one occasion with the duration of approximately 45 minutes. This type of meeting was selected for the expert to be able to build on each other's reasoning and for them to be able to discuss the concepts together. Two of the experts participated on site and one expert participated through an online meeting.

Table 5 Participants of the expert panel and their area of expertise.

	General field
Participant 1	Cognitive ergonomics

Participant 2	Design & Human Factors
Participant 3	Road infrastructure

Procedure

A digital presentation was prepared where each of the 9 concepts, including different alternatives of the concepts, was presented with descriptions and visualisations one by one. A representation of two traffic interchanges where the concepts were placed was also printed out on paper and placed on the table visible for the participants on site (see Figure 5). In addition, all visualisations were printed out on paper for the participants to be able to watch them more closely and to be able to view different concepts at the same time.

Figure 5 Setup for evaluation meeting with a map and pictures of concepts.

The evaluation was held in English and started with a short introduction to the project and the goal with the evaluation panel. Then some important aspects for older drivers and WWD was presented. The experts were also provided with three general questions to consider during the evaluation:

- How the concepts work together with other road users and other parts of the road infrastructure.
- Implementation and construction of the concepts.
- Their perspective on how older drivers will interact and be affected by the concepts.

Each concept was presented one by one and the participants were invited to share their thoughts and ideas after each concept was presented. Some guiding questions were asked to spark conversation and for concepts with different concept alternatives, the participants were asked to compare the different alternatives.

During the meeting, relevant comments were annotated and tagged with the respective participant. As a backup, the meeting was audio recorded to enable review of certain parts of the meeting afterwards.

During the meeting, six out of the nine concepts were evaluated. During the development of the concepts as well as during the meeting with the traffic engineer, the remaining three concepts were considered to have less assumed positive effects compared to the other concepts and where therefore not prioritised during the meeting. Which concepts that were evaluated or not by the expert panel can be seen in Chapter 9.

2.4.3.2 Evaluation with an Older Driver

The purpose of the evaluation with the older driver was to get insights on the concepts from the target group of the project. An interview with an older driver was scheduled on site with the duration of approximately 45 minutes. The format of a qualitative interview was selected to get deeper insights compared to for instance through survey responses.

Participant

The participant of the interview was a female older driver from an urban area.

Procedure

The procedure of the interview was the same as for the expert panel meeting. However, the interview was held in Swedish. The digital presentation was not shown to the participant, but the same printed map and visualisations were used, and the structure of the digital presentation was used as an interview guide. During the interview, relevant comments were annotated and for backup, the meeting was audio recorded.

For the interview, all the 9 concepts were presented and evaluated by the participant.

2.4.3.3 Analysis of Expert Panel and Interview with the Older Driver

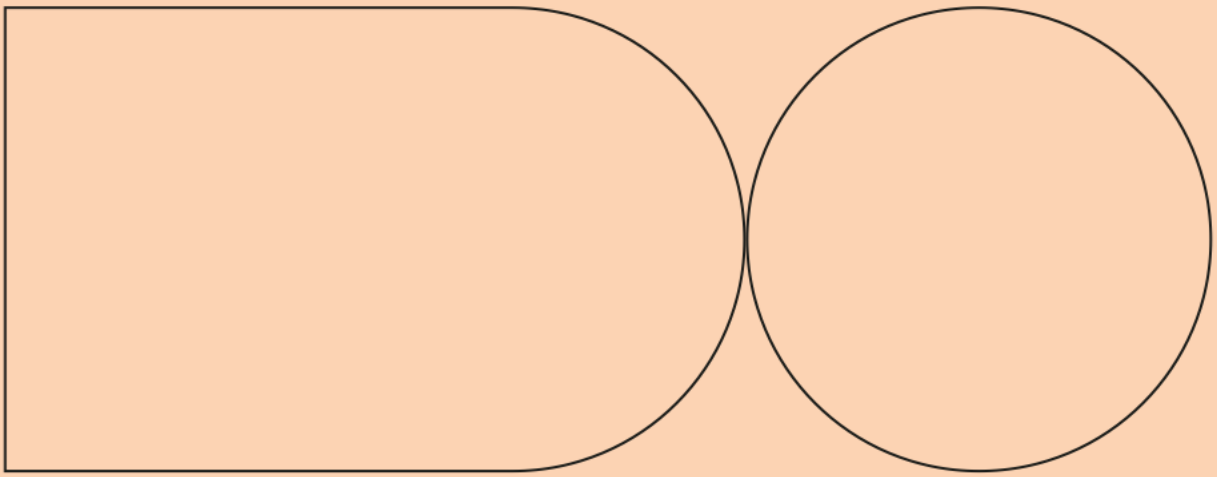
The expert panel meeting as well as the interview with the older driver was analysed with the help of a KJ-analysis. Comments regarding each concept was grouped together. Comments from the different evaluations were separated with post it-notes in different colours. For each concept, comments were categorised and summarised to see possible positive and negative aspects of each concept. In addition, suggestions on choice of concept alternatives and future improvements were made for each concept based on the evaluation.

2.4.3.4 Evaluation with List of Requirements

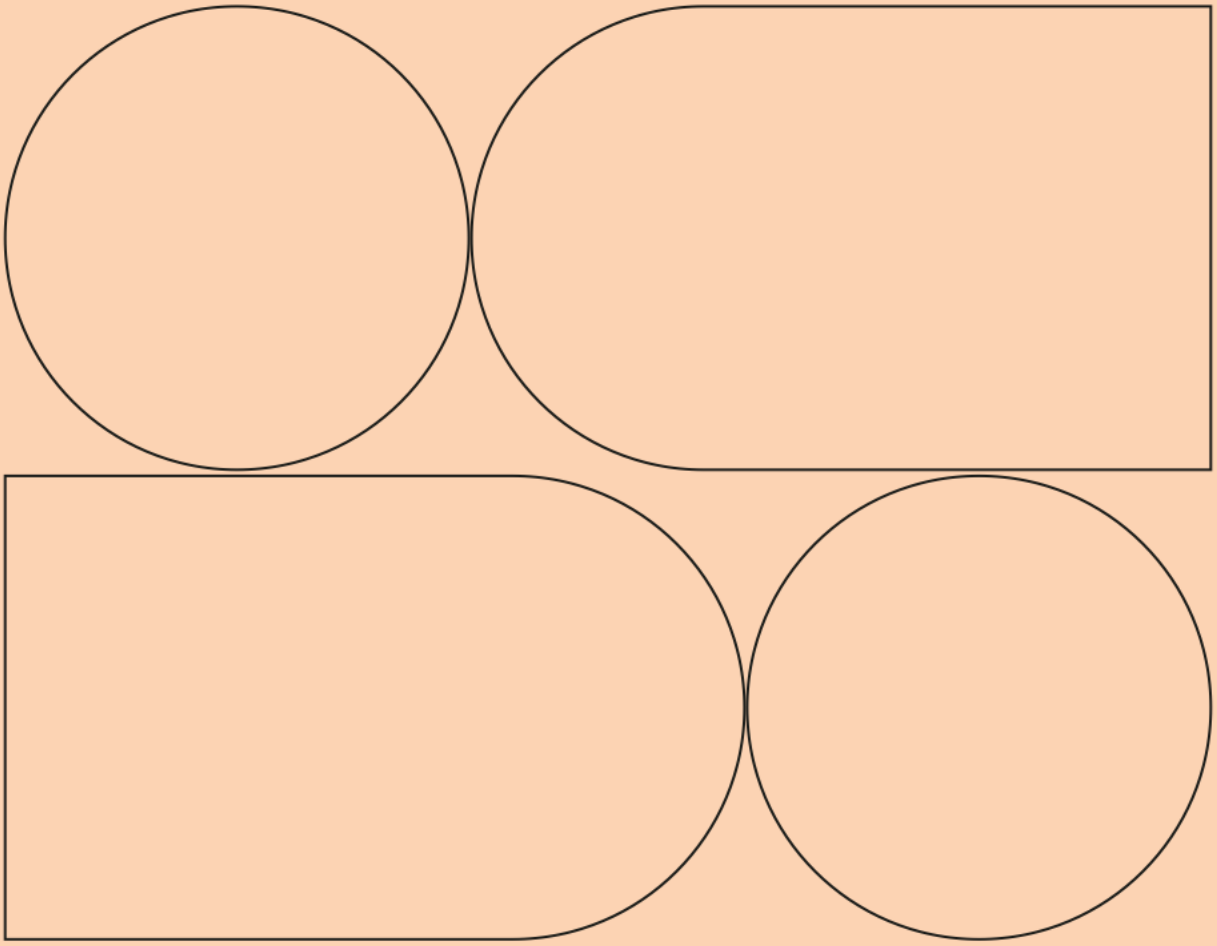
An evaluation based on the list of requirements was made to get a more objective and coherent evaluation of the concepts compared to the evaluations with the expert panel and the older driver.

Procedure

Each concept was evaluated individually to see if the requirements was fulfilled or not by the concept. Since all requirements are not applicable to all concepts (see explanation in Section 2.2.6), relevant requirements were selected. In cases were different concept alternatives differed from each other, additional comments were made to describe how they differed from each other. Afterwards, summaries and comments on possible improvements for each concept were made.



Problem understanding



3 Description of road infrastructure and driver system

This chapter explains the structure of how the findings from the literature study and user studies will be presented. Using the system model as the framework (Figure 6), it explains how findings about road infrastructure, an older driver and a vehicle interact with each other and contribute to complexity of WWD phenomenon.

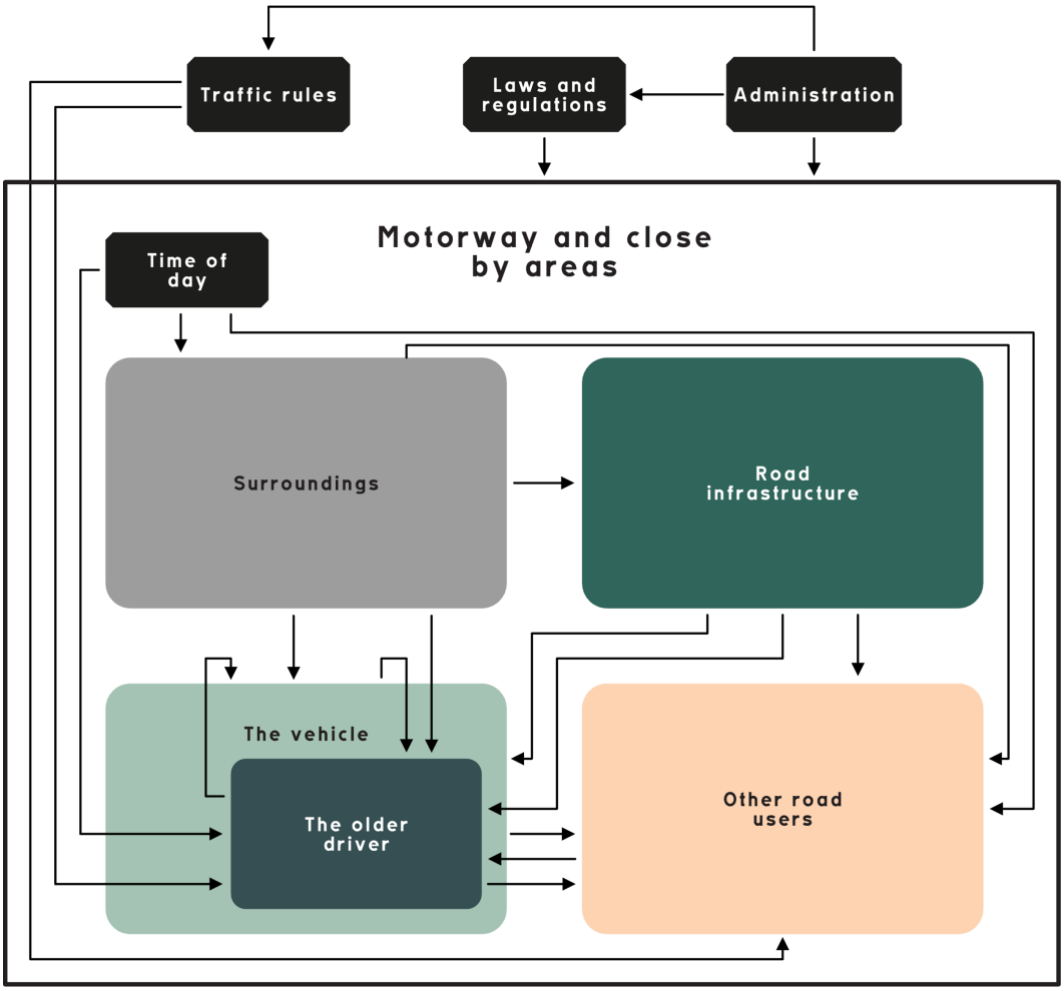


Figure 6 Systems model of the motorway and close by areas.

In this chapter different types of WWD will be presented along with the reasons behind them. Finally, a selection of different measures against WWD used in different parts of the world will be analysed.

4.1 Different Types of Wrong-way Driving

WWD can occur in different ways and in different places. The most common types of WWD happens when a driver enters a motorway on an exit ramp instead of an entrance ramp or when a driver makes a U-turn on the motorway (Holgaard & Møller, 2020). Different studies made in different countries indicate different amounts of these types of WWD, but around 30-40% off WWD seems to be related to exit ramps and a similar amount to U-turns on motorways (Larsen & Carstensen, 2011), (Unfallforschung der Versicherer, 2023). WWD can also happen in connection to road works or rest areas on motorways (Holgaard & Møller, 2020). In rare cases, WWD have also occurred from turning left onto a motorway from an entrance ramp or due to reversals on the motorway (Larsen & Carstensen, 2011).

4.1.1 Entering the Motorway from an Exit Ramp

Different types of interchanges and designs of ramps seem to be more or less vulnerable to inaccurate driving resulting in WWD. In a study from Illinois were known as well as estimated entry points for WWD were summarised, two types of interchanges were especially common: compressed diamond and diamond interchanges (Zhou et al., 2015). Continuing, also partial cloverleaf interchanges were quite common while full cloverleaf seemed to be one of the safest types of interchanges. Descriptions of some standardised interchanges can be seen in Section 5.2.

4.1.2 U-turns on Motorways

In some cases, U-turns on motorways occur when a driver misses an exit and turns back (Nihei et al., 2022). In other cases, drivers made U-turns to avoid paying for driving on motorways and a few happened when drivers lost control of their vehicles that began to spin and then they started driving against traffic (Larsen & Carstensen, 2011).

4.2 Reasons Behind Wrong-way Driving

Accidents caused by wrong-way driving lead to serious consequences but investigating the reasons behind them is challenging due to difficulties with gathering the data. According to the studies done in US only 10% of witnesses to WWD report the event to the authorities (Holgaard & Møller, 2020). Reports coming from the drivers that caused WWD are also limited because they must both survive and remember the course of events (Holgaard & Møller, 2020). It is usually very difficult to determine where the driver made the wrong turn which is a very important gap in the investigations of WWD (Ruer et al., 2015). However, the research study shows that there are some factors that lead to the wrong decisions being taken by the drivers involved in WWD.

4.2.1 Distractions

Being distracted can impact perception of the surroundings and confuse the driver (Sagberg, 2003). Distractions can occur while listening to radio (Holgaard & Møller, 2020) but also when a driver tries to find the way in an unfamiliar area.

Providing better navigation but also recognising possible mistakes and scanning the surroundings can be done by a passenger. In majority of cases, the drivers that caused WWD were alone in the car (Holgaard & Møller, 2020; Kemel, 2015; Zhou et al., 2015).

4.2.2 Road Geometry

Interchanges are parts of the road system where many cases of WWD begin. A poor overview of the traffic situation can confuse the driver and make it difficult to see where to drive and to plan the driving in advance (European Commission, n.d.). The geometry of a road can also suggest to the driver a possible decision to take. A soft turn from an exit ramp can be perceived as inviting and lure the driver onto the wrong path (Holgaard & Møller, 2020; Larsen & Carstensen, 2011).

As it was mentioned in Section 4.1.1, WWD tend to happen more frequently on partial cloverleaf and diamond types of interchanges (see Section 5.2 for more detailed description of different types of interchanges). The main reason for that is the relatively close placement of exit and entrance ramps, which can lead to additional confusion (Holgaard & Møller, 2020; Sørensen, 2016). According to statistics, the lowest risk for WWD occurs on full cloverleaf interchanges (Sørensen, 2016).

Intersections between the secondary road and exit/entrance ramps are the specific part of interchanges where many cases of WWD have begun (Figure 7). These can be designed as both traditional intersections with or without traffic lights and roundabouts. Roundabouts are generally perceived as the safest way of intersecting different traffic flows, but they can also confuse the drivers and lead to wrong turns (Larsen & Carstensen, 2011; Sagberg, 2003). More complex interchanges, usually in urban areas, that contain many connecting roads, several lanes, traffic lights and different modes of traffic can also increase the risk for WWD (Sørensen, 2016). In both cases, poor geometric design of roads and misleading soft turns can contribute to additional confusion (Zhou et al., 2015).

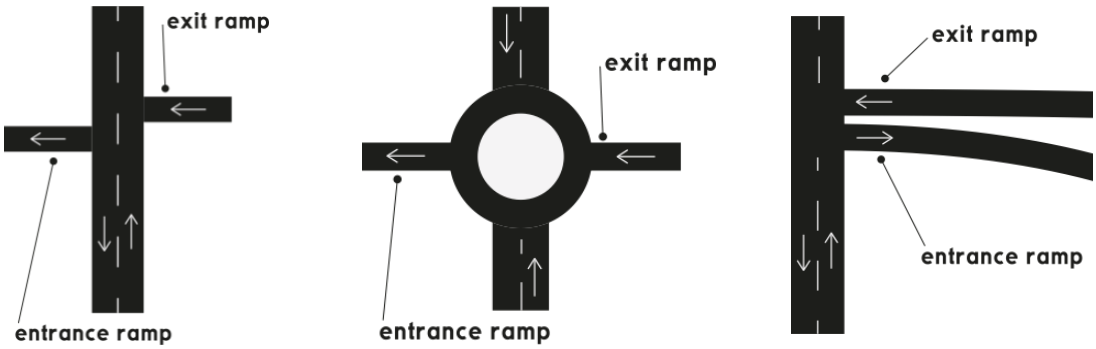


Figure 7 Examples of intersections around an interchange.

4.2.3 Signage

Road signs are one of the main parts of visual communication in road infrastructure and are an important measure in understanding and preventing WWD. Bad condition, poor visibility, lack of information, too high or too low number of signs and wrong size are factors that can contribute to WWD (Holgaard & Møller, 2020; Nihei et al., 2022; Sagberg, 2003).

Effectivity of road signs also depend on how often and how thoroughly the driver scans its surroundings. Confident drivers that are familiar with the surroundings tend to scan the environment briefly and less vertically (Nihei et al., 2022). Less careful scanning can lead to overlooking signage and therefore driving incorrectly.

4.2.4 External Conditions

There are also other external factors that can lead to WWD such as traffic congestion, weather conditions, season and time of the day. Driving a car during rush hours is generally perceived as stressful and demanding but it allows a driver to follow other cars and avoid WWD (Holgaard & Møller, 2020). The amount of traffic and complexity of road infrastructure is higher in urban areas which requires more mental resources and leads to higher risk for accidents caused by WWD than in rural areas (Holgaard & Møller, 2020; Zhou et al., 2015).

In general, bad weather conditions seem not to contribute much to WWD (Zhou et al., 2015) because it requires drivers to drive more carefully and adjust speed to the road conditions (Holgaard & Møller, 2020). On the other hand, bad weather conditions and darkness can decrease visibility and cause confusion (Sagberg, 2003). Along with tiredness and driving under influence it explains why WWD are more likely to occur at

night (Holgaard & Møller, 2020; Kemel, 2015; Larsen & Carstensen, 2011; Unfallforschung der Versicherer, 2023; Zhou et al., 2015).

However, there is no clear relation between time of week and risk of occurring WWD. According to statistics from Danmark and France, WWD are slightly more common during weekends, and it can probably be linked to driving under influence (Holgaard & Møller, 2020; Kemel, 2015; Zhou et al., 2015).

4.2.5 Reasons Behind U-turns

U-turns or driving backwards on motorways is usually caused by drivers forgetting that they are driving on the motorway or being distracted and missing the intended exit (Sagberg, 2003). Roadworks can also be a reason for a sudden increase of cognitive load and lead to drivers taking wrong turns (Holgaard & Møller, 2020).

WWD can also occur in crossways while turning left and turning onto the inner lane of the wrong direction. It is more likely to happen when the driver does not pay enough attention to the signs or when there is a poor overview of the crossroad (Sagberg, 2003).

4.3 Existing Measures Against Wrong-way Driving

There are several different measures against WWD around the world. Some of them are physical solutions or guidelines for design of the road area while others are related to policies or educating drivers. Some of the solutions aim to prevent the WWD from happening, others to minimise accidents caused by WWD. The solutions can also be in different scale and affecting different parts of the road areas.

4.3.1 Road Geometry Design of Interchanges

When it comes to the geometric design of interchanges, the road itself can be designed to clarify an intended path or a path not to take. Here follows some geometric factors that can be altered:

- **Overview of interchanges:** To enable drivers to get an overview of the area, the secondary road can be located higher than the primary road. This is especially a good measure for intersections (Sagberg, 2003).

- **Sharp turns:** Using sharp connections between the secondary road and the ramp where a driver is not supposed to enter makes the turn feel unnatural (Holgaard & Møller, 2020; Sagberg, 2003). A soft turn on the other hand can make the turn inviting (see Figure 8). Road markings can also be used to make the turn appear more sharp. This can work for avoiding both left and right turns.
- **Connection with secondary road and ramps**: Using a wide connection between the secondary road and the entrance ramp and a narrow connection for the exit ramp makes it feel more natural to turn onto the entrance ramp (Holgaard & Møller, 2020).
- **Connection between ramps**: In the Netherlands, entrance and exit ramps are connected with a ramp to enable WW-drivers on the exit ramp to drive onto the entrance ramp instead (Sørensen, 2016).

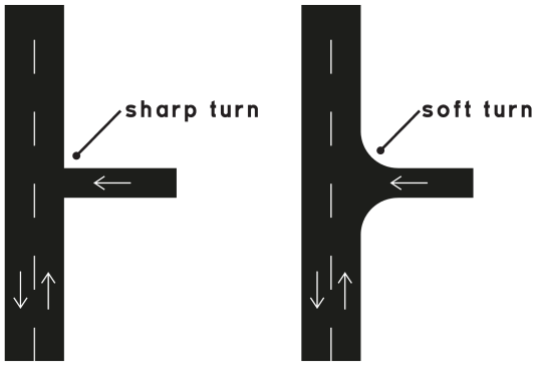


Figure 8 An illustration of a sharp turn (to the left) and a soft turn (to the right).

