

SCENARIO BASED PRODUCT DESIGN

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ISBN 978 90 365 2615 9

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Cover design by cab_graphic
Printed by PrintPartners Ipskamp

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PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Universiteit Twente,
op gezag van de rector magnificus,
prof. dr. W.H. Zijm,
volgens besluit van het College voor Promoties
in het openbaar te verdedigen op
vrijdag 28 maart 2008
om 16.45 uur

door

Martijn Tideman
geboren op 20 augustus 1979
te Amsterdam

Dit proefschrift is goedgekeurd door de promotor
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PREFACE

This thesis is the result of four years of research conducted at the University of Twente's Laboratory of Design, Production and Management. Although only my name appears on the cover of this work, many people contributed to its contents. Without their support, intellect, hard work and patience, I wouldn't have been able to complete my research.

This PhD research was inspired by the results of my Master's thesis. However, the drive to continue was only made possible by the enthusiasm of my supervisors Fred van Houten and Mascha van der Voort. Fred and Mascha were absolutely vital to getting this research on track and, then of course, making sure I stayed there.

Four other people played a decisive role in the beginning stages of this project: Bart van Arem, Gerd Spengelink, Dick Arnold and Ralph Klerkx. My discussions with them were incredibly valuable in shaping this research. Later, I received crucial support from Robert Wendrich, Eddy Heling, Arnout van den Broeke, Roy van Ophuizen, Ralf Sluimer, Wytze Hoekstra, Marika Hoedemaeker, Richard van der Horst, Peter van Wolffelaar and Wim van Winsum. Without their skills and knowledge, my ideas would never have materialized. In the end stages of this research, 60 volunteers helped me put these ideas to the final test. Also, Marieke Fransen offered her expertise in consumer psychology and Charlot Terhaar sive Droste lent this project her artistic talents.

During the last four years, colleagues from OPM, AIDA, TNO, Loosegoose Software, ST Software and T-Xchange provided a stimulating environment for performing my research. Also, I was often inspired by the energy and creative ideas of the many students I supervised. In addition, various late night discussions with friends gave me some critical insights. Scientific research doesn't always happen from 9 to 5 and can often be lubricated by a cold beer.

Last, but certainly not least, I can't forget my family, especially my sweet parents and my smart and beautiful wife, Angela. Their love, support, patience and good humor have not only been essential to this research, but also in shaping the person I am today.

Thanks everybody!

SUMMARY

Creating good products is not an easy thing to do. There are usually many different people who have an interest in the product. People such as the user, of course, but also marketing managers, production engineers, maintenance workers, recycling specialists, and government representatives, just to name a few. Each of these stakeholders has his own ideas and agenda, which may conflict with the ideas and agendas of others. Designers have an extremely tough job trying to satisfy the differing needs and desires of all stakeholders. Moreover, it is very difficult for designers to determine what those needs and desires are in the first place - especially when dealing with complex products and/or products that don't exist yet. To make matters worse, designers are always confined by time and cost constraints.

Through the years, various methods and tools have been developed that support designers in dealing with these difficulties. But, so far, these methods and tools have only been a band-aid on a wound. Design has essentially remained a process in which designers are forced to make assumptions about what other people want. This is especially true when designing products that are new, that are complex, and that involve many different stakeholders.

The goal of this research was the development of a new product design method that adequately supports designers in determining stakeholders' preferences and finding the best compromise between those preferences. A method that gives stakeholders insight into the consequences of their decisions and enables them to express their preferences. A method that provides designers with the information necessary to create a good design. A method that specifically supports the design of products that are new, that are complex, and that involve many different stakeholders.

The design method that was developed is based on the use of scenarios, virtual reality simulation and gaming principles. The method gives all stakeholders a proactive role in the design process. All stakeholders are allowed to create their own designs and immediately test these in a wide variety of scenarios.