4.3.2 Clarifying Direction of Traffic

To make WW-drivers aware of them driving against traffic, and/or to clarify the correct path, the direction of traffic can be clarified in different ways:

- Different types of **road markings** such as **stop lines** at the end of exit ramps (Holgaard & Møller, 2020), **road arrows** (Holgaard & Møller, 2020; Sagberg, 2003) and **road lines in different colours** (Sagberg, 2003; Sørensen, 2016).
- **Reflexes** on roadside posts/barriers or on the roadway. Red reflexes are visible to WW-drivers and sometimes white/yellow reflexes are visible to “right way”-drivers (Holgaard & Møller, 2020; Ruer et al., 2015; Sagberg, 2003; Song et al., 2024; Sørensen, 2016).

  - Worth mentioning is that roadway reflexes do not work very well in winter conditions with snow (Sørensen, 2016). Also, this type of solution is not very successful to prevent WWD which could be due to an often cognitively loaded condition among WW-drivers were there are not enough mental resources available to decode the meaning of the reflexes (Holgaard & Møller, 2020).
- **LED-lights at the road surface** (Holgaard & Møller, 2020).

4.3.3 Alerting Wrong-way Drivers on Exit Ramps

In some countries such as the US, “wrong way”-signs are often accompanied with different types of lights or dynamic signs activated by WW-drivers entering the exit ramp in the wrong direction. These solutions are generally considered effective and typically involve a sensor that detects WW-drivers with the help of for instance radar, laser or camera detection (Song et al., 2024) and some type of blinking lights such as LED lights (often red) (Holgaard & Møller, 2020; Ruer et al., 2015). In Slovenia, a similar solution with dynamic signs and road booms activated by video surveillance is being used (Song et al., 2024).

In Denmark, a similar solution with red diode lights mounted at the road surface in the centre of the lane was tested. These lights started to flash in such a way that the light appeared to be running towards the WW-driver This solution also had cameras that could document the WWD and it could be seen that most WW-drivers turned around proving the solution to be rather effective. However, some drivers deliberately continued driving in the wrong direction. The solution was also sensitive to snow (Vejdirektoratet, 2018).

Sometimes, videos are used to see if WW-driver self corrects and automatic messages are sent out to display messages on motorways, send out texts to people or to collect data (Song et al., 2024). Worth noting is that these types of solutions can be falsely triggered by for instance wind (Vejdirektoratet, 2018).

4.3.4 The Road Environment

The surrounding areas and the road environment can be a part of preventing WWD. Enhancing a good overview of interchanges and thereby navigation is one part, such as pruning of vegetation (Vejdirektoratet, 2018). Another example is using road lightning to ensure good visibility conditions in interchanges (Holgaard & Møller, 2020). Road lightning can also be used to manage the attention of drivers. For instance, lightning posts can be placed at entrance ramps to help draw the driver's attention towards the correct path (Vejdirektoratet, 2018).

4.3.5 Road Signs and Road Markings

When it comes to road signage and road markings, there are several factors affecting how drivers interpret the information. It can be the information displayed or the design of the signage itself, but also its size and placement as well as combination of different signage. Worth noting is that signage itself can only address unintentional WWD which is 36% of all WWD (Unfallforschung der Versicherer, 2023).

4.3.5.1 Design of Signage

Existing signage can be altered to better attract the attention of the driver. For instance, a yellow background can be used for a "no entry"-sign (Figure 9a). This alteration seems to be effective to prevent WWD, probably since the yellow colour attracts the driver's attention, but when the interpretation of the sign was tested, the yellow colour was difficult to understand for the test participants (Ruer et al., 2015). Another alteration is to display the information not only with a symbol, but also with text such as adding "Do not enter" on a "no entry"-sign (Vejdirektoratet, 2018) or "Turn back" (Sørensen, 2016) (Figure 9b).

(a) (b)

Figure 9 Alterations of the C1-sign where (a) has a yellow background and (b) has the text "do not enter" on it.

It is not only the appearance of the sign itself, but also the design of the signpost that can help make the signage more noticeable. For instance, a red reflective tape on the signpost can increase the visibility of the sign (Holgaard & Møller, 2020; Song et al., 2024).

Signs can also be traditional (static) or with lights. When it comes to usage of signage with lights, traditional road signs seem to be perceived as more important by older drivers which could be due to a longer exposure to traditional signage (Ruer et al., 2015).

When it comes to the size of the signs, some authors such as Song et al. (2024) suggests increased size of signs as a preventative measure, while other authors such as Holgaard & Møller (2020) do not consider it as rather effective.

4.3.5.2 Placement of Signs

The placement of signage as well as the combination of different signs can affect the driver in different ways. For instance, spreading out the information on the signs can help reduce the mental workload of the driver (Sagberg, 2003). Also to place the signage where the driver is expected to look, such as before an incorrect turn could be made, is important according to the author. Placing the signs closer to the ground (around 0,5-1,2m from the ground), and thereby closer to eye level, is another example (Holgaard & Møller, 2020; Song et al., 2024; Vejdirektoratet, 2018) and has been proven effective in for instance California (Vejdirektoratet, 2018). On the other hand, placing signage close to the ground worsens the noticeability from distance (Holgaard & Møller, 2020). To angle the signs to make them more visible is another intervention (Holgaard & Møller, 2020). When it comes to “no entry”-signs at exit ramps, they should be placed on both sides of the road (facing a potential WW-driver) (Song et al., 2024; Vejdirektoratet, 2018).

4.3.5.3 Signage Non-existent in Sweden

There are some road signs for exit ramps used in other countries:

- Signage with the text “Wrong way”.
- Signage with the text “Enter here” or “Motorway entrance”.
- Signage with the text “Warning for wrong way drivers”.
- “The Austrian hand”
    - There are several different designs in different countries (Figure 10). In Norway for instance, the background colour is red instead of yellow to clearly differ from other Norwegian road signs and thereby attract the driver’s attention (Sørensen, 2016).
    - This type of signage displays the same message in more than one way which is supposed to be more effective (Sørensen, 2016).

Figure 10 Polish road sign F-24 inspired by "The Austrian Hand" (Source: public domain).

4.3.5.4 Road Markings

Different type of road markings, both in 2D and 3D, can be used in different ways:

- Road lines can be used to guide a driver correctly on a left turn (Sagberg, 2003; Sørensen, 2016).
- Road markings that indicate the entrance of a motorway by displaying the road number and direction has been proven to be effective in the US (Ruer et al., 2015).
- 3D road marking that displays “STOP” for WW-drivers (Vejdirektoratet, 2018).

4.3.6 Digital Solutions

There are several digital solutions that can be used to stop WW-drivers such as audible warning messages (Song et al., 2024) or driver assistance-systems in cars. Driver assistance systems that do not intervene, such as traffic sign recognition, can however not affect intentional WWD (Unfallforschung der Versicherer, 2023). There are also some app solutions that detects the direction of travel with the help of GPS-systems and alerts WW-drivers as well as other nearby drivers (Unfallforschung der Versicherer, 2023). According to the authors, up to 95% of WWD could be addressed if digital solutions that communicate with both the WW-driver as well as other road users are used.

4.3.7 Physical Barriers

There are some solutions that can physically prevent WWD or stop WW-drivers:

- Road spikes that flat tires of WW-drivers can be used but has not been proven to be effective (Sagberg, 2003; Sørensen, 2016).
- Side roads on exit ramps with a reflective line that naturally guides a WW-driver of the exit ramp (Sagberg, 2003).
- Centre barriers on secondary roads that prevent wrong turns onto exit ramps (Sagberg, 2003).
- Traffic islands placed close to intersections (Song et al., 2024) and painted in bright colours to draw the driver’s attention (Song et al., 2024; Sørensen, 2016).
- Side lines with grooves can be used on secondary roads to alert drivers who make a wrong turn (Sagberg, 2003).

5 Road infrastructure

This chapter presents descriptions of the elements that were identified in the road environment and structured in the system analysis. Investigating them is necessary to understand the context in which WWD occur and to prepare the basis before the idea generation and concept creation phases. In this chapter, road elements (Figure 11) and different types of interchanges will be presented to give a better understanding on the variety of the cognitive load that can be experienced depending on the traffic situation and therefore help to identify possible improvement areas.

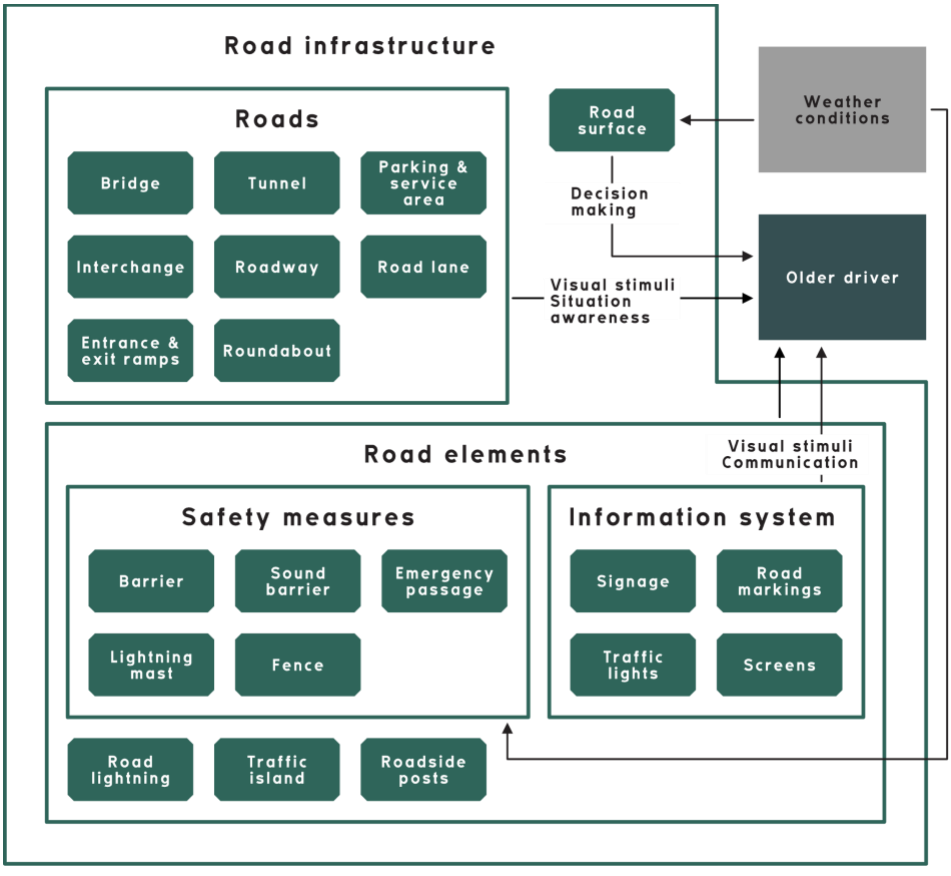


Figure 11 Systems model of the road infrastructure.

5.1 The Road Area and Road Elements

When talking about roads, it is not only relevant to address the roadway and its road elements, but also nearby areas. According to Swedish law, the road area (see Figure 12) includes the roadway, other areas and road elements needed for the existence, operation and use of the road (Trafikverket, 2020).

Examples of elements included in the road area are:

- Road signs and road markings
- Bridges
- Road safe zones (side areas)
- Rest areas and bus stops
- Road lighting
- Roadside strips
- Roadside posts
- Roadblocks

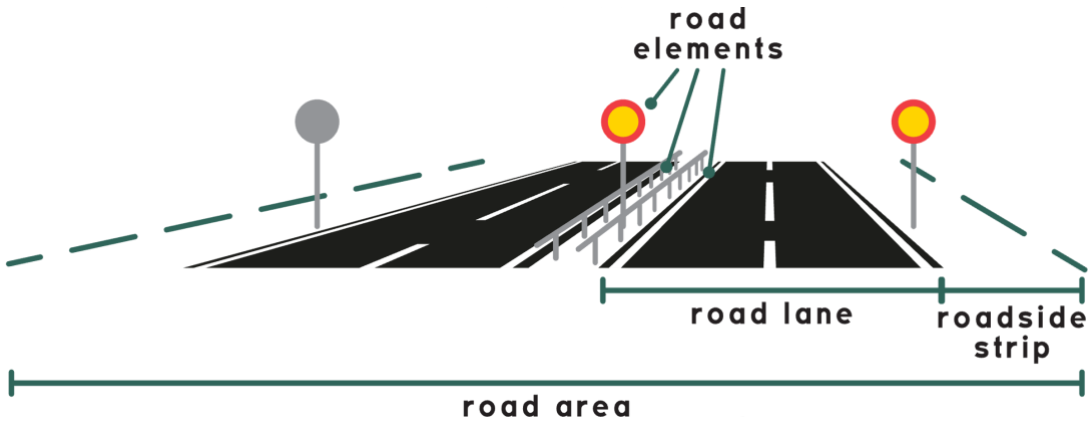
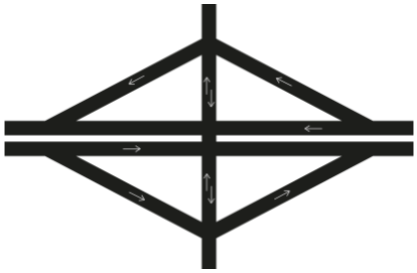
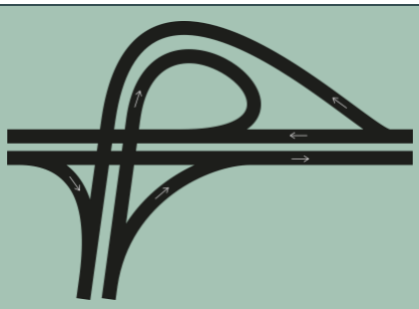
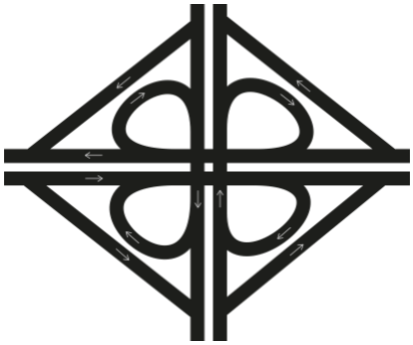


Figure 12 An illustration of the road area including road lanes, roadside strips and road elements.

5.2 Types of Interchanges

There are three types of grade separated junctions (Table 6) that are commonly used in connection to motorways and expressways (European Commission, 2026). These types can often be mixed and adjusted to the local needs. The main purpose of grade separated interchanges is to separate crossing streams of traffic and reduce accidents.

Table 6 Types of interchanges.

Type of interchange	Schematic view
Diamond	
Trumpet	
Cloverleaf	

Depending on the type of roads that are crossing and the type of the interchange itself there might be differences in the elements that are included in such junction. In general, all kinds of interchanges consist of at least two crossing roads, for example two motorways or one motorway and one main road, and ramps that connect the main roads.

In case of two motorways crossing (Figure 13) all streams of traffic are usually separated to avoid unnecessary speed limits and to guarantee safety and efficiency for the road users. The ramps can be formed in way that is compatible with how a typical cloverleaf junction looks like.

Figure 13 Trafikplats Petersborg 12, Malmö (Source: ©OpenStreetMap).

However, the majority of interchanges in Sweden are placed where a motorway crosses with smaller roads, both national and local. In those cases, the flows of traffic do not necessarily need to be separated and different kinds of street intersection can occur.

Interchanges in urban areas are in general built closer to each other (Vägars Och Gators Utformning, 2024) and can be quite complicated due to accommodation of needs of not only car drivers but also pedestrians, cyclists and public transportation. Size and form of interchanges depend usually on the limited space available in cities. It is also common that crossings between the secondary road and the ramps are roundabouts (Figure 14) or crossroads with traffic lights.

Figure 14 Eriksbergsmötet, Göteborg (Source: ©OpenStreetMap).

In rural areas where population density is lower, distances between interchanges are larger and are built close to towns along the motorway or in connection to other national or regional roads. Size and type of interchanges do not have that many limitations as in urban areas and can be motivated by e.g. traffic needs. In many cases (Figure 15) even usual crossroads without traffic lights or roundabouts can be applied.

Figure 15 Trafikplats Björklinge, Flöta (Source: ©OpenStreetMap).

In some cases (Figure 16), can exit and entrance ramp be merged into one road and get divided shortly before approaching the motorway.

Figure 16 Trafikplats Ångersjön, Myra (Source: ©OpenStreetMap).

5.3 Division of Responsibilities for Road Transport and Infrastructure

Within the division of responsibilities for Swedish road transport and infrastructure, there are several stakeholders responsible for different areas of the system. The responsibilities are as follows:

The Swedish Transport Administration is responsible for long-term transport infrastructure planning as well as building and maintenance of state roads and railways in Sweden (Government Offices of Sweden, 2014). In addition, The Swedish Transport Administration should ensure accessibility and safety within a transport system that takes the environment and the health of people into consideration (Trafikverket, 2022).

The Swedish Transport Agency is responsible for producing regulations and to regulate and supervise the transport sector (Government Offices of Sweden, 2014). In addition, Transportstyrelsen is responsible for traffic rules, road signs and to issue and revoke drivers' licenses (Transportstyrelsen, 2025).

Municipalities are responsible for building and maintaining municipal roads as well as to decide on certain local traffic regulations (Transportstyrelsen, 2025).

Polismyndigheten (The Swedish Police) is responsible for ensuring traffic is carried out according to current legislation (Transportstyrelsen, 2025).

5.4 Laws and Regulations

There are several documents that regulate planning, construction, re-construction and maintenance of roads in Sweden. For instance, they regulate the design of roadways but also usage of road signs. Some relevant documents are:

- Regarding road design: Vägars och gators utformning – TRVINFRA-00396 (Vägars Och Gators Utformning, 2024)
- Regarding road signs: Vägmärkesförordningen SFS 2007:90 (Vägmärkesförordning, 2025)

In this project, design suggestions both within and outside current jurisdiction are proposed.

5.4.1 Medical Requirements for Driver's License

Transportsyrelsen (Swedish Transport Agency) are responsible for issuing driving licenses in Sweden. In TSFS 2010:125 (Transportstyrelsens Föreskrifter Och Allmänna Råd Om Medicinska Krav För Innehav Av Körkort m.m. (Konsoliderad Elektronisk Utgåva), 2026), medical requirements for driver's license are described. Some relevant points are summarised below:

- To be allowed to have a driver's license, one must be able to drive safely, and therefore personal conditions (such as certain neurologic and cardiovascular diseases, impaired mobility and usage of certain medicines) that can harm driving abilities can be an obstacle for driver's license.
- Doctors are required to report conditions that might affect driving abilities negatively.
- When it comes to vision, the visual acuity should be at least 0,5 at 4-6 m from the eyes (correcting lenses are allowed) and the visual field should be at least 120 degrees horizontally and 40 degrees vertically. Also, a driver should not be too sensitive to glare and should have enough contrast sensitivity and night vision.
- Severe cognitive disorders such as dementia are an obstacle for driver's license. During an assessment, the following factors are assessed: attention, judgment, the ability to perceive and process visual stimuli, mental flexibility, memory, executive functions, psychomotor pace, emotional lability and fatigue. However, for mild dementia, driver's license could be allowed.

6 Older drivers

This chapter presents some different factors and conditions that can affect older drivers and their abilities. A visualisation of this can be seen in Figure 17. Investigating these factors is necessary to understand factors that can contribute to WWD but also to understand how the road infrastructure can be adapted to older drivers. In this chapter, aging as well as some different physical and cognitive factors among older adults will be presented. Also, some characteristics of older drivers in relation to road infrastructure and WWD will be presented.

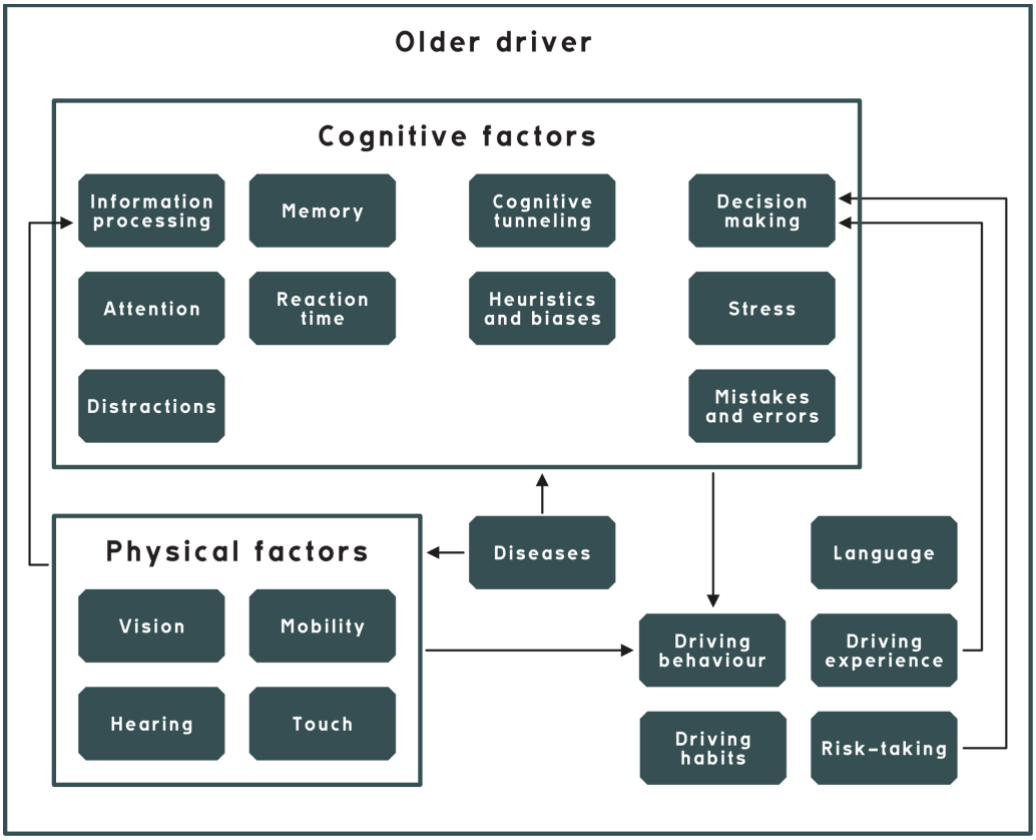


Figure 17 Systems model of the older driver.

6.1 Aging

With aging comes certain changes with the body and the brain. There are however big individual differences when it comes to aging (Fisk & Rogers, 1997). A concept sometimes used is a division between universal biological processes affecting everyone sooner or later (primary aging) and processes associated with diseases, lack of exercise, poor nutrition etc. that affects many but not all (secondary aging) (Erber, 2010).

6.1.1 Age Related Diseases

There are several diseases often related to aging such as dementia, neurologic diseases, stroke and arthritis. Although aging often comes with more diseases, the two are often seen as separate (Erber, 2010). These age-related diseases can have big negative influences on driving behaviour (Selander & Sandin, 2021).

For instance, neurologic diseases such as Parkinsons and MS can affect psychomotor skills, attention and reaction time which are affecting the ability to overview traffic environments, switching between lanes and to manage pedals (Selander & Sandin, 2021). Another example is a stroke that can affect attention, memory, quick decision making as well as field of vision (Selander & Sandin, 2021). Osteoarthritis, a form of arthritis, is an example of a disease affecting the mobility with loss of movement in the knees, hips, spine, fingers, wrists, elbows and neck (Erber, 2010).

6.1.1.1 Dementia

Dementia diseases are quite common among older adults (around 10% of older adults in the age group 80-84 have a dementia diagnosis) and affects cognitive functions (Tucker-Drob, 2019). In a Swedish study, more than half of older drivers involved in accidents had brain changes suggesting early stages of dementia (Selander & Sandin, 2021). It is however important to note that dementia gradually evolves and is typically diagnosed when cognitive functions has dropped below a certain threshold that affects the daily life (Tucker-Drob, 2019).

Since dementia affects cognitive factors important for driving, a diagnosis can be a cause of withdrawal of driver’s license. Drivers with mild dementia could however be allowed to continue driving for a certain amount of time (Selander & Sandin, 2021).

6.1.1.2 Eye Diseases

There are some common age-related eye diseases such as glaucoma, senile cataracts and macular degeneration. Glaucoma often comes gradually and initially affects the peripherical vision and later on also the central vision. With senile cataracts, areas of cloudiness appear which reduces visual acuity and increases sensibility to glare. Macular degeneration affects vision for fine details needed for driving and is associated with loss of nerve cells (Erber, 2010). How some issues with vision affects driving is explained in Section 6.2.1.

6.2 Physical Factors

6.2.1 Vision

With aging comes some typical changes of the vision such as seeing in dim light, colour sensitivity, sensibility to glare, visual acuity, contrast vision, distance and light adjustment and field of view. These changes can both come from general aging as well as certain eye diseases (Pinheiro & Da Silva, 2012).

In Table 7, some common factors affecting the vision of older adults are presented.

Table 7 Descriptions of different factors concerning the vision of older adults.

Category	Factor	Source	Driving relevance
Distinguishing between visual elements	Issues with distinguishing between visual elements with little space between them such as when reading.	(Kroemer, 2006)	Reading signage.
Contrast vision	Bigger contrasts and sharper edges are needed to see properly.	(Pinheiro & Da Silva, 2012)	Reading signage, seeing road markings and other road elements
	Road markings should be three times brighter than the road surface for older adults to see them properly.	(European Commission, n.d.)	Seeing road markings.

Colour vision	Difficulties with distinguishing between shades of blues and greens compared to shades of reds and yellows.	(Erber, 2010; Kroemer, 2006; Pinheiro & Da Silva, 2012)	Reading signage and seeing other road elements.
	Strong colour contrasts are needed to be able to distinguish objects.	(Pinheiro & Da Silva, 2012)	Reading signage and seeing other road elements.
	Response times can be shortened by increased colour contrasts.	(Fisk & Rogers, 1997)	Reading signage and seeing other road elements.
Field of view	Reduced peripherical vision can lead to difficulties in overviewing traffic environments. Providing a good and clear overview of interchanges as well as assist in making left turns and in roundabouts can help older drivers.	(European Commission, n.d.)	Overviewing traffic environments.
	The useful field of view (UFOV), the visual field which can be processed in one glance, is negatively affected by aging.	(Fisk & Rogers, 1997)	Overviewing traffic environments.
Visual acuity	Difficulties with visual acuity and to quickly focus their eyes, especially on nearby objects (called presbyopia or far-sightedness) due to impaired eye muscles and thicker lens.	(Erber, 2010; Kroemer, 2006; Pinheiro & Da Silva, 2012)	Overviewing traffic environments and reading signage.
Motion perception	Difficulties determining the speed and distance of other vehicles in the traffic environment and often therefore drive more carefully to avoid accidents.	(Erber, 2010)	Overviewing traffic environments.
Depth perception	Difficulties estimating distances between objects. This is mostly declined through the 70s.	(Erber, 2010)	Overviewing traffic environments.

Lightning and glare	Due to a smaller pupil and yellowing of the lens, older adults have difficulties seeing in dim light and darkness, and therefore need more light so see properly.	(Erber, 2010; Kroemer, 2006)	Nighttime driving.
	Sensitivity to shifts in lightning (glare) and longer time to recover from it since the pupil takes longer time to adjust to lightning. This can for instance become a problem with nighttime driving due to headlights from passing cars. To limit glare, indirect lighting is preferable.	(Erber, 2010; Kroemer, 2006; Pinheiro & Da Silva, 2012)	Nighttime driving.
	Disturbance by clutters of light from traffic environments with signs with lights in different colours, advertisements, traffic lights etc.	(Kroemer, 2006)	Overviewing traffic environments and reading signage.
	Perceive flickering lights as continuous at lower frequencies compared to younger adults.	(Erber, 2010)	Interpreting light signals.

6.2.2 Hearing and Touch

The vision is not the only sense affected by aging. For instance, older adults often have difficulties hearing low and high frequencies of sound (Erber, 2010; Kroemer, 2006). Hearing abilities can be relevant to driving for instance when detecting audible signals such as at a railway crossing. They are also often less sensitive to touch and have higher thresholds for detecting vibrations (Erber, 2010). Detection of vibrations can for instance be relevant to driving when it comes to detecting haptic feedback from driving on noise stripes in the road.

6.2.3 Mobility

Older adults can have difficulties turning their head due to reduced head and neck mobility (European Commission, n.d.) which can affect their ability to scan the environment when driving.

6.3 Cognitive Factors

6.3.1 Information Processing

In general, older adults need more time to process information, detect changes in the environment and to identify objects from visual stimuli, especially for complex tasks and for tasks requiring bottom-up processing (Ebaid & Crewther, 2019). This is important for driving since a driver needs to scan the road environment, identify objects and information from signage, road geometry, surroundings, other road users etc., interpret them and then make decisions on how to drive. One way to reduce the time needed for processing visual information is to increase colour contrasts (Fisk & Rogers, 1997).

6.3.2 Attention

Aging comes with **reduced attentional resources** which can lead to difficulties dealing with complex tasks, distractions and to switch between tasks (Erber, 2010).

- **Switching attention** can be difficult for older adults which can affect the ability to switch between different sources of information as required when driving (Fisk & Rogers, 1997).
- For complex tasks, older adults can have difficulties **dividing attention**, such as talking on the phone while driving. For simple tasks however, there are no big differences between young and older adults (Erber, 2010).
- With aging comes decreased **selective attention** which means difficulties to focus on relevant stimuli while ignoring irrelevant or distracting stimuli (Erber, 2010; European Commission, n.d.). This can be important to be able to find important information such as road signage describing how to navigate when approaching interchanges.

6.3.3 Distractions

Older adults can have difficulties ignoring irrelevant stimuli, especially presented in different modalities in complex situations (Ebaid & Crewther, 2019; Weeks & Hasher, 2014). For instance, listening to the radio could impair older adults' comprehension of text while reading (Weeks & Hasher, 2014). This could for instance suggest that listening to the radio while driving can impair the ability to interpret road signage.

- Congruent distractions (e.g. pictures that enhance the message presented by text) can help older adults to process information in a better way and shorten their reaction time. For instance, older adults can benefit from multisensory information such as reading and listening to the same information (Weeks & Hasher, 2014).
- Reducing the spatial distance between text and graphics could increase older adults' comprehension of information (Weeks & Hasher, 2014).
- If new stimuli are presented while other previous information is processed, the new stimuli can influence and disturb the information processing (Weeks & Hasher, 2014).

6.3.4 Memory

With aging, some types of memory are affected while others are not. For instance, for simple memory tasks, there are no clear indications of impaired ability among older adults to remember small amounts of information (Fisk & Rogers, 1997). The working memory however is more affected by aging. Erber (2010) suggests this relates to processing of information held in the working memory. This can be relevant to driving when it comes to remembering information from signage.

6.3.5 Reaction Time

In general, older adults have longer reaction times than younger adults, especially for complex tasks involving several different stimulus and possible responses (Erber, 2010) as well as for tasks requiring bottom-up processing (processing new stimuli on its own without previous knowledge) (Ebaid & Crewther, 2019). They also have more issues processing stimuli presented one after another in a short period of time and therefore need more time in between presented stimuli (Erber, 2010). Ebaid &

Crewther (2019) however points out that results from tests of reaction times involving button-pressing might be affected by motor slowing of older adults and not only processing of stimuli. Reaction times can be relevant to driving since decisions often quickly have to be made based on detected stimuli from the road environment such as deciding to stop at an intersection when there is an oncoming car from the crossing road.

6.3.6 Cognitive Tunnelling

Cognitive tunnelling is another factor that can affect a driver. This is a situation where someone stop receiving and processing information from the environment because their attention is captured somewhere else (Carroll, 2022).

6.3.7 Decision-making and Stress

There are several factors affecting decision-making such as stress and time pressure (Carroll, 2022). The author also mentions factors such as uncertainty, since an understanding of the situation must be made to make a decision, and expertise, since more experience and knowledge makes it easier to extract relevant information from a situation. Another aspect is humans' tendency to make decisions based on previous experiences by finding patterns from previous situations and applying them to a current situation, so called recognition-primed decision-making (Carroll, 2022).

Stress can also affect decision-making with reduced confidence and quality of the decisions being made, as well as shrink the perceptual field and minimise attentional resources (Carroll, 2022). A stressed driver could therefore be less inclined to perceive all relevant information from road infrastructure and make suitable decisions based on it.

When it comes to older adults, they tend to focus more on emotional aspects, need more time to make decisions and are more affected by complex and changing circumstances in their decision-making (Peters et al., 2007). This can be relevant to driving since traffic environments often can be complex and shifting. On the other hand, older adults tend to be more cautious than younger adults (Erber, 2010).

6.3.8 Heuristics and Cognitive Biases

There are several mental shortcuts, so called heuristics and cognitive biases, that can affect decision-making. These shortcuts are often used due to limited time or information (Carroll, 2022). Some examples of heuristics and biases are presented below:

- **Anchoring bias**: a tendency to rely on information presented first, despite new information that disproves the old (Carroll, 2022). This bias could affect a driver's navigation based on information from signage.
- **Choice overload**: a tendency to be overwhelmed when there are too many options available (*List of Cognitive Biases and Heuristics - The Decision Lab*, n.d.). This bias could affect a driver's ability to make decisions when there are many alternative routes.
- **Recency effect**: a tendency to best remember the most recent information (*List of Cognitive Biases and Heuristics - The Decision Lab*, n.d.). This bias could affect a driver's navigation based on information from signage.
- **Risk compensation**: a tendency to be more risk-taking when the feeling of safety is increased (Selvefors et al., 2023). This could affect a driver's decisions to turn in an interchange.
- **Salience bias**: a tendency to focus on the most prominent information (Carroll, 2022). This bias could affect what information a driver will remember.

6.3.9 Mistakes and Errors

When decisions are made, and actions are performed, there are several different mistakes and errors that can occur. For instance, an incorrect action can be performed due to an incorrect understanding of a situation, a so-called knowledge-based mistake (Carroll, 2022). Factors such as misinterpretation and limitations in working memory can lead to these mistakes, as well as little experience and high attentional demand (Wickens et al., 2012). For older drivers, this could be relevant when driving in a new type of traffic environment.

Errors such as accidently turning up the volume of the car radio instead of switching station (so called slips) can also occur. Slips are more likely to happen when attention is not directed towards the action (Wickens et al., 2012). In the radio-example, this could be when a driver is focusing on driving when trying to switch radio station.

6.4 Older Drivers' Characteristics

Being able to drive a car is essential for many older adults' in fulfilling their social needs or accessing different services such as healthcare, leisure or shopping (Selander & Sandin, 2021). This becomes fundamental for older drivers living in the countryside where other transport modes are less available. Today's older drivers tend therefore to drive more frequently than the previous generations.

Despite aging processes and following physical and cognitive impairments, older drivers are generally more experienced and pay higher attention to different safety measures e.g. seatbelts or driving within the speed limits (Selander & Sandin, 2021). They are conscious about their limitations, and especially women, are willing to accommodate them by adapting the driving to their needs (Selander & Sandin, 2021).

Cognitive and physical limitations increase the risk of older drivers being involved in car accidents. Failure to read road signs from a distance and to notice other road users are related to difficulties with seeing, scanning and processing the surroundings (European Commission, n.d.; Selander & Sandin, 2021). Accidents involving older drivers tend to happen in complex traffic environments where the road user is required to perform several actions, such as scanning the environment or completing driving manoeuvres, at the same time (Selander & Sandin, 2021). Misinterpretations, reduced reaction time and confusing the gas pedal with the breaks can also contribute to higher vulnerability of older drivers while managing stressful traffic situations (Kroemer, 2006).

6.4.1 Older Drivers and Road Infrastructure

Aging processes and technical development make some elements of road infrastructure more challenging for older drivers than other. Table 8 presents these elements with the explanations of difficulties and potential improvement areas.

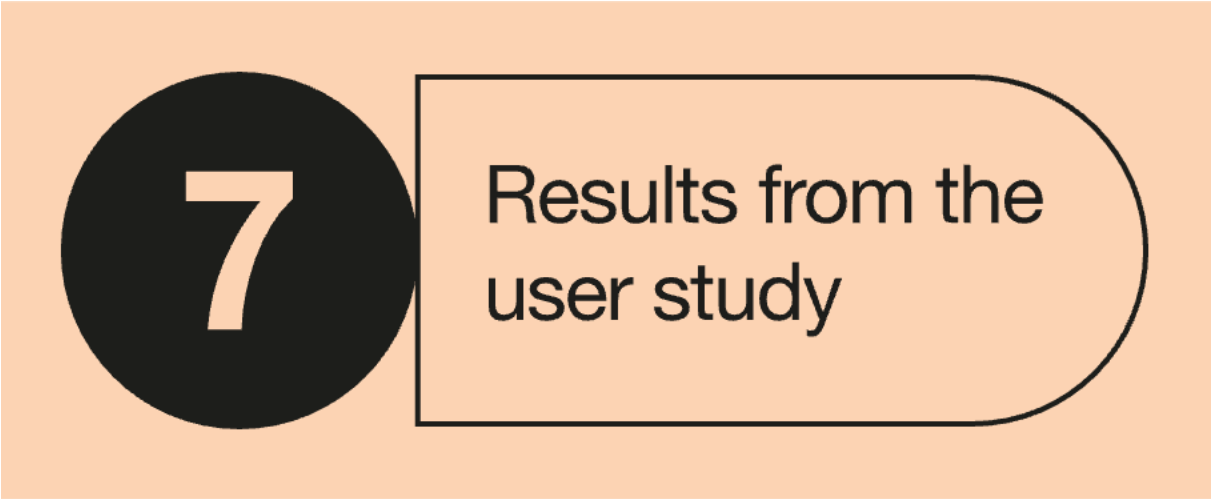
Table 8 Road elements that are perceived as the most challenging by the older drivers.

Road element	Explanation
Highways	According to studies made on older drivers, improved lighting, more clear and robust lane guides and width of travel lanes can improve the perceived safety on motorways (European Commission, n.d.).
Intersections	Navigating through intersections can be demanding for older adults due to higher requirements on the reaction time and attention capabilities. Moreover, many accidents in intersections are caused by failing to notice other road users (European Commission, n.d.; Selander & Sandin, 2021).
Interchanges	Eliminating weaving sections, shortening merge areas, providing better and more clear exit signs and fixed lighting are some of the improvements of interchanges requested by the older adults (European Commission, n.d.).
Roundabouts	Many older drivers perceive roundabout as a relatively new road element causing an unexpected and confusing stimuli. Right angle connections are preferable over the tangential ones in order to minimise the need of turning head to see other road users (European Commission, n.d.).

6.4.2 Older Drivers and Wrong-way Driving

Reduced peripheral vision and decreased selective attention caused by aging are some of the reasons behind the overrepresentation of older adults in WWD statistics (European Commission, n.d.). To accommodate their needs there are some measures that can be taken to provide clarity and safety on the motorways such as prioritising the right information in complex situations or improving the lighting conditions around the places with higher exposure for risk of occurring WWD.

Another important safety measure that takes older drivers' visual impairments into account is improving the signage (European Commission, n.d.). Road signs, in particular "no entry"-signs, should be placed in the driver's field of vision, be more retroreflective and contain larger text. Conspicuous signs with additional information and advice can reduce the risk of older drivers being confused or in doubt, which often leads to rushed decisions and sudden movements.



In this chapter, findings from both the survey and the interviews are combined and will be presented in four categories: navigation, challenges, older drivers' habits and external factors.

7.1 Navigation

The respondents have in general been open to try modern navigation tools such as mobile apps or build-in GPS functions in their cars but a physical, paper map is perceived as the most reliable one. Paper maps are also a popular tool while planning the route before a longer trip. They appreciate also to have a passenger guiding them while driving, especially if the guide is competent.

Participants pay attention to road markings and appreciate the development in this area such as introducing junction numbers, that has been made since they took the driving license. Road signs are perceived as guiding and presented only, when necessary, which reduces the amount of information that they need to process. While driving on roads with several lanes they prefer to see road signs placed over the lanes. On motorways, directions signs are placed in advance and repeated at least two times which usually gives enough information about when to exit the motorway. Road numbers are also a helpful tool to follow, both while looking into a paper map and while driving longer distances.

7.2 Challenges

Many participants in the user study have stated that road environments that they are not used to, such as driving past construction works or navigating in new areas make them feel uncomfortable and nervous. They often feel pressure from other road users and consider the current traffic situation as stressful because they are expected to make decisions quickly. They are also conscious about the risk of being distracted by phone usage, controls inside the car or by driving on a monotone road. They are afraid of making mistakes and they can imagine that they would be able to commit a WWD.

7.3 External Factors

The external factors that impact how the respondents behave as drivers are weather, visibility and other road users' behaviour. Older drivers, due to their relatively long experience, know how to adjust their driving to the weather conditions and usually avoid driving when the conditions are troublesome. They are also conscious about their capabilities that may be reduced to different aging processes and therefore some older drivers decide to avoid driving in darkness or strong sunlight. A problem that some of the respondents pointed out is the pressure coming from other road users, especially when they are not driving safely and responsible.

7.4 Driving Habits

There are also other reasons whether older adults that were interviewed choose to drive or not, such as environmental concerns, travel length or availability of public transportation. Car remains also a fundamental tool that allows them to socialise with their families and friends, to participate in different activities and to stay independent. Many of the study participants responded that they drive a car at least once a week. However, there is no correlation between the type of a road and willingness to drive. Their experience allows them to adjust their driving styles to different traffic conditions, but they think that motorways are in general monotone and should be improved with more frequent rest areas.

In this chapter, a function analysis, a user definition followed by a list of requirements will be presented. At the end of the chapter, a design problem will be presented.

8.1 Function Analysis

The function analysis of the selected road elements has resulted in fourteen tables containing the identified and classified functions for each of the road elements included in the project scope (see

Appendix D). Identified functions consider not only the physical aspects such as protecting road users from accidents or allowing road maintenance but also the cognitive aspects of how lighting, forms and colours communicate with the drivers, guide them and allow interaction between the vehicles.

8.2 List of Requirements

The findings made in the research phase of the project were translated into a list of requirements consisting of following categories:

- Cognitive needs – requirements addressing the cognitive needs such as reduced distractions, providing the information clearly or effective guiding through the intersection.
- Physical needs – requirements that accommodate impact of road geometry, traffic and weather conditions on road safety.
- Older drivers - requirements that take the cognitive and physical needs of older drivers into account.
- Maintenance – requirements that describe how the solution should be designed in relation to maintenance routines in road infrastructure.
- Sustainability – requirements that lower the environmental impact of the solution and prolong its expected product lifetime.

All requirements are descripted, have relevant notes and are classified into necessary or desirable. The complete list of requirements is available in

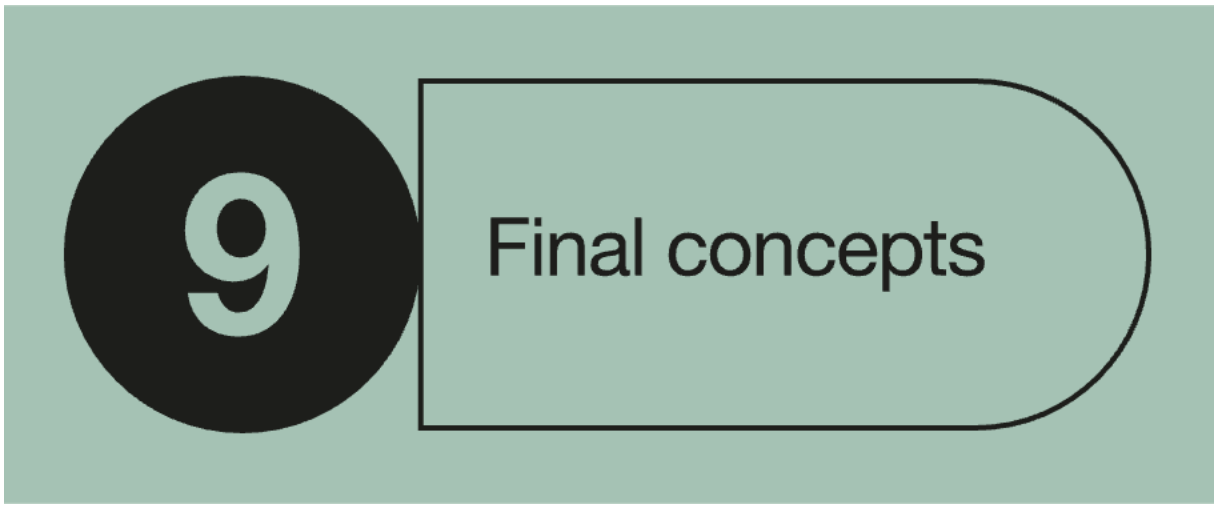
Appendix E.

8.3 Definition of Design Problem

In this section, a definition of the design problem is presented.

This project addresses a design problem of older drivers getting confused and making wrong decisions while navigating on motorways and in interchanges, which can eventually lead to serious accidents, such as WWD. The indented use of the road infrastructure should therefore be communicated explicitly in a way that fits the older drivers' cognitive and physical needs.

Design phase



In this Chapter, the 9 final concepts are presented as well as the results from the evaluation studies with the expert panel and target group.

Note: The presented concepts are not supposed to replace existing elements in the road infrastructure but rather to work as a complement.

9.1 Concept 1 – Entrance Ramp Sign

Background

One reason behind WWD is confusion that can occur when navigating in interchanges, especially when driving in new environments. It can be difficult to know how to drive in the interchange and to know how to enter the motorway, especially in complex road environments.