While applying the new method, the design process is split into two separate phases. The first phase is aimed at developing a design environment that is a valid representation of the world relevant to the product, including the technology that may be usefully applied to the product. This design environment enables a stakeholder to generate designs and scenarios, and to realistically experience the behavior of those designs in the scenarios. The second phase of the design process is aimed at specifying a good design. Representatives from all stakeholder groups are invited for design sessions in which they must iteratively work towards a personal "most attractive design". The generated information is used to specify a compromise between the preferences of all stakeholders.

The new product design method was evaluated by applying it to a design case: the design of a lane change support system. This is a product that supports car drivers during lane change maneuvers. The

design process that emerged was analyzed by testing hypotheses about the new product design method's viability and the degree to which it fulfills its functions.

It was found that the new product design method is viable in the sense that people understand their role in the design process, that they are able to perform the specified activities, and that these activities yield actual results. It was also found that the new product design method fulfills its functions in the sense that it stimulates and enables the designer to create a consistent image of everybody's preferences and to reach a compromise between all those preferences.

An analysis of the impact of the case-specific circumstances on the assessment process revealed that the findings are generally applicable. The new product design method can be successfully applied to the design of all products that have a certain level of modularity or configurability. It should, however, be technically possible to create interfaces for stakeholders to generate candidate designs and test environments, and to offer simulations of those designs in those environments such that stakeholders can make a reliable assessment of the designs' properties.

The added value of applying the new product design method will not always be worth the investment. It costs a significant amount of time and money to create a design environment, perform sessions with stakeholders, and continuously assure that all information is consistent. The chances of getting a "return on investment" generally increase the less familiar designers are to the product, the more complex the product is, and the more stakeholders are involved in the process.

The investment will certainly be returned when the new product design method is used to design products that should be "first time right" in order to not endanger users and to not affect the company's image. Products such as, for example, a lane change support system. If such a product doesn't work properly when it is introduced on the market, the driver's safety is endangered and the manufacturer's market position is affected. Therefore, for companies such as automotive manufacturers, using the new product design method would be worth the investment.

SAMENVATTING

Een goed product maken is niet makkelijk. Er zijn vaak veel verschillende mensen die een belang hebben bij het product. Gebruikers natuurlijk, maar bijvoorbeeld ook mensen als marketingmanagers, productie-ingenieurs, onderhoudstechnici en overheidsfunctionarissen. Ieder van deze “stakeholders” heeft een eigen, unieke, kijk op het product. En de behoeften en voorkeuren van de één kunnen botsen met die van een ander. Voor ontwerpers is het vaak lastig om iedereen volledig tevreden te stellen. Bovendien is het moeilijk om te bepalen wat ieders behoeften en voorkeuren nu eigenlijk precies zijn - zeker als het gaat om een complex product en/of een product dat geheel nieuw is. Tot overmaat van ramp beschikken ontwerpers altijd maar over een beperkte hoeveelheid tijd en geld.

In de loop der jaren zijn er allerlei methoden en gereedschappen ontwikkeld die ontwerpers ondersteunen bij het omgaan met deze problematiek. Maar tot op heden zijn deze methoden en gereedschappen slechts druppels op een gloeiende plaat gebleken. Ontwerpen is nog altijd een proces waarin ontwerpers gedwongen zijn aannames te doen over wat andere mensen willen. Dit geldt met name bij het ontwerpen van complexe producten, producten die geheel nieuw zijn, en producten waarbij veel verschillende stakeholders betrokken zijn.

Het doel van dit onderzoek was de ontwikkeling van een nieuwe productontwerpmethode. Een methode die ontwerpers ondersteunt bij het achterhalen van de voorkeuren van stakeholders en bij het vinden van het beste compromis tussen deze voorkeuren. Een methode die alle stakeholders de mogelijkheid biedt inzicht te krijgen in de gevolgen van beslissingen en die ze in staat stelt aan te geven wat hun voorkeuren zijn. Een methode die ontwerpers van alle informatie voorziet die ze nodig hebben om een betrouwbare conclusie te trekken over wat een goed ontwerp zou zijn. Een methode die met name bedoeld is voor het ontwerpen van complexe producten, producten die geheel nieuw zijn, en producten waarbij veel verschillende stakeholders betrokken zijn.