The main source of inspiration for this concept was an idea of creating a clear visual distinction between the entrance and exit ramp. It would help the older drivers to navigate especially in interchanges where these two ramps are placed next to each other.

Initially, more unusual colour and pattern variants were proposed that could attract the attention more effectively by sticking out from the background (Figure 18).

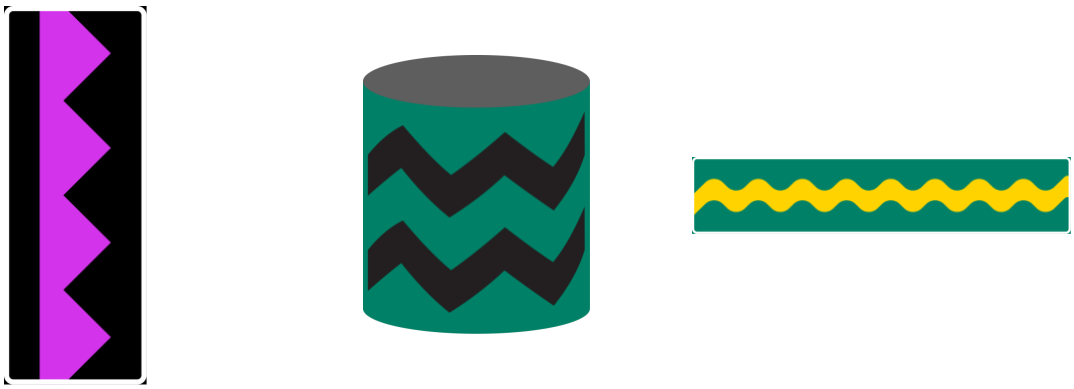


Figure 18 Different colour and pattern alternatives in early stages of the idea creation.

However, evaluation of those ideas showed relatively low contrast values and that troubles with associating these forms with other road elements could rather confuse the drivers than guide them safely. In further development of the ideas, different colour combinations both within and outside the current regulations were explored regarding their contrast values (Figure 19).

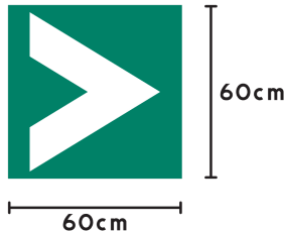
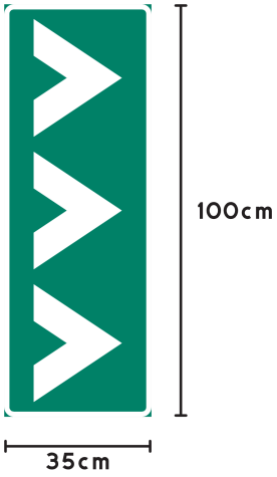
Figure 19 Different colour alternatives that were investigated in the contrast value exploration.

Description

The concept simplifies navigation by creating a mutual identification sign for entrance ramps. When navigating, a driver can look for this sign and be certain that they will enter a motorway since it is always placed next to an entrance ramp. The sign both works as a visual cue that can help the driver towards the entrance ramp and as a confirmation before they make a turn. The sign should be easily spotted.

The concept is a sign with three different variants for different applications: “the box”, “the wide”, “the tall”. Dimensions of the signs are presented in Table 9:

Table 9 Dimensions and motivations for dimensions of variants of concept 1.

The box	The tall	The wide
		
The size of this variant is based upon sizes of speed limit-signage (C31-sign) according to TSFS 2019:74, 4 Kap 1 §.	According to TSFS 2019:74, 16 Kap 1 §, the X3-sign (sign used to mark for instance speed bumps) should be at least 40cm tall and have the dimensions 4:1. This sign is a bit wider than that to be spotted more easily.	The height of the sign is estimated to be roughly the size of a car wheel to not block the view of a car driving on the exit ramp (Estimated wheel size: around 40-50 cm in diameter). The width of the sign is estimated to not be longer than the length of a car.

The signage should be placed by the entrance to the entrance ramp, visible from both directions of driving on the secondary road. “The box” (see Figure 20) should be placed around 150-200 cm from the ground *(in TSFS 2019:74, 1 Kap 13§ height placement is between 100-200 cm)* and can be spotted from a distance in all directions.

Figure 20 Placement of "the box" in an environment.

Both “the tall” (see Figure 21) and “the wide” (see Figure 22) should be placed close to the ground so they can be spotted from a closer distance right before the turn should be made. The placement makes it easier to spot when close by since the eyes often focus closer to the ground.

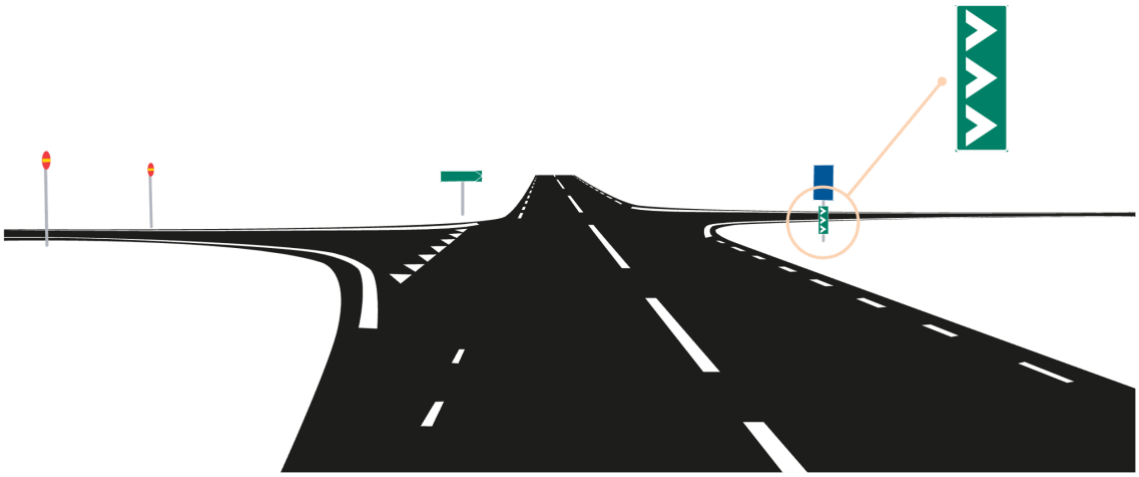
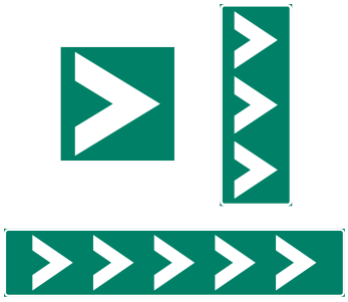
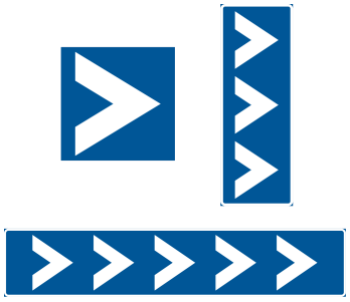
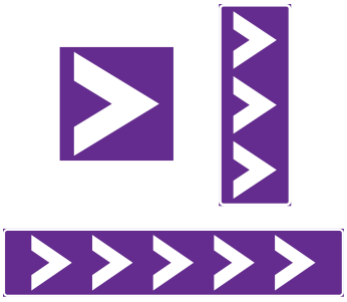


Figure 21 Placement of "the tall" in an environment.

Figure 22 Placement of "the wide" in an environment.

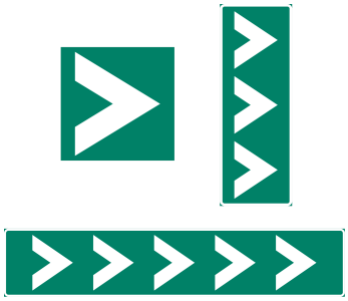
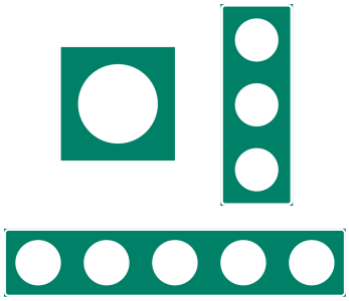
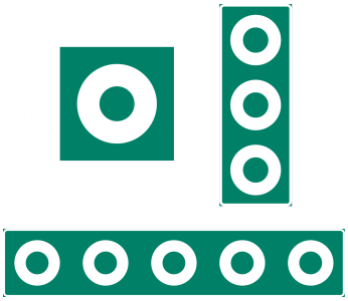
Apart from different size and form variants, three different colour alternatives were created (see Table 10):

Table 10 Colour alternatives and motivations for concept 1.

Green and white	Blue and white	Purple and white
		
This colour combination is commonly associated with motorways in Sweden. However, it might be difficult to distinguish from the vegetation in the background.	This high contrast colour combination is used to describe national roads that in many cases also are motorways. However, it might blend in with sky or water in the background.	This colour combination was proposed thanks to its high contrast value and novelty that can help the sign to stick out in the road environment. Purple though is not used today in road signage and there might be problems with associating it with other road signs.

Finally, three different pattern alternatives were proposed (see Table 11):

Table 11 Pattern alternatives and motivations for concept 1.

Pattern 1	Pattern 2	Pattern 3
		
This pattern provides a direction that unconsciously guides the driver towards the entrance ramp.	A big circle that sticks out against the background colour. Functionality of it does not dependent on viewing it from a certain direction.	A new symbol in the road environment that can be connected to this new type of signage. Not dependent on viewing it from a certain direction.

This new sign should be applied on every interchange in Sweden to create a universal visual cue that the drivers will be looking for while they are about to enter a motorway. Hopefully, following these signs will become intuitive and will support the existing signage around the entrance ramps.

Advantages and challenges

The expected positive outcome of this solution is:

- Improved navigation by “looking for landmarks”.
- Giving the driver confirmatory feedback before making a turn.

Following challenges with the concept are also addressed:

- Can lead to information overload since an extra road element is added to the road environment.
- Since this is a new type of information within the road environment, the solution must exist during certain time for drivers to get used to it.

Older drivers' perspective

The solution minimises the cognitive load, stress and uncertainty when navigating in an interchange since it guides the older driver and gives confirmatory feedback. The driver does not have to wonder whether they are heading towards an entrance ramp or an exit ramp. The sign attracts attention and minimises the time required to scan the environment.

Evaluation with the expert panel and the target group

- If "the wide" is put directly on the ground, car lightning cannot touch it.
- "The wide" is the alternative that is most prominent in the road environment according to both the experts and the older driver. It also guides the most (with the arrows).
- The pattern alternative with arrows guides and indicates a direction and was preferred by both experts and the older driver.
- The green colour is associated with the motorway.
- The experts notes that it is important to not only indicate where to turn, but also where not to turn.

Evaluation against the list of requirements

- The version with arrows clarifies clearly the direction of traffic and type of ramp.
- The purple version has higher contrast between graphical elements and is easier to distinguish from the background than the green one. However, due to its colour it might be confused with commercial signs.
- "The wide" sign's placing reflects the car light and can lead to glare.
- Arrows can confuse drivers that do not intend to enter a motorway which can get them to drive slowly and impact traffic flow negatively.

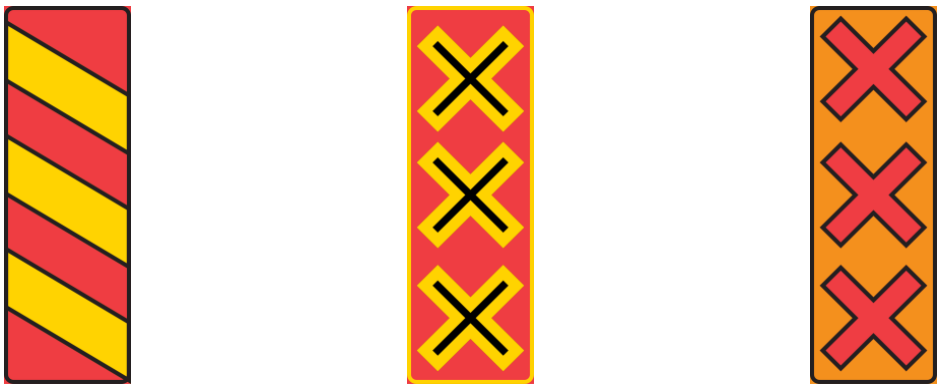
9.2 Concept 2 – Exit Ramp Sign

Background

This concept continues the principle used in *Concept 1 – Entrance Ramp Sign*, that entrance and exit ramps should be easier to distinguish visually. It is crucial in situations where both types of ramps are placed next to each other and technically allows the driver to drive on them.

There is already a sign used to inform the driver that driving against the direction of traffic on an exit ramp is prohibited - the C1-sign ("no entry"-sign). However, it can sometimes be missed by a driver and can therefore lead to a wrong turn onto an exit ramp and WWD. There is theory suggesting that the C1 sign might be placed too far from the ground for a WW-driver to spot it from a close distance. The sign can also blend into other elements in the road environment of an interchange.

Along the development process of this solution there have been several different ideas on the form and colour selection for how to provide a better complement for the C1-sign (Figure 23). Some of them were eliminated due to too high similarity to the signage used around railway crossings (a), some of them were eliminated because they were not coherent enough with other road elements (b) and finally some got eliminated because of poor contrast values and low visibility (c).



(a) (b) (c)

Figure 23 Different types of exit ramp signs that were developed in the idea generation phase.

Description

This concept attracts the attention of a WW-driver before they make a wrong turn onto an exit ramp, and it allows them thereby to self-correct. The sign, in combination with the C1-sign (see Figure 24), further enhance the information that entry is prohibited.

The new exit ramp sign is a vertical sign designed to cover a large vertical area to make it easier to spot compared to the circular shape of the C1-sign. It should be placed on the signpost below the C1-sign, on both sides of the road lane of the exit ramp, in an angle spottable from a direction where a WW-driver can see it (see Figure 25). Placement of C1-signs or similar between 0,5-1,2 m from the ground has been proven effective to prevent WWD since it is closer to eye level (Holgaard & Møller, 2020). The sign should however not be placed so it is blocking the view of a driver coming from the exit ramp and turning onto the secondary road.

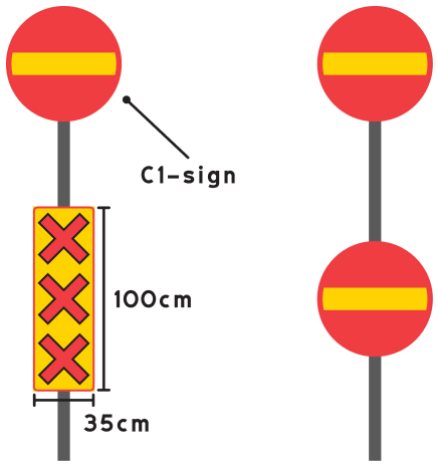


Figure 24 To the left: the final version of the new exit ramp sign in a suggested application together with C1-sign. To the right: existing placement of two C1-signs placed on the same signpost.

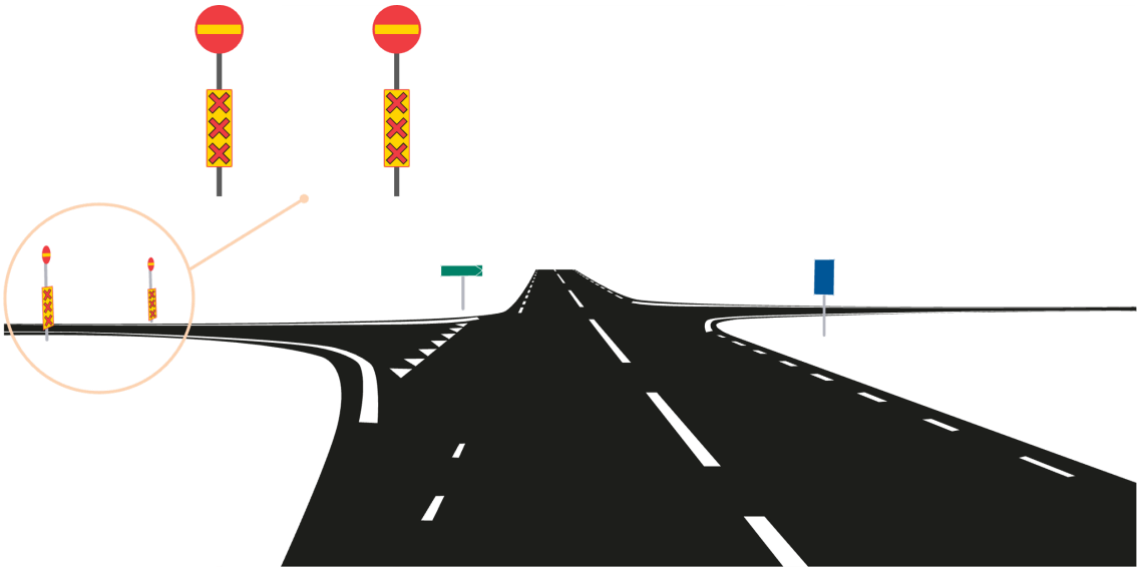
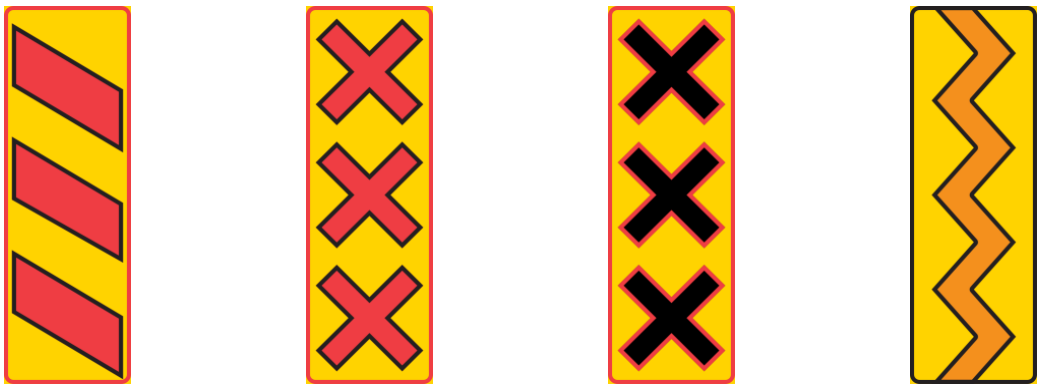


Figure 25 The exit ramp sign put an in environment.

The dimension of the sign is based on the X3-sign (sign used to mark for instance speed bumps). According to TSFS 2019:74, 16 Kap 1 §, the X3-sign should be at least 40 cm tall and have the dimensions 4:1. This sign is a bit wider than that to be spotted more easily.

There are four alternatives of the final design with different colour and pattern choices (Figure 26). In all variants yellow was chosen as a background colour due to its ability to attract attention. Red in alternatives (a), (b) and (c) is associated with warning and request to stop. Black details in all four alternatives are meant to increase contrast and visibility of the sign. Black, red and yellow together are also commonly used on warning signs. Orange in alternative (d) was selected to tone down the visual appearance of the sign in the surroundings but is less preferred due to low contrast values against yellow.

The pattern chosen in alternative (a) was inspired by a X3-sign that warns the driver on speed bumps and other obstacles in the road lane. However, after applying the pattern together with the selected colours, it appeared that the road sign was similar to A38-sign that is used around the railway junctions. Crosses used in alternatives (b) and (c) signals clearly that the driver must stop their vehicle. Zig-zag selected in variant (d) should attract the attention of the driver but not communicate anything more.



(a) (b) (c) (d)

Figure 26 The four final alternatives of the concept with different colour and pattern selection.

Older drivers' perspective

Older drivers tend to focus their eyes closer to the ground and can sometimes have difficulties spotting signage in a road environment since it "disappears". This sign helps older driver to spot the C1-sign and to more easily see that a turn towards it is incorrect.

Advantages

- The exit ramp sign attracts the attention of the driver to make them realise they are driving in the opposite direction or to stop them from entering an exit ramp from the wrong direction.

Challenges

- A sign that attracts the attention of a driver can in some cases have the opposite effect and make someone drive towards it, especially in a stressed situation.
- High similarity to the signs used in railway crossings (for alternative (a)).

Evaluation with the expert panel and the target group

- Both the older driver and the experts mentioned that the exit ramp sign gives an additional warning that can be seen more easily than the regular C1-signs.
- The shape of the exit ramp sign makes it more apparent.
- Both the older driver and the experts preferred pattern option (b) with the crosses since it is more intuitive. The older driver mentioned that it looks like roads that are crossing and the experts mention that the crosses indicate a

clear “no” that makes you stop and consider (even if you would not directly understand its meaning).

- According to the experts, pattern options (a) and (d) are confusing since (a) is similar to a railway and (d) does not tell you anything. Alternative (b) was most preferred due to the red colour that is a clearer “no” than the black and since it can be seen more easily at night.

Evaluation against the list of requirements

- This solution informs the driver how not to drive in a very clear way.
- However, it can distract drivers passing by, which also has a negative impact on traffic flow efficiency and can lead to stress.
- Similarity to railway crossings can be confusing.

9.3 Concept 3 – Horizontal Exit Ramp Sign

Background

Another way to distinguish the entrance and exit ramp visually is to indicate the direction of traffic on each ramp for the drivers on the secondary road. Usually, the direction can be indicated by the cars approaching or leaving a given intersection, but in the interchanges far away from urban areas there might be not enough cars to provide this information all the time.

Seeing the direction that is opposite to the one indented by the driver will probably persuade them away from the exit ramp. Currently this function is by the C1-sign that indicates that proceeding to exit ramp is prohibited. However, this sign can sometimes be missed by a driver and can therefore lead to a wrong turn onto an exit ramp and WWD. There is theory suggesting that the C1-sign might be placed too far from the ground for a WW-driver to spot it from a close distance. Also, the sign can blend into other elements in the road environment of an interchange.

The first iterations of this idea consisted of three different pattern alternatives (Figure 27), but all of them had the same form and were placed close to the ground. Alternative (c) got chosen thanks to its clarity in showing the direction of traffic, good contrast against the surroundings and low risk of getting confused with other road signs.

Figure 27 Three alternatives developed in early iterations of the idea: a blue-yellow sign usually used to warn about sharp turns (a), a red signs with three C1-symbols (b) and a blue sign with white arrows (c).

Description

The concept solves the problem of drivers taking a wrong turn onto the exit ramp from the secondary road by displaying the correct direction of traffic on the exit ramp so that a driver can see that they should not enter there.

This horizontal sign is placed close to the ground so that it can be seen by a driver focusing their eyes close to the ground. It is designed to be big and therefore be easily spotted by a driver. The sign guides the driver by displaying the intended direction of traffic. The sign can be placed either in a roundabout or in a crossroad.

The height of the sign is estimated to be roughly the size of a car wheel to not block the view of a car driving on the exit ramp (Estimated wheel size: around 40-50 cm in diameter). The width of the sign is estimated to not be longer than the length of a car (Figure 28).

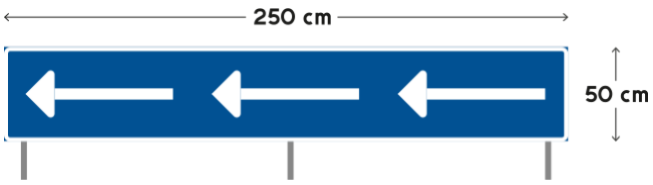


Figure 28 The final version of the horizontal exit ramp sign with its dimensions.

In Figure 29, the sign can be seen placed in an environment.

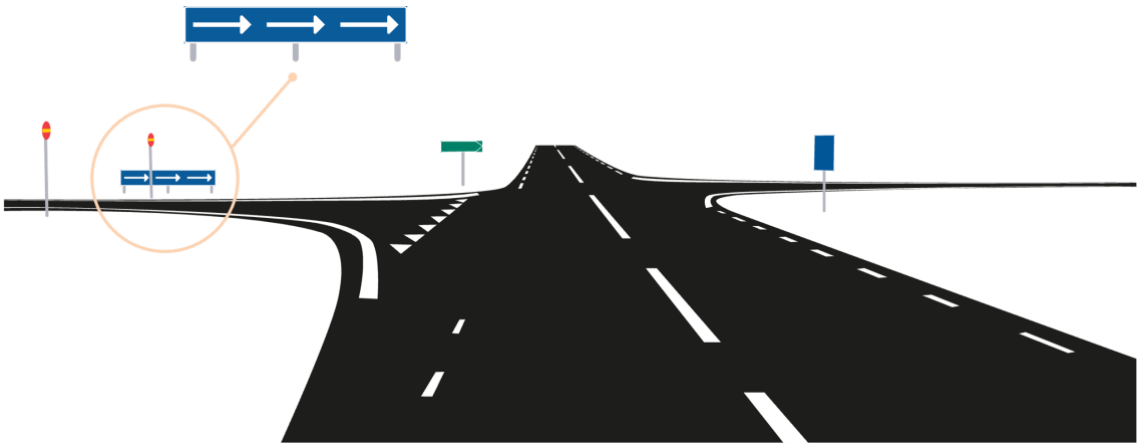


Figure 29 The horizontal exit ramp sign placed at an interchange.

Older drivers' perspective

Older drivers tend to focus their eyes closer to the ground and can sometimes have difficulties spotting signage in a road environment since it "disappears". This sign helps older driver to see the intended direction of traffic which guides them not to turn there.

Advantages

- This sign and its form attract the attention of the driver.
- It indicates the correct direction of traffic.

Challenges

- Can possibly block the view.
- Can be a disturbance during road maintenance.
- Can lead to information overload since an extra road element is added to the road environment.
- Position close to the ground leads to direct reflection of car lights and can glare the drivers.

Evaluation with the target group

- The older driver would probably wonder what the purpose of the sign was if seeing it while driving.

Evaluation against the list of requirements

- This solution reminds the driver about the direction of traffic on the exit ramp.
- It is placed in the middle of the visual field while scanning the exit ramp in order to detect the oncoming cars.
- The sign ha high colour contrasts.
- The sign improves the comprehension of the interchange.
- The "horizontal" sign is placed right next to car lights, which leads to glare and light reflection.

9.4 Concept 4 – Road Illusions

Background

In some cases, distracting the driver can effectively prevent them from taking a wrong turn or driving too fast. It can be achieved by placing unusual elements (e.g. sculptures) in the road environment or adding obstacles in a road lane.

This solution is inspired by “elevated” pedestrian crossings that take advantage of optical illusions to persuade a driver that a road marking is in fact a physical obstacle. Ideally, this illusion should confuse them enough to lower the speed and to pay more attention to the pedestrian crossing and people around it.

Another motivation to develop this idea was the attempt to achieve the effects of a physical object being placed in a road without all the negative consequences that are related to it, such as unnecessarily big impact on the drivers that are driving correctly or more difficult and resource consuming road maintenance. This topic is explained more thoroughly in Section 4.3.7.

Several patterns were taken into consideration in the development process of this concept. The “elevated” give-way line could alternatively be a stop line or an edge line, and the “elevated” concrete blocks could also be a barrier or an arrow (Figure 30).

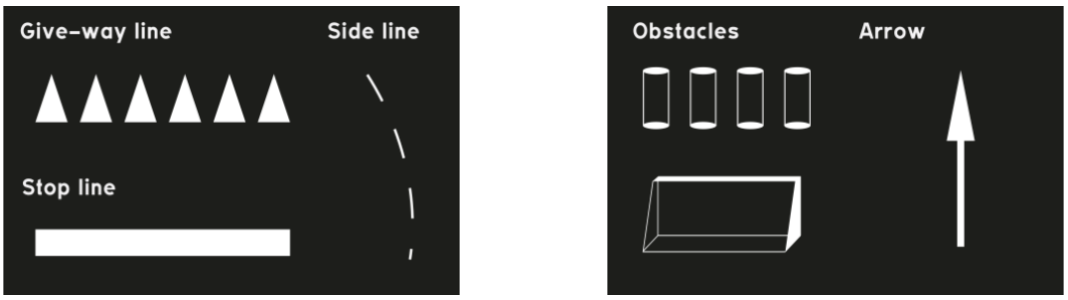


Figure 30 Alterations to the solution placed in an intersection (left) and to the solution placed on a exit/entrance ramp (right).

Description

There are two possible applications for this concept (Figure 31). The first one should prevent wrong way driving in intersections and roundabouts and should discourage the driver from taking a wrong turn. In the other scenario the illusion is applied further in the exit ramp and should get a wrong-way driver to stop the vehicle. In both cases it is important to not to distract the drivers that are driving correctly.

Figure 31 Illusion that prevents wrong turn in intersections (left) and illusion that stops the WW-drivers in the middle of an entrance/exit ramp (right).

In order to allow easy and effective set-up, the ambition was to develop a template that could be used to paint the illusion on a road surface with only white paint. To achieve this the further investigation is needed since each intersection has different geometry and therefore the illusion will be seen from slightly different perspectives.

Older drivers' perspective

From the older driver's point of view there are some measures that need to be taken in order fulfil the intended functionality of the concept:

- Size and location of the illusion should take the extended reaction time in the consideration.
- There should be no doubts if the illusion is inviting to take a turn or not (reduced cognitive load).

- Colour(s) of the illusion should create a high contrast to the colour of the road (ratio 2:1).
- If there are any other signs relating to the situation it is important to synchronise them and avoid contractionary cues.
- Limited active field of view - if the solution should be seen from a given distance, how is it placed then?

Advantages

- This concept gives an impression of a three-dimensional object without all the negative consequences of installing road spikes or road bumps. It allows to target the WW-drivers without affecting the correct driving vehicles.
- The solution changes the road environment relatively cheap using existing methods and materials in road marking maintenance.

Challenges and further development

However, this concept is still far away from being ready to be implemented and there are some challenges that need to be addressed in further development:

- Developing a template that can be effectively applied no matter the intersection geometry is necessary to implement the solution on a bigger scale.
- The extensive road maintenance during winter and darkness will probably limit the functionality of the solution.

Evaluation with the expert panel and the target group.

- Both the experts and the older driver mentioned that it is difficult to imagine how this solution would work without testing it.
- The older driver mentioned that it could perhaps be like seeing a speed bump and lowering your speed.
- One of the experts was familiar with the solution but had no positive experience from it. The others had not seen it before.
- This solution only works in a small time-gap from a certain distance.
- For the option on the exit ramp, the older driver mentioned that even though you would notice the illusion it can be difficult to know what to do.

Evaluation against the list of requirements

- This concept is visible and can grab attention due to its unusuality.
- High contrast between white pain and black asphalt (just as in other road markings). Road paint can also reflect light.
- In ideal scenario the concept should inform about how not to drive but it is questionable whether the information alone is clear enough. It will probably work as a complement to other road signs.
- Novelty of this type of solution can confuse the drivers.
  The illusion will not work for the drivers driving correctly which will probably confuse them.
- It is difficult to standardise this solution and therefore installation and maintenance will require both time and economical resources. Each illusion needs to be adjusted to the particular context.
- Both traffic and weather conditions lead to relatively short product lifetime. The solution will be erased by tires and road maintenance.
- It is questionable whether the solution will be visible in snow, rain or darkness.

9.5 Concept 5 – Right Turn-blocker

Background

WWD often occur when a driver is in a stressed or confused condition and is in a cognitive loaded stage. In this condition, it is possible that the driver have few mental resources to detect and interpret signage or other information provided in the road environment. Therefore, a wrong turn onto an exit ramp could be made simply because there is nothing to stop the driver.

Many intersections and roundabouts that have been analysed in this project have so called “soft turns” between the secondary road and the exit ramp (more on that in Section 4.2.2). It makes it technically possible to take a wrong turn and proceed against the direction of traffic even though the road signs prohibit this. However, soft turns and additional side areas cannot be removed because they are used while e.g. over-dimensional transport needs to pass by.

The idea for the right-turn blocker appeared while trying to improve the road geometry and block the driver from making a wrong turn onto the exit ramp without reconstructing the road. In early stages of the development, different types of physical features were analysed such as road spikes or sand but they were further replaced by three, final alternatives.

Description

The solution is placed on the right side of the lane in the space between the secondary road and the exit ramp where a wrong right turn could be made and works in both roundabouts and other crossings. The concept comes in three alternatives that block or alert the driver: bumps (Figure 32), gravel (Figure 33) and a bumpy plate (Figure 34).

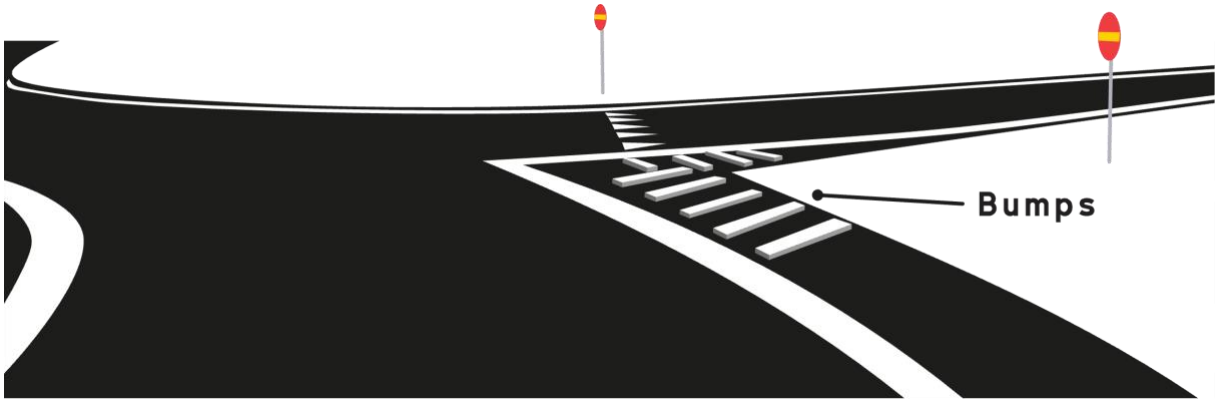


Figure 32 Bumps placed at an intersection.

“The bumps” consists of modules of speed bumps mounted in the road surface.

Specifications of the bumps:

- Width around 20cm, height around 3cm, length dependent on placement.
- White colour to not be confused with speed reduction.
- Placed in a pattern similar to closed of areas with road lines (swe. “spärrområde”).

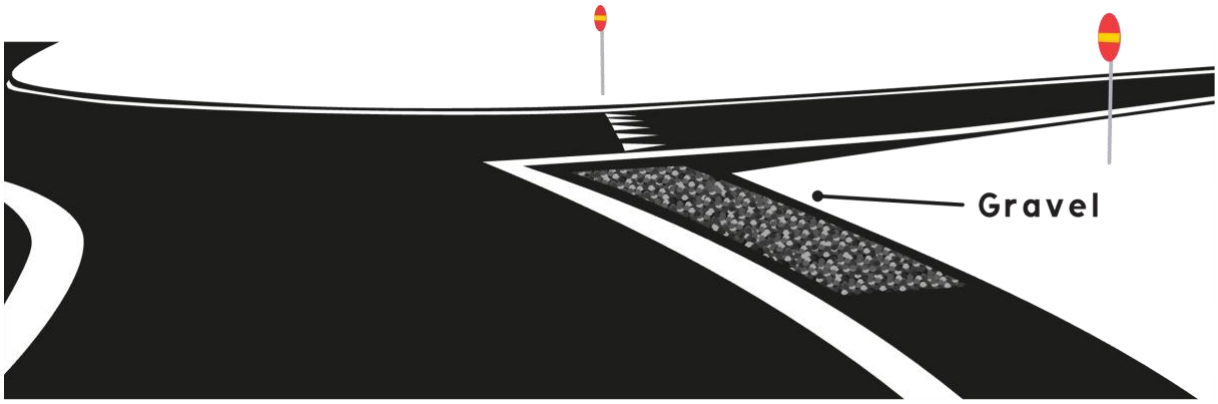


Figure 33 Gravel placed at an intersection.

“The gravel” consists of an area filled with medium sized gravel. The gravel will provide a variation in the road surface but will not blow away with regular wind.

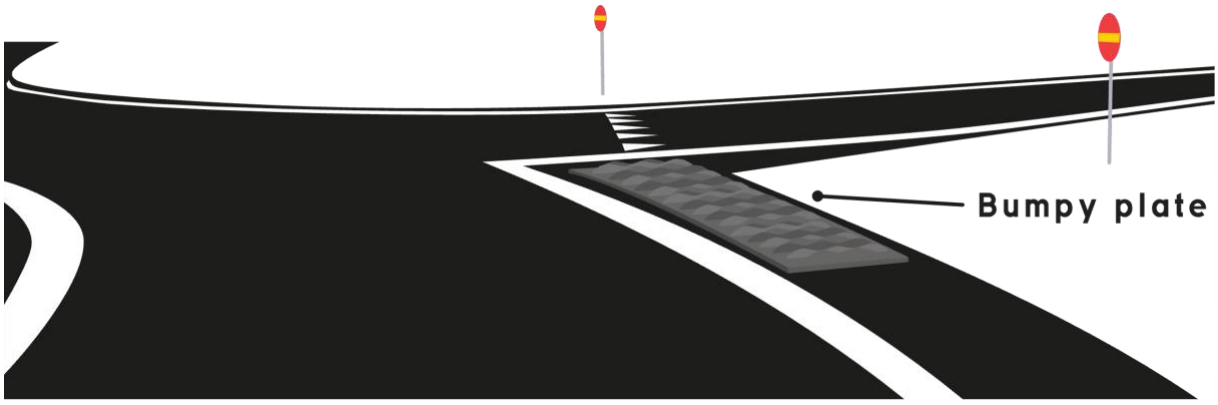


Figure 34 The bumpy plate placed at an intersection.

“The bumpy plate” consists of a plate with angled edges and a pattern of “hills” mounted onto the road surface. The plate can be removed if needed for maintenance of the road surface or the plate itself.

Specifications of the bumpy plate:

- Size of hills: Around 4 cm deep. Around 20 cm between peeks.
- The size is based on TRVINFRA-00396, K237829 which is about sizes of sinus grooves at edges of roads. But the depth is doubled to make a more apparent shift of the road surface. The bumps should be big enough for the driver to clearly notice and for them to lower the speed/stop the vehicle. But it should also be possible to drive past it for “right way”-drivers.

Older drivers' perspective

All alternatives of the concept are designed to not attract additional attention which is good for older drivers who might be more affected by distracting elements in the road area. This is a solution that should not be noticed unless a driver makes a wrong turn.

Advantages

- For drivers in a cognitive state where information from signage cannot be processed, this solution will block or alert the driver anyway, hindering them from continue driving onto the exit ramp.
- Even though it is a physical object it does not complicate the road maintenance and will not impact the traffic flow negatively since it is placed in a side lane.

Challenges and further development

- Large vehicles should be able to drive through the interchange, so the solution should not stop a vehicle who drive over it without making a wrong turn.
- If the gravel solution is used, gravel might come onto the roadway and disturb drivers.
- A bumpy surface could be problematic during wintertime if water or snow get stuck there.

Evaluation with the expert panel and the target group.

- The experts agreed that the blockers need some visual cues to not only alert the driver after they made a wrong turn but to alert and inform them beforehand. For instance, they suggest using a C25-sign (don't turn right/left), or the concept *entrance ramp sign "the wide"*.
- There were divided options regarding which alternative is preferred.
- The bumps are most visible in darkness but it almost looks like arrows pointing towards the exit ramp.
- The bumpy plate was generally liked and the older driver thought it was clear that you should not drive on it while the experts thought it needed some more visual cues.

- When the vehicle starts to shake it should be a clear indication that something is wrong and that you should not continue.

Evaluation against the list of requirements

- This solution is based on physical changes at the road lane which will be apparent even to drivers who are for instance distracted and are not susceptible to information presented on road signage. This is the only solution (out of the final concepts) that physically blocks these drivers.
- This solution is designed to not be noticed by drivers who are driving correctly to minimise processing of irrelevant information. On the other hand, this solution does not provide the driver with any information in advance and could therefore benefit from being combined with signage or other information giving elements.
- The physical changes can also make road maintenance difficult and obstruct larger vehicles. It could also be difficult to perform maintenance on the solution itself since for instance snow could get stuck.

9.6 Concept 6 – Navigation in Roundabouts

Background

Larger interchanges consisting of several roundabouts are often perceived as complex and stressful to navigate through. Confusion can lead to additional risk of committing WWD therefore it is beneficial to improve the navigation tools and reduce the cognitive load. In this concept the approach was to distinguish exits from roundabouts and describe the directions of them in a clearer way.

The first ideas for solving the problem were about assigning different colours or symbols to each exit. It would require though that sometimes there could be at least 10 different colours or symbols used in one interchange which in the end would be less practical than following destination signs.

Description

In this concept each roundabout in an interchange has been assigned a letter and each exit from a roundabout has gotten a number (Figure 35). The goal with this solution is to make it easier for the driver to follow the signs through an interchange and enter the motorway in the right place depending on the indented destination.

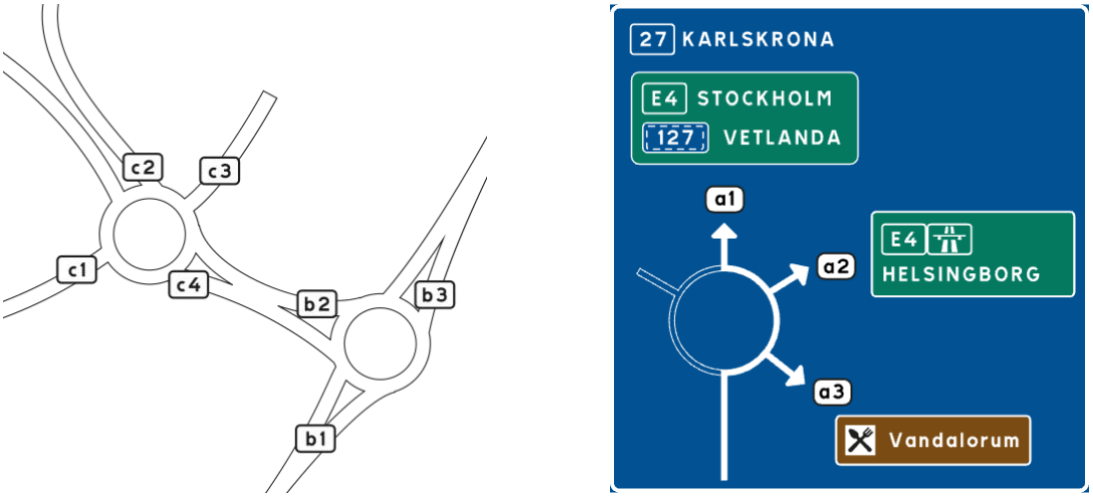


Figure 35 Schematic view of the new symbols assigned to roundabouts in an interchange (a), example of a road sign with new symbols (b).

The schematic symbols should be introduced in advance before the interchange so the driver can associate a symbol (e.g. “a2”) with the destination they are heading to (e.g. “Helsingborg”). This rule would be also applied on the road signs within a roundabout (Figure 36).

Figure 36 A road sign within a roundabout with improved navigation.

Older drivers’ perspective

Minimising the information needed to pass through an interchange from a road number and a destination to a short symbol can lower the cognitive load and make complex traffic situations easier to manage. This solution would hopefully give more confidence to the older drivers and lower the risk of committing a WWD.

Advantages

- A simplified navigation through complex interchanges with several roundabouts.
- A symbol system that can be used by digital GPS services such as Google Maps or Apple Maps.

Challenges

- High risk of confusing the drivers and increasing the cognitive load instead of lowering it.

Evaluation with the target group

- The older driver had a hard time imagining how this solution would affect the driving but thinks that it possibly could help in an interchange with several roundabouts if the letter is presented in advance.

Evaluation against the list of requirements

- The sign present both possible and not possible options for the driver which provides an easier understanding for the traffic environment. However, this additional information could cause information overload.
- The labels for the different exits from the roundabout are presented well in advance and are repeated which gives the driver time to spot and process the information before making decisions. However, the labels could be confusing for a driver since navigation is possible with both the labels and destinations.

9.7 Concept 7 – Rumble Strips

Background

According to the literature and the user studies, being confused or distracted is one of the main reasons behind WWD. These factors are known for contributing to other road accidents caused by e.g. ignoring or missing speed limits. In order to prevent that, it is crucial to alert the driver by e.g. installing rumble strips that provide an audial and haptic cue through the car.

The question that initiated this idea was how to wake up the driver before an interchange so they can focus on the traffic situation and avoid wrong turns? Another challenge that inspired this solution was how to inform the driver in other than the visual way.

Idea generation got directed quite early to different types of transverse rumble strips, both raised and milled (Figure 37). This solution is already quite common in Sweden and Europe and is usually being used to warn the driver and get them to drive slower before a toll station or a pedestrian crossing.

Figure 37 Two main types of rumble stripes: raised (a) and milled (b).

Description

In this concept the rumble strips are placed on roads leading to complex interchanges (Figure 38) in order to prepare the driver for a higher cognitive load that is required to guide correctly through the road cross. To emphasize the functionality of this solution it is recommended to install advance direction signs to make the driver familiar with the interchange, road numbers and destinations.

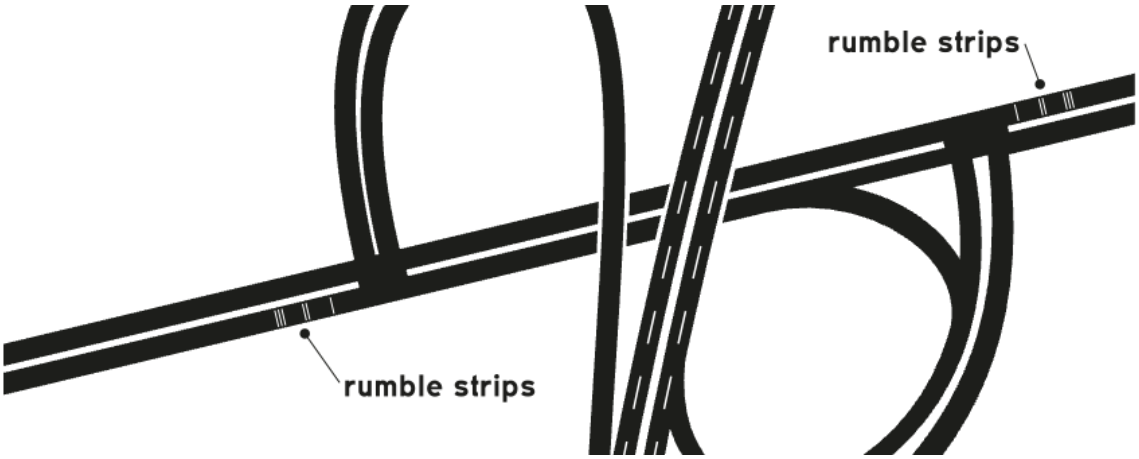


Figure 38 Suggested placement of the rumble strips in an exemplary interchange.

Older drivers' perspective

This solution increases the cognitive capacity of older drivers while driving through complex traffic situations by making them aware in advance and waking them up after driving on more monotone roads.

Advantages

- Functionality of this concept does not depend on the older drivers' visual impairments since it takes advantage of audial and haptic feedback.

Challenges

- Since rumble strips are usually put in the middle of the drive lane, they can be easily worn out by the cars driving over them, road maintenance or weather conditions. Therefore, it is important to paint new rumble strips regularly in order to prolong their functionality.
- Another aspect is the audial impact on the surroundings that can be perceived as disturbing. The sound that is being made by car wheels riding over the strips is difficult to isolate and therefore this solution should not be installed close to inhabited areas.

Evaluation with the expert panel and the target group

- Rumble strips are associated with lowering speed, not directly with being alert and considering your choices.
- The experts mentioned that the rumble strips must be combined with clear visual cues and also that they should be placed so that a driver has time to lower their speed but also not too far away so that they start accelerating too soon.
- The older driver mentioned that "waking up" before the interchange gives you time to think.
- One of the experts mentioned that this solution will probably disturb most "ordinary drivers" and would therefore not be accepted.

Evaluation against the list of requirements

- The solution is easily noticeable for drivers, but it can also be confusing since rumble strips are normally associated with reducing speed. Reducing speed in an interchange can however be preferable to provide more time for drivers to

make decisions. On the other hand, reducing speed can also block an efficient flow of traffic.

- Road markings such as rumble strips can be covered by snow.
- Since the road markings are placed over the road lane, they can easily wear out due to traffic and road maintenance.

9.8 Concept 8 – Wrong-way Sign

Background

First ideas for this solution came from analysing the type of WWD that is about making U-turns on motorways. Among the reasons behind those cases are when the driver is getting tired of driving long distances on motorways or missing their exit (more on that topic in Section 4.1.2.) The question was both how to remind the driver about the direction of traffic but also if WWD has already happened how to stop the driver and evacuate from the road lanes safely.

The sign had two sides from the beginning: the one that is turned towards the drivers being on the correct side of the motorway and the one turned towards WW-drivers. The “wrong” side has been developed the most: in the beginning the sign was red with the C1-symbol in the middle (Figure 39a), then the safety recommendations were added on how to leave motorway safely (Figure 39b) and finally the background was changed to yellow (Figure 39c).

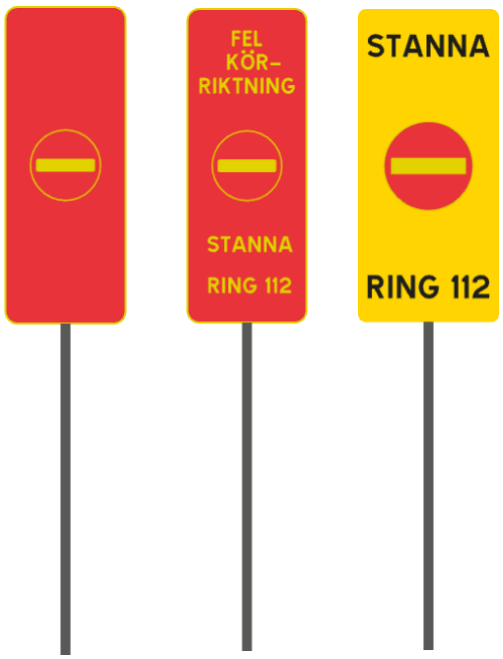


Figure 39 Three alternatives of the "wrong side": the one with the red background and C1-sign (a), the upgraded version with text saying "wrong way, stop the vehicle, call 112" (b) and a new version with the yellow background (c).

Deciding on how to pick the right recommendations was important since the space available on the sign is limited and the risk for a serious accident extremely high. The urgent request to stop the vehicle (swe. *stanna*) and call the European Emergency Number (swe. *ring 112*) were picked since these are the easiest to explain and communicate in a brief way. However, the information about driving off the road to avoid the oncoming vehicles was missing.

Description

The sign is intended to address the problem with U-turns on motorways by giving confirmation on, for the drivers, being on the right side of the road and by giving a warning for drivers that are driving against the direction of traffic. They are intended to be installed close to the places that are more exposed to the risk of wrong-way driving such as motorway junctions, rest areas och service lanes. The signage will be placed on both sides of the road lane which will ensure that the information will be accessible equally for all drivers (Figure 40).

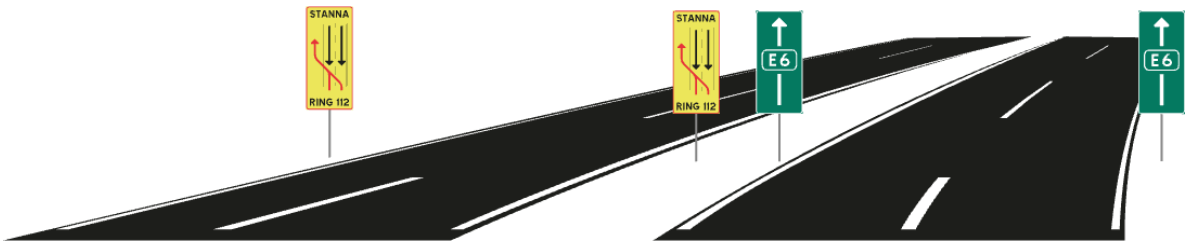


Figure 40 Suggested placement of the "wrong-way" sign.

This road marking is designed to be seen from a distance that allows the driver to read it in a couple of seconds (Figure 41). Given that the highest allowed velocity on the Swedish motorways is 120 km/h, the most important information should be understandable from 150-200 m. The vertical shape emphasises the direction of traffic and brings the attention of the driver to the arrow that is the main visual element of the sign.

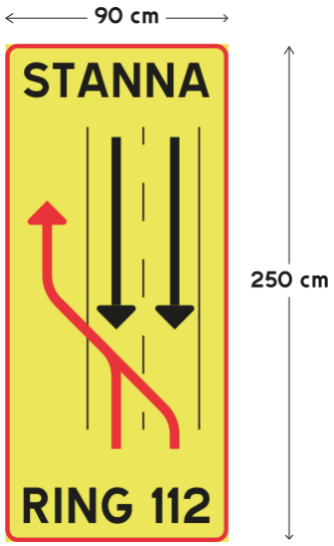


Figure 41 The final design of the road sign against U-turns with the suggested dimensions.

The “correct” side is green and blue (Figure 42a) depending on the type of the road and includes an arrow indicating the direction of traffic as well as the road number and destination. The “wrong” side has a neon-yellow background (Figure 42b) with an illustration urging the driver to drive off the road and stop the vehicle. This side includes also a request to call the emergency number 112, which is one of the most important safety measures if one has taken a wrong turn on motorway.

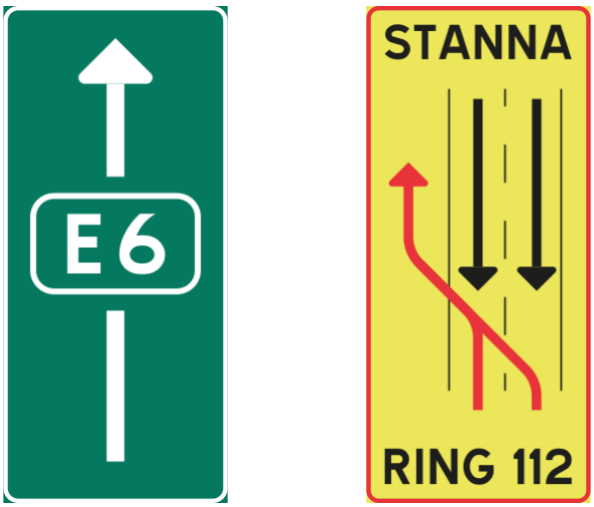


Figure 42 The "right" side of the sign (a) and the "wrong" side (b).

Older drivers' perspective

As stated before, older adults prefer to receive an information at least twice in order to process it and to feel confident in their decisions. That is why it is advised that these road markings should be shown frequently on a motorway, especially close to the places that are excessively exposed for a risk of occurring WWD. The arrow and the illustration are dominating visually which emphasise the purpose of this road marking. It allows the order drivers to comprehend the information quickly and to confirm the direction of traffic. The unusual shape of this road sign will also attract the attention and awake consciousness.

Advantages

- Improved colour selection on the ”wrong” side with a brighter yellow background than in Swedish warning signs to grab the attention even better and emphasize the extremely high risk with WWD. The background colour got inspired by yellow-green hue on the “Austrian hand” sign (example in Section 4.3.5.3).
- The C1-sign is replaced with an illustration more relevant for the type of warning.

Challenges

- It is questionable whether the illustration is understandable for the older drivers.
- The sign might get overseen by the drivers on the other side of the road.

Evaluation with the target group and the expert panel

- The green side of the sign gives you a clear indication that you are on the right path. The experts however do not believe it would help reduce U-turns.
- According to the experts, the sign should only be placed on the outside of the road lane to not disturb drivers in the correct direction.
- According to the experts, the black and red arrows should switch colours since the oncoming cars (now black arrows) are the danger to the WW-driver.
- According to the expert, this sign could benefit from only having text with a clear message and not to use the symbols with the arrows since it could be confusing.
- The older driver though that the yellow sign was clear.

Evaluation against the list of requirements.

- The visual design of this road sign fulfils the majority of the requirements such as high colour contrasts, font size and distance between objects that should guarantee that the information will be understood correctly by the older drivers.
- Since the text information is written in Swedish, there are concerns if the graphical information will be enough to achieve the functionality perceived by non-Swedish speakers.
- It should also be tested whether the reflective layer on the yellow side of the side will not lead to unnecessary glare effect.
- Another aspect that should be investigated is the impact of the sign being placed on both sides of the road lane. There is a risk that the drivers on the opposite lane will oversee the “wrong” side of the sign and get confused.
- Road signs are in general easy to assembly and disassembly in case of wider transports being carried out on the motorway. They are also sufficient to maintain, repair and replace, and the signposts can be recycled easily. However, it is important to investigate whether the colour film does not contain or emit any hazardous materials in production, usage and end-of-life stages.

9.9 Concept 9 – Side Line Arrows

Background

As it was mentioned before, reminding the older driver about the current direction of traffic might help to prevent the U-turns on motorways. This can be achieved by introducing new type of signage (*Concept 8 – Wrong-way Sign*) or improving the existing road elements such as road marking.

Side lines are one of the fundamental road markings that are common in all European countries. They can indicate whether it is allowed to park or not, where to take a turn or determine how wide a road lane is. In this concept, side lines were developed to show the direction of the traffic on a given road lane.

The idea of improving existing side lines begun while trying to analyse the elements that are the closest to the centre of the field of view while driving a car since these are the easiest to scan for the older drivers. Sidelines are often close to middle of that field, especially when the driver is looking further to scan the environment, to estimate the distance to the next car and to plan the next manoeuvre.

Different colour and form variants were proposed initially to represent different approaches of addressing this issue. In the first variants (Figure 43), the left-side line and right-side line had different colours which hopefully could help the driver to identify the direction of traffic because the pink line would always be on the right side of the vehicle. If the driver would see the pink line on the left side of the vehicle it would mean that they were driving against the direction of traffic. However, the evaluation of this idea showed that it would be unnecessarily complicated and in the best case ignored by the driver.

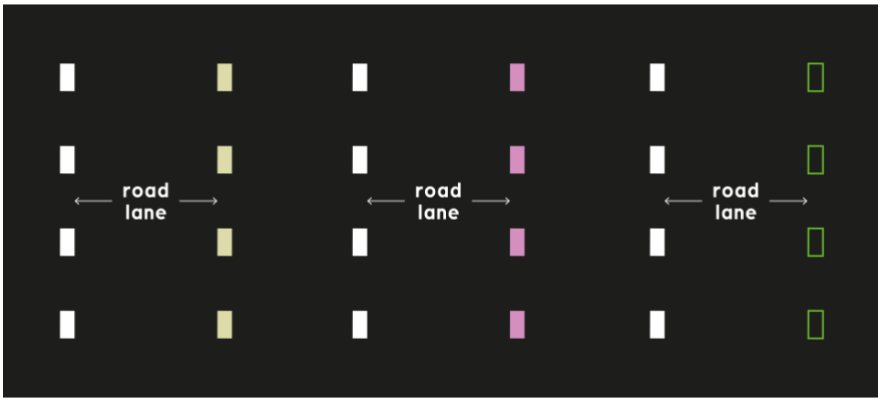


Figure 43 Different form and colour variants of the side lines in the first iteration of the idea.

Further iterations instead lead to side lines improved with different types of arrows (Figure 44) that clearly show the direction of traffic. This idea was also chosen to be proceeded with in the concept creation phase.

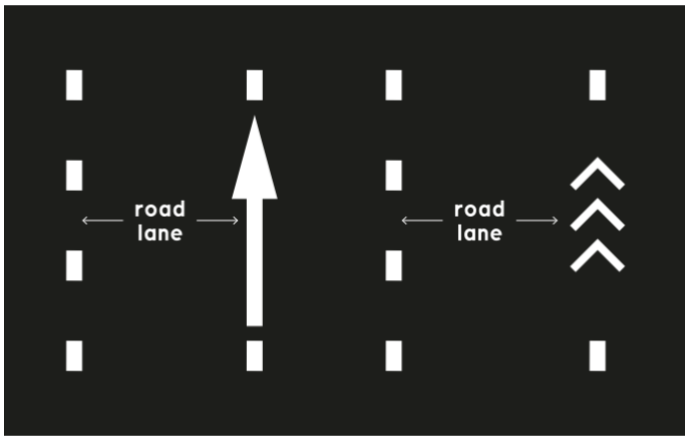


Figure 44 Different types of arrows that could improve the existing side lines.

Description

The new side lines are improved with arrows that will be repeated every 1 km on motorways and roads with separated road lanes (Figure 45). The arrows will remind the driver about the direction of traffic and help them to concentrate even if they have missed their motorway exit. It is important to mention that the arrows will not be visible in places where there is possible to choose another direction of travel, e.g. close to the exit or enter ramps.

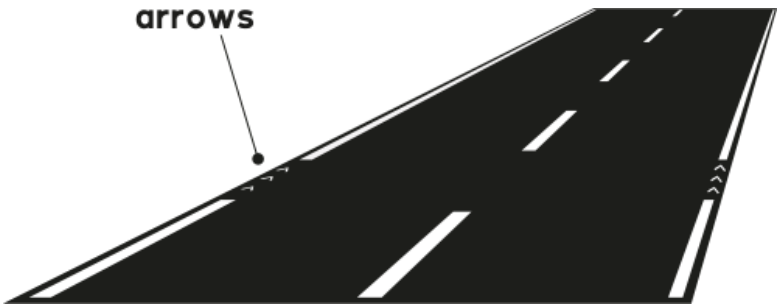


Figure 45 Side lines with a series of three arrows on each side of the road lane.

Older drivers' perspective

This concept has been developed in response to the needs of older drivers. The new side lines are still white, with high level of reflectivity to guarantee a high contrast no matter the time of the day, all year round. One of the main benefits is the reduced risk of U-turns on motorways which can be achieved by regularly repeating the direction of

traffic. Another example of the adjustment is the size and the distance between the arrows. Each arrow should be easy to distinguish when the side lines are observed within the field of view, from a longer distance. They should also be painted in parallel on both sides of the road to provide a visual cue, even within the peripheral field of view.

Advantages

- Compared to road markings painted in the middle of the road line, side lines are less exposed to the risk of wear from tires and snow clearance machines.
- This solution is flexible and easy to implement on a bigger scale with existing road paint and machines.
- Many modern cars can scan the side lines to keep the vehicle in middle of the road lane. It gives a possibility to introduce a new function where the cars will be able to detect the direction of traffic and stop the driver from making a U-turn.

Challenges

- It should be investigated how the weather conditions impact the functionality of this solution e.g. if the sidelines tend to be covered by snow during the winter.

Evaluation with the target group

- The arrows give a clear indication you are driving in the correct direction.
- Side lines are not something you directly think about while driving. However, it can be very disturbing if they are missing.

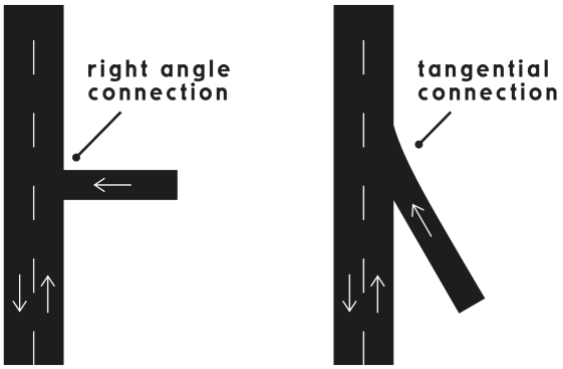
Evaluation against the list of requirements

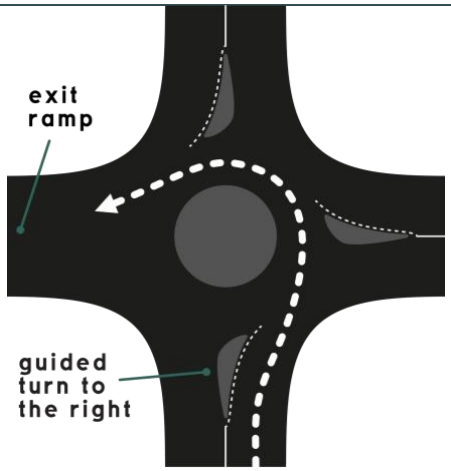
- The solution gives clear information on the intended direction of traffic. However, it is not located in the centre of the field of view and can therefore be missed by the driver.
- Road markings can be covered by snow which makes it an uncertain solution in wintertime.
- Road markings must be maintained due to wear and tear. However, compared to placing road arrows in the middle of the road lane the side lines are more long lasting.

Adjusting the road infrastructure for older drivers' needs to prevent WWD should be done in several different areas. Therefore, a set of guidelines for design of road infrastructure have been formulated as a complement to the nine concept solutions presented in Chapter 9. The guidelines are divided into different categories and are presented in Table 12. Apart from preventing WWD, some of the guidelines can also be applied to other parts of the road infrastructure.

Table 12 Guidelines for road design to prevent wrong-way driving with a focus on older drivers.

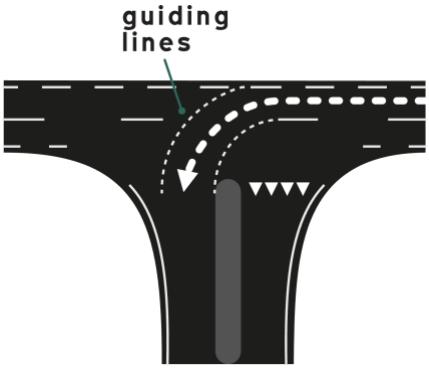
General design of interchanges
Lightning posts should be placed to minimise glare.
Minimise distracting lights.
Minimise distracting elements in the road environment to minimise cognitive load.
The most important information should be most apparent in the road environment (especially in complex road environments) to compensate for older drivers' reduced peripherical view and selective attention.
Important visual information should have clear colour contrasts.
Road markings should be three times brighter than the road surface for older drivers to see them properly.
Signage and road markings should be maintained to be visible all year round.
Interchanges should be designed to enable a good overview of the traffic environment.

Reduce complexity in interchanges regarding road geometry and placement of signage etc.
Avoid placing entrance and exit ramps next to each other to prevent wrong turns onto the exit ramp.
Entrance and exit ramps should be designed to be easily distinguishable from each other.
Call attention of drivers in places with higher risk of WWD.
Right angle connections (illustration to the left) are preferable compared to tangential connections (illustration to the right) since they give a better overview of the traffic environment and requires less physical effort such as turning the head. 
Interchanges should be well-lit to improve navigation and overview of the traffic environment.
Design interchanges to make wrong turns as difficult as possible and to make correct turns as easy as possible.
When possible, minimise possible navigation options to reduce cognitive load.
Exit ramps should be wide enough for two vehicles to fit next to each other in parallel so that a possible WW-driver can get out of the way.
Lower speed limits through interchanges to minimise time pressure and stress to allow for more time to make decisions.
Guiding correct turns
Design entries to roundabouts with a traffic island and road lines that guides a turn to the right (see the illustration) to avoid a wrong left turn into the roundabout that could cause a wrong turn onto an exit ramp.



Wrong turns should be sharp to not be inviting.

To simplify left turns, use guiding road lines.



Placement of signage

Signage should be placed as close to the centre of the field of view as possible (alternatively they should be visible from far distance).

Place signage well in advance and repeat the information several times to reduce cognitive load, reduce stress and to give good enough time to make correct decisions.

Place signage closer to the ground since older drivers (as well as drunk drivers) tend to see lower placed signage better.

Older drivers can have difficulties estimating placement of signage in relation to other road elements such as crossing roads. Signage should therefore be placed accordingly.

Avoid placing signage with different information close to each other to reduce risk of confusion.

Place direction signage inside roundabouts, especially for larger roundabouts, to reduce cognitive load.

C1-signs should be placed to be visible to possible WW-drivers before they make a wrong turn. For instance, the signs could be angled or curved/bent.
Design of signage
Prioritise the most important information on signage to reduce cognitive load.
Make signage bigger to make them more visible.
Signage should be visible in darkness, but the retro-reflectivity should not cause too large light shifts since it can glare especially older drivers.
Symbols and text on signage should be big, clearly separated and have sharp edges to be clearly visible.
Positive signage (such as “drive here”) could be used instead of negative signage (such as “don’t drive here”) to simplify decision-making for stressed drivers.
Visual elements on signage should correspond to the physical road environment as good as possible.
Avoid using colour combinations with blue and green since older drivers have more difficulties distinguishing between shades of blues and greens compared to reds and yellows.

In this chapter, aspects of the thesis work, such as the complexity of WWD, the process and results are discussed. Finally, ethical concerns and connections to sustainability goals are presented.

11.1 The Complexity of Wrong-way Driving

As presented in this report, the topic of WWD is complex and can be the cause of several different factors in both the road environment and the driver. In addition, it is often difficult to investigate exact reasons behind a specific incident since the WW-driver must survive and be able to remember what happened which is often not the case. In addition, there is little data on WWD in a Swedish setting. Therefore, many assumptions have been made based on research from other countries and in connecting fields such as cognitive ergonomics, Swedish regulations on road infrastructure and by investigating driving habits among Swedish older drivers.

Apart from the complexity of WWD and the varying factors behind it, the road environment system is complex and shifting due to site-specific conditions. Therefore, there is not one universal solution that can prevent WWD in all situations at all locations. The result of this project was therefore several types of solutions with different ways of preventing WWD which could be implemented at different locations. This is also the reason why no recommendations of “a final best solution” has been made but rather reflections on positive and negative aspects with each concept.

Another aspect of solutions to prevent WWD is how large changes can be made in the road infrastructure with the sole reason to prevent an issue that is relatively small (however often with severe consequences). The road environment has many different

functions and is used by many different road users. Therefore, it is important to consider how different changes can affect other road users or other parts of the road as well as to consider which compromises in comfort could be made with the purpose of avoiding severe accidents. A solution that is designed to hinder a WW-driver could also be disturbing to an ordinary driver. A solution that is designed to call attention of a WW-driver in the opposite direction of traffic could be confusing to a driver in the correct direction. A solution that is designed to be visible to older drivers could be more difficult to view by a younger driver. All in all, it is important to consider that a solution that is supposed to reduce one issue for one group of drivers does not cause other issues for other drivers.

Instead of focusing on preventing accidents resulting from WWD, which is a common approach as can be seen in Section 4.3, this project focused mainly on preventing WWD from occurring in the first place. This approach was selected to bring a new perspective to the area of WWD but also to be able to solve the cause of the problem rather than the effect of it, which is something that differentiates this study. However, this strategy is thereby less proven, and the design concepts are more speculative with less predictable effects. The concept solutions are rather theoretical and indicates a direction rather than being implementable in their current state since no practical testing or evaluation has been made. To connect back to the complexity of WWD, it can however be difficult to test these types of solutions in practice since WWD is uncommon.

11.2 The Process and Methods

The selection process of design concepts

In this project, the goal was to propose different ways of preventing WWD by creating several different concept solutions. Working towards presenting different solutions that can be implemented for different situations have impacted the selection process during the concept development since the goal was not to develop one final best solution. Instead of comparing different solutions to each other, the focus of the selection process was rather to narrow down the solution space and continue working on solutions with different focus to get a variety of concepts in the end.

User studies

Recruiting participants for user studies was a challenge in this project. One issue was how to contact older individuals, which as a group, is generally not very active on digital platforms. Therefore, they had to be contacted in other ways which in this study was through senior associations. An issue with this was however that the boards of the associations were difficult to get hold of and where generally hesitant to forward the digital survey and invitations to the study or to help gathering participants among their members. Instead, recruitment of participants for the interviews were made on site at the location and day of the scheduled interview and participants were thereby selected by being the ones who signed up that day. A result was that the group of participants was rather small and the sample was less controlled. In addition, some alterations in the interview guide had to be made for the second shorter interview since the participants were not available for participating in a full-length interview. To get more survey respondents, the survey was shared in a Facebook group for older adults which also was less controllable in terms of respondents. However, although limited, the user resulted in valuable insights for the project that provided a deeper understanding of the problem.

The target group

A consideration during the project has been the definition of the target group “older adults” or “older drivers”. When conducting research, different sources has stated different ages to define what an older adult is and could vary from 55+ to 80+ years old. In addition, there are large differences between different individuals (Fisk & Rogers, 1997) although there are some general tendencies that certain functions are affected by aging. Therefore, it was difficult to define a specific age range when defining the user group since there could for instance be a 65-year-old with reduced field of view and an 85-year-old with perfect eyesight. Instead, the project focused on different factors and abilities connected to driving that can be affected by aging and could be relevant to some individuals but irrelevant to others. On the other hand, when recruiting participants for the user studies, an estimation of age had to me made to have some basis for selection. An assumption was made that seniors are more likely to have personal experiences relevant to the study or know others with these experiences.

11.3 Results

One of the goals in this project was to deliver several solutions characterised by high variety and level of innovation, both within and outside the current regulations, which also requires more work than developing one, final concept. The scope of the project was limited by available time and resources which influenced the level of inclusion of users as well as testing and validation possible within the project. Therefore, findings should be interpreted as indicative rather than generalisable. The results of this thesis work are supported by a thorough literature study and user studies, but further user testing on physical or digital prototypes would be valuable to evaluate and validate the proposed solutions in real-world conditions.

The idea generation process has resulted in many innovative solutions that e.g. explored introducing new colours and forms to the road sign system. However, as the concept development process proceeded, the ideas got gradually more similar to the existing road elements. It was a conscious decision since the current colour system used on the road signs is well-known, easy to recognise and characterised by good contrast values. Swedish road sign font *Tratex* is also an excellent tool to communicate visually, with clear distances between the elements and high recognition among older drivers. Changing the font or colour palette drastically could be perceived as confusing or non-intuitive by the target group. Even other objects such as rumble strips or speed bumps were selected considering existing products since their installation and maintenance have already been tested in Sweden.

11.4 Fulfilment of Sustainability Goals and Ethical Concerns

This project was defined and conducted having both sustainability and ethical issues in mind, referring to specific UN Sustainable Development Goals that are described more thoroughly in Section 1.6. Execution of the goals will be presented below:

- **Goal 3** - fulfilled: Results from the project present a set of solutions and design guidelines that adjust the road infrastructure around motorways to older drivers' cognitive and physical needs. Applying these measures can not only

help to prevent WWD but also lower the risk for other severe accidents where older adults might get injured. In addition, WWD committed by older drivers are also setting other road users in danger which emphasize the fact that inclusive design usually benefits more people than only the target group.

- **Goal 10** – fulfilled: The problem with social exclusion of older adults and their loneliness have been addressed throughout the project, showing the question of older drivers' safety in traffic in a broader picture. Results from the user studies (Chapter 7) show that being able to drive a car in places where access to public transportation is limited, is crucial for older adults to take care of their social connections with friends and family. It allows them to stay active, practice their hobbies and feel relevant. Moreover, findings from the literature study acknowledge that older adults are not a homogenic group and difference in cognitive and physical abilities between the individuals are significant. That was the reason why the target group in this project is not defined by age and why current regulations regarding driving license were not questioned, by e.g. proposing a certain age limit when the license would be withdrawn.

Another important ethical issue in this project was related to conducting user studies on how aging processes impact driving skills, which is a delicate subject that touches both physical and cognitive abilities of every individual. Therefore, the real goal with the user studies was reformulated while recruiting the participants. The title of the survey invited participants to share their opinions that could be useful in improving the road infrastructure rather than to tell their perception of how ageing impacts their vision or hearing. The interviews were also conducted with focus around the road infrastructure through asking questions about how the older adults perceive driving on different types of roads or understanding different road signs rather than asking them directly whether they have noticed any changes in their driving abilities over time.

The aim of the thesis work was to develop solutions that can prevent WWD on Swedish roads with a special recognition of older drivers' information needs. The problem was investigated from a systems point of view to ensure that relevant aspects was considered. During the project, decision making processes in a traffic environment among older adults was investigated along with how the road environment is designed as well as of underlying causes for WWD. Based on this, nine design concepts with different focus and a set of guidelines for road design was developed which represents solutions that accommodate the needs of older drivers to prevent WWD.

Apart from developing new solutions, this project has also contributed with a new perspective on how to tackle the problem of WWD by focusing on how to prevent WWD in the initial phase rather than minimising severe effects of it. In addition, some of the concepts are designed partly outside current regulations, such as the *entrance ramp sign* and *the side line arrows*, which brings a new perspective to road design.

It is recommended that proposed design concepts and guidelines are seen as a part of the road infrastructure systems rather than independent solutions. It is unlikely that small adjustments such as only implementing one solution or one guideline independently can make the difference required to prevent WWD in all contexts since WWD is a complex issue set in a complex environment. Therefore, it is recommended to implement different solutions dependent on the specific situation and location to ensure the best possible effect.

When it comes to how aging affects driving abilities:

- Older drivers are generally experienced and safe drivers.
- There are general tendencies in how the cognitive and physical abilities are affected by aging processes, but they depend strongly on each individual's predispositions.
- Some factors generally affected by aging are cognitive factors such as information processing, attention, distractibility, stress and reaction time as well as physical factors such as the ability to turn the head, colour vision, visual acuity, a decreased field of view and that older drivers often tend to focus their eyes closer to the ground. These factors can affect:
    - Decision-making in traffic.
    - Perceiving, reading and understanding of signage.
    - The ability to scan and perceive the road environment and the traffic situation.

When it comes to WWD and preventative measures:

- WWD is a complex issue which can occur in different places and due to several different factors or combination of factors. Often there is a combination of human factors, how the road environment is designed as well as external factors.
- Examples of human factors are distractions, difficulties with navigation, the current mental state of the driver as well as if there is a passenger in the car that can help the driver detect mistakes.
- For road design, the overview of the road environment and the traffic situation, perceiving and understanding of signage as well as placement and design of ramps is important.
- External factors are often related to visibility conditions and the traffic situation.
- It can be difficult to implement new solutions in the road infrastructure since many parts have been looking the same for a long time and since a solution should cooperate with many different road elements.

- Although doing visual changes in the road environment might be less effective to affect WW-drivers, physical changes are generally more difficult to implement and might also harm other road users.

When it comes to older drivers' information needs in road infrastructure to prevent WWD it is important to:

- Present information in a clear way, both visually and information-wise, as well as repeating it.
- Provide good enough time for drivers to make correct decisions.
- Reduce the complexity of the road environment and prioritise to show the most important information.
- Reduce the cognitive load of drivers.
- Design the road environment so that it is easy to drive correctly and difficult to drive incorrectly.

Following recommendations were made in order to apply the results of the thesis work in reality and to continue the developments of the proposed solutions:

- More data about the WWD cases should be collected including details about the course of events and the driver in each case. This data should be used to identify places where WWD is more likely to happen. These places should be observed and investigated to give more local context for different solutions that were presented in this paper.
- A larger user group should be recruited that would include people in different ages and living in both rural and urban parts of the country. Together with testing the solutions through physical and digital prototypes it would help to find the aspects that need to be developed in the future.
- Experts from other fields than industrial design engineering should be involved in the development process to address the technical issues with the installation and maintenance of the solutions in the road environment. The design guidelines should also be revised by the wider group of experts to translate them into concrete actions that can improve the road environment.

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Appendices

Appendix A

Interview guide

- Introduce participants to the study
    - Explain what the purpose of our project is without revealing that older adults are the object of the study
    - Introduce the topic, what is wrong-way driving etc.
    - Explain how the collected data will be handled (with respect to integrity)
    - Introduce participants to how the discussion will be conducted
    - Hand out agreements that the participants will sign, inform them about their rights to ask question, stop/leave the study
- Block 1
    - Warm up: how often do you drive on a motorway? Why? What are your experiences?
        - When driving on a motorway: you miss an exit. What do you do?
        - If they ever had any issues with entering motorways?
    - When do you drive/don't you drive? Why?
        - Weather conditions, season, time of day etc.
        - How they adjust their driving according to it
    - Mediating object (e.g. a picture of a traffic interchange, or a scenario)
        - *Goal with this exercise is to make it easier for the participants to imagine a possible scenario and think about their behaviour in a given context.*
        - How would you manage a situation at a traffic interchange?
        - How do you get your information? (Signs, road marks, passenger etc.) What do you prefer?
        -
- Fika-break
- Block 2

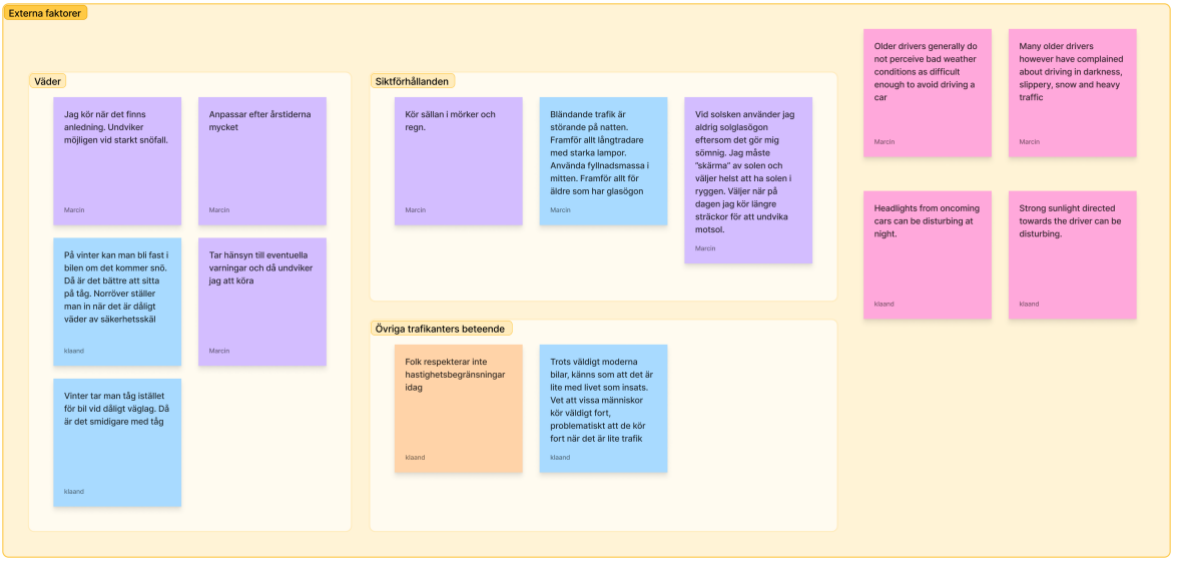
    - Go through different channels of information (GPS, signs, road marks, road geometry, other drivers, passengers etc). What do they think about them?
    - Do you face any other challenges when driving? How do you manage them?
        - Stressed by other road users?
        - How they navigate
- Conclusion
    - Summarise the discussion and the participants' opinions
    - Tell the participants how we are going to work on the topic further
    - Ask them if they want to participate in the future

Appendix B

KJ-analysis


Navigering
Överblick
När man är i trafikplatsen (stadsmiljön) är det svårare att se (men ser tydligt ut uppifrån)
Rondeller är bra för då kan man köra ett extra varv
Personlig navigering
Kollar kartor fysiskt
Många vill ha både digitalt och fysiskt
Har lite erfarenhet med GPS i bilen. Stör sig på rösten
Om kartläsaren är kunnig känns det bekvämt. Klart bäst (båda håller med)
Använder google maps
GPS i bilen
Förlitar sig inte bara på kartor/google maps
Atlas är mest emotionellt (nostalgiskt)
Ena personen: Telefon i sätet på sidan med ljudet på, funkar. GPS i bilen funkar ganska bra. En karta i bilen kan vara bra att ha i bilen om man vill titta på närmsta väg. Har ofta en uppdaterad atlas
Mobil med GPS kan vara osäkert hur det funkar (framför allt i städer med vägarbeten)
Använder lite både och (google maps/gps och fysiska kartor), letar efter saker som händer på vägen
Vägatlas kanske inte riktigt är uppdaterade (typ guide för hur man kör i städer)
Kolla på kartan vilken avfart man ska ta (utifrån nummer?)
Extern navigering
Idag är det lite bättre skyltar och bättre vägar
Oftast enklare med körfiler om skylten sitter över vägen tycker den ena
Traditionell skyltning funkar ofta bra
Med tydlig skyltning utan distraktioner hamnar man nästan alltid rätt.
Kollar skyltar, vägnummer och avfartsnummer ibland
Den ena använder inte trafikplatsnumren. Tror att yrkestrafik har stor nytta av dem (framför allt för utländska förare)
Påfarter till motorvägar kan vara krångligt. Enkelriktat-skylten kan stå lite konstigt. Står i mitten.
Gillar inte skylten om "Hammar". Otydligt att man hamnar på samma ställe oavsett vilken fil man tar (både vänster och rakt framåt)
Tycker att skyltarna ofta är instruktiva
Rentvättade skyltar på vintern behöver göras
Den ena använder inte trafikplatsnumren. Tror att yrkestrafik har stor nytta av dem (framför allt för utländska förare)
Föredrar landsvägsskyltning
Avfartskyltarna är tydliga. Får oftast två chanser så att man inte helt missar infon
Rondell funkar bra om man hinner se namnen dit man ska
Tänker mycket på vägnummer när man ska någonstans. Kan vara svårt att veta "slutdestinationen" på vägskylten
Lite undermedvetet orienterar sig efter landmärken (statyer, affärer etc.)
Ibland kan nya ställen på vägen/hus/omgivande miljön kan göra att man blir lite distraherad
Man måste förbereda sig så att man inte missar var man ska svänga
Skyltningen är bra om man inte kör för fort (förkortar betänketiden)
Märkt att man idag tar bort distraktioner (förbjudna skyltar). Medvetenheten om att det förstört uppmärksamheten är bättre
Förbederande navigering
Gillar att kolla i bilatlas/kartor för att välja roligaste vägen (om inte tidsaspekt är viktigt)
Åker inte spontant
Signs placed over driving lanes are easy to see and understand.
Older drivers can use personal and external navigation tools in combination (looking at a map and signage).
Some older drivers use physical maps, others use digital maps (mostly on a phone) and some use both.
Older drivers think that signage in interchanges can be difficult to understand.
They are familiar with junction numbers
Older drivers prefer roundabouts (if they have time to see and remember the signage) since you have a possibility to drive another lap if you miss your exit.
Older drivers use their geographical memory and recognise destinations, roads and landmarks while navigating on longer routs.
If signs are place well in advance it is easier to see the information and plan the driving.
If there is little distractions it is easier to navigate.
Older drivers like to plan their trip in advance (how they will get there, where to make stops etc.).
Older drivers appreciate road signs with clear information that is repeated at least twice.


Äldres körbeteende
Vägpreferens
Jag kör på alla typer av vägar, men helst inte motorväg på eftermiddagen, eftersom jag vid ett tillfälle höll på att falla i sömn! Vaknade efter en mikrosekund av en tutande bil. En skräckupplevelse! Det borde finnas tätare möjligheter på motorvägar att köra av för paus och vägarna borde ha större variation, de är så monotona.
Undviker helst landsväg vid mörker, annars kör jag gärna landsväg.
Tycker det fungerar bra att köra på motorvägar
Där det finns alternativa vägar, väljer jag det som passar mitt "ärende". Motorväg och 2+1-väg om jag skall åka långt och vill minimera restiden. Mindre landsväg om jag vill njuta av landskapet och kunna stanna och rasta när det passar mig. Vad är alternativet till stadsgator? Jag kör dit jag har mitt ärende.
Motorvägar bra om man snabbt vill komma till sitt mål. Mindre vägar eller tåg bra om man vill se saker
Jämförelse mellan olika färdmedel
använder bilen när det behövs
Väljer buss eller tåg om man inte har så bråttom
Klimatskäl. Väljer ofta kollektivtrafik för att det funkar bra
Jag gillar att köra bil. Det är en oemörd frihet att kunna ladda min bil med solel och åka vart jag vill.
Tåg om det går. Ibland är det lättare med bil. Ibland kan man hyra bil när man kommer fram
Försöker gå o cykla, när det är möjligt
Tågfan alla årstider. Bil kan man ta för att spara tid. Undviker buss (obekvämt)
Jag kör till ställen det är svårt att ta sig kollektivt. Tidigare körde jag ofta under tiden som yrkesarbetande.
Possibly monotone roads can make you a bit unaware of your own driving.
Many older drivers seem to go by buss or train when travelling longer distances.
Driving car allows older drivers to socialise
They have different preferences but they did not mention that they refuse driving car due to aging.
Older drivers still drive a car frequently (at least 2 times a week)
They could understand that WWD could occur at interchanges since they can be a bit tricky, but they could not understand how U-turns on motorways could happen for a "normal" driver.
Older drivers does not generally seem to avoid motorways.
Sociala aspekter
Besöker min man på äldreboende, gör inköp, olika aktiviteter
Är en aktiv pensionär och av den anledningen på många möten i Varberg, Falkenberg och Halmstad. Kör även ner till Skåne en del där jag har mina syskon och kusiner, gamla arbetskamrater och klasskamrater.
Bilen är allt för att komma ut
Besök hos bekanta.
Är aktiv och spelar golf
styrelsesammanträde i Halmstad och Falkenberg
Sommartid till stugan
Köromfattning
Jag kör ca 2500 mil om året
Jag kör buss också.
Lämplighet som förare
Tror att U-svängsförare måste vara olämpliga förare
Känner någon med epilepsi som inte hade körkort.
Känner en 92 åring som kör bil. Anpassar sin körning och kör inte när det är mörkt. Frisk
Hade själv lämnat in körkortet om han hade gjort något sådant (gjort en U-sväng på motorvägen)


Externa faktorer
Väder
Jag kör när det finns anledning. Undviker möjligen vid starkt snöfall.
Anpassar efter årstiderna mycket
På vinter kan man bil fast i bilen om det kommer snö. Då är det bättre att sitta på tåg. Norröver ställer man in när det är dåligt väder av säkerhetsskäl
Tar hänsyn till eventuella varningar och då undviker jag att köra
Vinter tar man tåg istället för bil vid dåligt väglag. Då är det smidigare med tåg
Siktförhållanden
Kör sällan i mörker och regn.
Bländande trafik är störande på natten. Framför allt långtradare med starka lampor. Använda fyllnadsmassa i mitten. Framför allt för äldre som har glasögon
Vid solsken använder jag aldrig solglasögon eftersom det gör mig sömnig. Jag måste "skärma" av solen och väljer helst att ha solen i ryggen. Väljer när på dagen jag kör längre sträckor för att undvika motsol.
Övriga trafikanters beteende
Folk respekterar inte hastighetsbegränsningar idag
Trots väldigt moderna bilar, känns som att det är lite med livet som insats. Vet att vissa människor kör väldigt fort, problematiskt att de kör fort när det är lite trafik
Older drivers generally do not perceive bad weather conditions as difficult enough to avoid driving a car
Many older drivers however have complained about driving in darkness, slippery, snow and heavy traffic
Headlights from oncoming cars can be disturbing at night.
Strong sunlight directed towards the driver can be disturbing.

Appendix C

Evaluation matrix

Idea	Requirement	Grade (+/0/-)	Notes
Skilja på på- och avfartsramper - färg på vägbanan	Clarity	-1	Difficult to select colurs (eg. red could feel as stop and blue for police etc). A new type of information that doesn't exist today can take time to learn/understand. Unless you know the meaning, it is hard to interpret the solution
	Visibility	1	
	Sustainability	-1	
	Guidance	-1	
	Attracting attention	1	
	Potential cost	1	
	Innovation	1	
	Other road elements	-1	
	Final score	0	

Idea	Requirement	Grade (+/0/-)	Notes
Skilja på på- och avfartsramper - sidolinjer	Clarity	-1	Difficult to see colours, difficult to see in bad weather conditions, questionable guiding effects, subtile solution.
	Visibility	-1	
	Sustainability	-1	
	Guidance	1	
	Attracting attention	1	
	Potential cost	1	
	Innovation	1	
	Other road elements	1	
	Final score	2	

Idea	Requirement	Grade (+/0/-)	Notes
Skilja på på- och avfartsramper - markeringsskärmarna	Clarity	1	Colour choice and placement is important
	Visibility	1	
	Sustainability	1	
	Guidance	0	
	Attracting attention	0	
	Potential cost	1	
	Innovation	1	
	Other road elements	0	
	Final score	5	

Idea	Requirement	Grade (+/0/-)	Notes
Skilja på på- och avfartsramper - Skyltar	Clarity	1	
	Visibility	1	
	Sustainability	1	
	Guidance	1	
	Attracting attention	0	
	Potential cost	1	
	Innovation	1	
	Other road elements	1	
	Final score	7	

Idea	Requirement	Grade (+/0/-)	Notes
Körfältvägvisare	Clarity	1	1b and 1d
	Visibility	1	
	Sustainability	1	
	Guidance	1	
	Attracting attention	0	
	Potential cost	1	
	Innovation	0	
	Other road elements	1	
	Final score	6	

Idea	Requirement	Grade (+/0/-)	Notes
U-svängar	Clarity	1	Content of the signs can be adjusted. May not attract attention of stressed WW-drivers. Should it be placed on both sides of the lane?
	Visibility	1	
	Sustainability	1	
	Guidance	0	
	Attracting attention	-1	
	Potential cost	1	
	Innovation	1	
	Other road elements	1	
	Final score	5	

Idea	Requirement	Grade (+/0/-)	Notes
Pil I vägbanan	Clarity	1	Mjust be combined with other information.
	Visibility	-1	
	Sustainability	-1	
	Guidance	0	
	Attracting attention	-1	
	Potential cost	1	
	Innovation	-1	
	Other road elements	1	
	Final score	-1	

Idea	Requirement	Grade (+/0/-)	Notes
Ledlinjer i vägbanan	Clarity	-1	All different driving options cannot be showed since there would be too many lines. The absence of lines for all could therefore be confusing
	Visibility	-1	
	Sustainability	-1	
	Guidance	1	
	Attracting attention	-1	
	Potential cost	1	
	Innovation	-1	
	Other road elements	0	
	Final score	-3	

Idea	Requirement	Grade (+/0/-)	Notes
Vägräknare	Clarity	1	If these signs are placed over each entry it could be distracting.
	Visibility	1	
	Sustainability	0	
	Guidance	-1	
	Attracting attention	1	
	Potential cost	1	
	Innovation	1	
	Other road elements	0	
	Final score	4	

Idea	Requirement	Grade (+/0/-)	Notes
Upphöjda kanter	Clarity	0	
	Visibility	1	
	Sustainability	0	
	Guidance	1	
	Attracting attention	-1	
	Potential cost	1	
	Innovation	-1	
	Other road elements	1	
	Final score	2	

Idea	Requirement	Grade (+/0/-)	Notes
Skyltar med aktuella/inaktuella vägar	Clarity	1	
	Visibility	1	
	Sustainability	1	
	Guidance	1	
	Attracting attention	0	
	Potential cost	1	
	Innovation	0	
	Other road elements	1	
	Final score	6	

Idea	Requirement	Grade (+/0/-)	Notes
Vägvisningsskylt inne i rondell	Clarity	1	Exists in some places, but should be implemented in more places.
	Visibility	1	
	Sustainability	1	
	Guidance	1	
	Attracting attention	0	
	Potential cost	1	
	Innovation	-1	
	Other road elements	1	
	Final score	5	

Idea	Requirement	Grade (+/0/-)	Notes
Skyltar i olika former	Clarity	0	
	Visibility	1	
	Sustainability	1	
	Guidance	-1	
	Attracting attention	0	
	Potential cost	1	
	Innovation	-1	
	Other road elements	1	
	Final score	2	

Idea	Requirement	Grade (+/0/-)	Notes
Namn/nummer/färg på avfart i cirkulationsplatsen	Clarity	-1	The different options for the roundabouts needs some extra thought.
	Visibility	1	
	Sustainability	1	
	Guidance	-1	
	Attracting attention	0	
	Potential cost	1	
	Innovation	1	
	Other road elements	1	
	Final score	3	

Idea	Requirement	Grade (+/0/-)	Notes
Trafikplats rondell 2.0	Clarity	0	Providing information for the driver (signage) is a challenge
	Visibility	0	
	Sustainability	1	
	Guidance	1	
	Attracting attention	0	
	Potential cost	-1	
	Innovation	1	
	Other road elements	-1	
	Final score	1	

Idea	Requirement	Grade (+/0/-)	Notes
Skyltar som finns vid infarter till tunnlar	Clarity	1	Consider placement.
	Visibility	-1	
	Sustainability	0	
	Guidance	1	
	Attracting attention	1	
	Potential cost	1	
	Innovation	1	
	Other road elements	1	
	Final score	5	

Idea	Requirement	Grade (+/0/-)	Notes
Trafikplats cloverleaf 2.0	Clarity	0	Not possible to go back to secondary road from the interchange without entering the motorway.
	Visibility	0	
	Sustainability	1	
	Guidance	1	
	Attracting attention	0	
	Potential cost	-1	
	Innovation	1	
	Other road elements	-1	
	Final score	1	

Idea	Requirement	Grade (+/0/-)	Notes
Låg och utsträckt skylt i korsningar	Clarity	1	
	Visibility	1	
	Sustainability	1	
	Guidance	1	
	Attracting attention	-1	
	Potential cost	1	
	Innovation	1	
	Other road elements	0	
	Final score	5	

Idea	Requirement	Grade (+/0/-)	Notes
Utnyttja bländskydd	Clarity	-1	Can impair visibility of other road users. Can be difficult to interpret the arrow.
	Visibility	0	
	Sustainability	1	
	Guidance	-1	
	Attracting attention	1	
	Potential cost	1	
	Innovation	1	
	Other road elements	-1	
	Final score	1	

Idea	Requirement	Grade (+/0/-)	Notes
Kantstolpar	Clarity	1	
	Visibility	1	
	Sustainability	1	
	Guidance	1	
	Attracting attention	-1	
	Potential cost	1	
	Innovation	0	
	Other road elements	1	
	Final score	5	

Idea	Requirement	Grade (+/0/-)	Notes
Vägillusioner	Clarity	0	Clear for drivers seeing it from the correct angle but can be unclear for other drivers. Can be difficult to see in darkness. Requires more maintenance than regular road marks.
	Visibility	-1	
	Sustainability	-1	
	Guidance	1	
	Attracting attention	1	
	Potential cost	1	
	Innovation	1	
	Other road elements	1	
	Final score	3	

Idea	Requirement	Grade (+/0/-)	Notes
Extra ramp på påfarten	Clarity	1	Could be improved with guiding lines. Must be a sharp connection for righ way drivers not to turn there. Could be difficult to notice by a confused WW-driver.
	Visibility	1	
	Sustainability	1	
	Guidance	1	
	Attracting attention	0	
	Potential cost	-1	
	Innovation	-1	
	Other road elements	1	
	Final score	3	

Idea	Requirement	Grade (+/0/-)	Notes
Hinder för att undvika felaktig högersväng - farthinder	Clarity	-1	Speed bumps are mostly used to drive over them and make people lower their speed, not to hinder people from driving there.
	Visibility	1	
	Sustainability	1	
	Guidance	-1	
	Attracting attention	1	
	Potential cost	1	
	Innovation	1	
	Other road elements	-1	
	Final score	2	

Idea	Requirement	Grade (+/0/-)	Notes
Hinder för att undvika felaktig högersväng - refug	Clarity	1	This solution should guide the driver in a more unconscious way
	Visibility	0	
	Sustainability	1	
	Guidance	0	
	Attracting attention	0	
	Potential cost	1	
	Innovation	-1	
	Other road elements	1	
	Final score	3	

Idea	Requirement	Grade (+/0/-)	Notes
Hinder för att felaktig högersväng - vägspikar	Clarity	1	Things placed in a roundabout can be difficult to spot since the view can be blocked until you are "too close" to see them. Road spikes are not common on Swedish roads.
	Visibility	0	
	Sustainability	0	
	Guidance	1	
	Attracting attention	1	
	Potential cost	1	
	Innovation	0	
	Other road elements	0	
	Final score	4	

Idea	Requirement	Grade (+/0/-)	Notes
Hinder för att undvika felaktig högersväng - snad/grus/bucklig yta	Clarity	1	Sand/stones can spread and make the road surface "slippery". The bumpy surface can be harmed by ice. The solution doesn't attract attention beforehand, but if they drive onto it, they will notice.
	Visibility	-1	
	Sustainability	-1	
	Guidance	1	
	Attracting attention	0	
	Potential cost	1	
	Innovation	0	
	Other road elements	-1	
	Final score	0	

Idea	Requirement	Grade (+/0/-)	Notes
Guidade lampor i vägbanan	Clarity	1	Good visibility in darkness, but poor visibility in daylight. Doesn't work well during winter time.
	Visibility	-1	
	Sustainability	-1	
	Guidance	1	
	Attracting attention	0	
	Potential cost	-1	
	Innovation	1	
	Other road elements	0	
	Final score	0	

Idea	Requirement	Grade (+/0/-)	Notes
Stopplinje/väjningsplikt i annan färg	Clarity	-1	
	Visibility	1	
	Sustainability	-1	
	Guidance	0	
	Attracting attention	1	
	Potential cost	1	
	Innovation	1	
	Other road elements	0	
	Final score	2	

Idea	Requirement	Grade (+/0/-)	Notes
Trafiköar	Clarity	1	The roadway might have to be broadened to fit a traffic island.
	Visibility	1	
	Sustainability	1	
	Guidance	1	
	Attracting attention	0	
	Potential cost	1	
	Innovation	-1	
	Other road elements	1	
	Final score	5	

Idea	Requirement	Grade (+/0/-)	Notes
Uppmärksamma distraherade förare/haptisk feedback	Clarity	1	The haptic feedback could be cobined with a visual "warning".
	Visibility	0	
	Sustainability	1	
	Guidance	0	
	Attracting attention	1	
	Potential cost	1	
	Innovation	0	
	Other road elements	1	
	Final score	5	

Idea	Requirement	Grade (+/0/-)	Notes
Uppmärksamma distraherade förare/farthinder/chikan	Clarity	1	Can disturb traffic flows. Can take up a lot of space.
	Visibility	1	
	Sustainability	1	
	Guidance	-1	
	Attracting attention	1	
	Potential cost	0	
	Innovation	-1	
	Other road elements	-1	
	Final score	1	

Idea	Requirement	Grade (+/0/-)	Notes
Kantlinjer i olika färger	Clarity	1	The arrows in alt. 2 could perhaps be misinterpreted as lane arrows. A stresses WW-driver will perhaps not notice this. The road lines are not directly noticed by drivers and are pnot located in the middle of the visual field.
	Visibility	1	
	Sustainability	-1	
	Guidance	1	
	Attracting attention	-1	
	Potential cost	1	
	Innovation	0	
	Other road elements	1	
	Final score	3	

Idea	Requirement	Grade (+/0/-)	Notes
U-svängar från servicefickor	Clarity	1	Can the sign negatively impact the energy absorbance of the barrier?
	Visibility	1	
	Sustainability	1	
	Guidance	1	
	Attracting attention	1	
	Potential cost	1	
	Innovation	-1	
	Other road elements	-1	
	Final score	4	

Appendix D

Results of the function analysis

Road signs

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to inform a driver	• TSFS2019:74 (and the updates) regulates the size and position of the sign	MF	Necessary
to alert a driver about a possible danger	• *varningsskyltar* • a yellow triangle pointing upwards with a red outline. • usually a black icon representing the danger.	PF	Necessary
to distinguish from the background		SF	Desirable
to be visible in the darkness	• e.g. retroreflective signs acording to TSFS2019:74	SF	Necessary
to direct traffic flows	• *påbudsskyltar* • a blue, round sign with a white icon and outline	PF	Necessary
to organise/give priority to different traffic flows	• *väjningspliktsmärken*	PF	Necessary
to prohibit drivings	• *förbudsskyltar* • a yellow/blue round sign with a red outline and black icon	PF	Necessary
to inform about about a road type/ element	• *anvisningsmärken* • always have a sign introducing and ending the part of the road • rectangular signs	PF	Necessary
to inform all road users	• both Swedish and international drivers • no matter age	MF	Desirable
to provide safety on a road		MF	Necessary
to provide an information clearly		SF	Desirable
to give unified information together with other road elements		PF	Desirable
to give directions	• *lokaliseringsmärken*	PF	Necessary
to give feedback	• *reactive signs*	SF	Worth considering

Road marks (on the roadway)

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to inform a driver	• TSFS 2010:171	MF	
to distinguish from the background	• roadway is usually black • weather conditions can impact • lighting conditions can impact	SF	Desirable
to separate roadways	• *sidelines/ centerlines*	PF	Necessary
to close an area on a roadway	• *spärrområde*	PF	Necessary
to give directions	• *sidelines/ centerlines/ merge arrows* • *road numbers*	PF	Necessary
to guide the driver/ to limit the roadway	• *sidelines/ centerlines*	PF	Necessary
to organise/give priority to different traffic flows	• *stop lines/give way lines*	PF	Necessary
to prohibit drivings	• *stop lines/give way lines*	PF	Necessary
to guide different types of road users	• lines for cyclists, road drivers, busses, pedestrians	PF	Necessary
to inform about about a road type/ element	• e.g. BUS/ SCHOOL/Road number/Speed limit • Parking lots	PF	Desirable
to give a tactile feedback		SF	Worth considering
to be visible in the darkness		SF	Necessary

Traffic lights

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to regulate traffic flows		MF	Necessary
to reduce speed		SF	Desirable
to organise/give priority to different traffic flows		MF	Necessary

Verge

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to safely stop the vehicle in case of emergency	• *emergency lane* (not parking)	MF	Necessary
to enable driving outside of the lane	• cyclists, mopeds, pedestrians (not on a motorway)	MF	Necessary
to make the driver pay attention to the ending of a road	• grooves at the edge of the lane	SF	Desirable

Roadway

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to guide a driver		MF	Necessary
to carry load from traffic		MF	Necessary
to connect road elements		PF	Necessary
to organize traffic flows		PF	Necessary
to connect different destinations		MF	Necessary
to harmonize with the surroundings		SF	Worth considering

Lighting

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to provide the driver with surrounding light		MF	Necessary
to make the road elements more visible		MF	Necessary
to make other road users visible		PF	Necessary
to increase safety		SF	Desirable
to help the driver navigate		MF	Necessary

Barriers

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to separate traffic	• *center barrier*	MF	Necessary
to prevent cars from going off the road	• *side barriers*	MF	Necessary
to guide a driver		PF	Desirable
to take kinetic energy from a crash		PF	Necessary
to hinder light from the opposite vehicles		SF	Worth considering

Side areas

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to drain the roadway		MF	Necessary
to improve visibility	• make oncoming traffic visible	MF	Nexessary
to isolate wildlife from the road area	• *viltstängsel*	SF	Desirable

Surrounding area

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to avoid distractions	in some cases there are requirements on what is allowed along the road	SF	Desirable
to make the visual impact of the road smaller in the local environment		SF	Desirable
to absorb noise from traffic		SF	Desirable

Traffic island

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to separate different roadways		MF	Necessary
to guide the driver		PF	Necessary
to close some parts of the roadway from traffic		MF	Necessary
to physically hinder vehicles driving in a non-intended way		SF	Desirable
to hinder vehicles from exiting the intended lane		MF	Necessary

Road posts

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to inform on direction of traffic	• TRVINFRA-00396 • K237873: Reflective rectangle on right side and two circles on the left side on two-way road. • K237874: Reflective rectangles on left and right side visible along correct driving direction.	MF	Necessary
to show dimensions of road	• when the road is covered with snow • in darkness • in fog	MF	Necessary
to inform on speed of traffic/type of road	• 50 m on regional roads • 100 m on motorways • sometimes 25 m in curves	PF	Desirable
to help assume the distance between vehicles		PF	Necessary
to identify the road side		PF	Necessary
to guide a driver		SF	Desirable
to identify different road sections	• yellow indicates a crossroad • white is used along roads	PF	Worth considering

Roundabaout

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to manage crossing traffic flows		MF	Necessary
to reduce speed on a road section	• *9.2.2.3*	PF	Necessary
to avoid stops next to a road crossing		PF	Desirable
to make oncoming traffic visible	• TRVINFRA-00396 9.2.2.2: road users driving into/next to the roundabout in the close by the nearest entry/ exit should be visible	PF	Necessary
to guide driver to the right exit	• signs describing exits • geometry suggesting the right side of a roadway	PF	Necessary

Ramps

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to increase speed of the vehicles	• entrance ramp	PF	Necessary
to enable vehicles to enter a motorway	• entrance ramp • free sight on the vehicles on the motorway	MF	Necessary
to decrease speed of the vehicles	• exit ramp	PF	Necessary
to enable vehicles to exit a motorway	• exit ramps	MF	Necessary
to provide a safe entrance to the motorway	• entrance ramp	PF	Desirable
to enter the traffic flow in a harmonized way	• entrance ramp	PF	Desirable
to provide a safe exit from a motorway	• exit ramp	PF	Desirable
to exit the traffic flow in a harmonized way	• exit ramp	PF	Desirable

Crossroad

Function (verb + noun)	**Limits** (measurable)	**Class** (MF/ PF/SF)	**Priority** **N**ecessary **D**esirable **W**orth considering **U**nnecessary
to enable vehicles to travel through crossing roads		MF	Necessary
to enable vehicles to turn onto another road		MF	Necessary
to organise/give priority to different traffic flows	• e.g. vehicles from small secondary roads must stop for vehicles on primary roads	SF	Desirable
to manage crossing of different types of road users		PF	Desirable
to enable safe travel through crossroad		SF	Necessary
to guide the driver onto the right lane		SF	Necessary

Appendix E

List of requirements.

Category	Requirement description	Necessary/Desirable	Note
Cognitive	Inform the driver on how to drive	N	
Cognitive	Provide the driver with congruent information	N	
Cognitive	Minimise non-congruent distractions	N	Solution should not confuse the users or use their attention unnecessarly
Cognitive	Information should be universal	D	Language(s) of the verbal information, accomodating needs of users with differen impairments
Cognitive	Road lanes should be separated	D	
Cognitive	Clearify the direction of driving	N	
Cognitive	Guide the driver within the designated lane	N	
Cognitive	Encourgaes the driver to stick to speed limits	D	
Cognitive	The attention of the driver should be called at interchanges	D	
Cognitive	Ensure feeling of safety in interchanges to minimise stress	N	
General	Prevent the driver from WWD	N	
Maintenance	Enable easy maintenance	D	
Maintenance	Enable easy reparation	D	
Maintenance	Enable easy cleaning	N	
Maintenance	Allow easy set up	D	
Maintenance	To be self-sufficient if energy will be needed	D	
Older drivers	Place important information right in the middle of the visual field	D	
Older drivers	Use traditional signage to emphasise importance of information	D	Older adults perceive traditional signage to be "superior" to LED-signs
Older adults	Important information should be repeated	D	
Older drivers	Colour choises should be propriate for older adults	N	
Older drivers	Provide a good and early view on the intersection	D	

Older drivers	Assistance in making left turn if needed	D	
Older drivers	Right-angle connection between roads	D	To accomodate restricted neck mobility
Older drivers	Information should be presented in good enough time for older adults to process before decisions should be made	N	
Older drivers	Information should be distributed to avoid mental over load	N	
Older drivers	Merge areas should be long	D	
Older drivers	Minimise time pressure	N	
Older drivers	Reduce complexity of traffic environments	D	
Older drivers	Present a piece of information in several ways	D	Makes it easier for older drivers to comprehend the information
Older drivers	If audible stimuli is used, it should be adjusted to noticable frequencies	N	
Older drivers	Clear separation between visual elements.	N	Especially for signage
Older drivers	Hinder direct or reflected light from sun or other cars	D	
Older drivers	Use clear colour contrasts	N	
Older drivers	If flickering lights are used, the frequency should be adjusted to be noticed by older drivers	D	
Older drivers	Most important information should be presented in a drammatic manner	D	
Older drivers	Visual information should be placed in the field of vision	D	
Older drivers	Avoid glare	D	
Older drivers	The percieved brightness contrast between road markings and the carriageway should be 2.0	N	Road markings should be at least 3 times as bright as the carriageway
Older drivers	Enable easy depth perception between objects	D	
Older drivers	Exits should be signed clearly and in good time	N	
Older drivers	Should simplify for the driver where to allocate their attention	N	

Physical	Visibility in darkness	N	Can be measured with parameters describing light source/reflexibility
Physical	Information-giving road elements should be distinguishable from the background	D	Contrast between the color of the solution and the background
Physical	Provide physical safety for drivers	N	Consider physical safety of the user, how big is the risk of an eventual accident?
Physical	Compatibility with other road elements	N	Road elements should be coherent
Physical	Meet strenght requirements	D	
Physical	Visibility in daylight	N	High contrast no matter light conditions, solution should not glare the user
Physical	Nearby road users should be visible for the driver	N	Road users that a driver need to encounter on their drive.
Physical	Enable efficient flow of traffic	D	Traffic flows should not be stopped without a reason
Physical	Enable entry and exit to motorway	N	
Physical	To funtion properly in snowy weather	D	Information should be visible in snowy weather
Physical	To function properly in cold weather	N	Should be resistant to cold and ice
Physical	Allowed turns should be soft, forbidden turns should be sharp.	N	
Physical	Signage should be placed so that it can be seen by the intended driver	N	Be viewable from the right angle (e.g. if a sign should prevent a possible WW-driver to turn, the sign should be viewable from that direction)
Physical	Information should be visible in rain	D	
Physical	Information should be visible in snowfall	D	
Physical	Information should be visible in windy conditions	D	
Sustainability	Long-lasting solution	N	Ask TV what is the expected lifetime span of an eventual solution
Sustainability	To not contain any hazardous chemicals	D	
Sustainability	Easy construction with limited material usage	D	
Sustainability	Different materials should be easy to separate	D	

Sustainability	To use primarly recycled materials in the production	D	
Sustainability	Durable against road maintenance	D	
Physical	Allow bigger transport		

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