De nieuwe productontwerpmethode is gebaseerd op het gebruik van scenario's, virtual reality simulatie en speltechnieken. De methode geeft alle stakeholders een actieve rol in het ontwerpproces. Alle stakeholders mogen zelf hun eigen ontwerpen maken en deze direct testen in allerlei verschillende scenario's.

Het ontwerpproces dat ontstaat wanneer de nieuwe methode toegepast wordt bestaat uit twee fasen. De eerste fase is gericht op het ontwikkelen van een ontwerpomgeving die een afspiegeling is van de voor het product relevante werkelijkheid (inclusief de technologie die toegepast zou kunnen worden in het product). Met deze ontwerpomgeving kan een stakeholder ontwerpen genereren, scenario's genereren, en levensecht ervaren hoe de ontwerpen zich gedragen in de scenario's. De tweede fase van het ontwerpproces heeft als doel een goed ontwerp te specificeren. Stakeholders mogen iteratief naar een persoonlijk “favoriet ontwerp” toewerken. Met de informatie die hierbij gegenereerd wordt kan vastgesteld worden wat het beste compromis tussen de voorkeuren van alle stakeholders.

De nieuwe productontwerpmethode is geëvalueerd door hem toe te passen op een ontwerpcase: het ontwerp van een rijstrookwissel-assistent. Dit is een product dat autobestuurders ondersteunt bij het wisselen van rijstrook. Het ontwerpproces dat ontstond is geanalyseerd door hypothesen te testen over de levensvatbaarheid van de methode en over de mate waarin zij haar functies vervult.

Uit de evaluatie bleek dat de nieuwe productontwerpmethode levensvatbaar is: stakeholders begrijpen hun rol in het ontwerpproces, ze zijn in staat om de voorgeschreven activiteiten uit te voeren, en deze activiteiten leiden tot daadwerkelijke resultaten. Het bleek ook dat de nieuwe methode haar functies vervult: de ontwerper wordt gestimuleerd en in staat gesteld een consistent beeld van ieders voorkeuren te creëren, en een betrouwbaar compromis tussen al deze voorkeuren te specificeren.

Uit analyse van de invloed van de case-specifieke omstandigheden op het evaluatieproces volgde dat de bevindingen algemene geldigheid bezitten. De nieuwe productontwerpmethode kan succesvol toegepast worden op het ontwerp van alle producten die een zekere mate van modulariteit of configureerbaarheid bezitten. Het moet echter wel technisch mogelijk zijn om interfaces te maken waarmee stakeholders ontwerpen en scenario's kunnen genereren. Ook moet het mogelijk zijn om simulaties van deze ontwerpen in deze scenario's aan te bieden, zodanig dat stakeholders de eigenschappen van de ontwerpen op een betrouwbare manier kunnen beoordelen.

De toegevoegde waarde van het gebruiken van de nieuwe productontwerpmethode zal niet altijd de investering waard zijn. Het kost veel tijd en geld om een ontwerpomgeving te ontwikkelen, om sessies met stakeholders uit te voeren, en om te zorgen dat alle informatie steeds consistent is. In het algemeen geldt dat hoe complexer het product is, hoe minder bekend ontwerpers zijn met het product, en hoe meer verschillende stakeholders betrokken zijn bij het proces, hoe groter de kans is dat de investering zich zal terugbetalen.

De investering zal zich vrijwel zeker terugbetalen wanneer de nieuwe productontwerpmethode gebruikt wordt om producten te ontwerpen die "in één keer goed" moeten zijn. Dit zijn producten die, als ze niet goed functioneren, gebruikers in gevaar brengen en het imago van het bedrijf aantasten. Producten zoals bijvoorbeeld een rijstrookwissel-assistent. Als zo'n product bij marktintroductie niet goed werkt, wordt de veiligheid van bestuurders in gevaar gebracht en de marktpositie van de fabrikant aangetast. Voor bedrijven zoals automobielfabrikanten zou het gebruik van de nieuwe productontwerpmethode daarom de investering waard zijn.

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INTRODUCTION

1

The research that is presented in this thesis is about the development of a new product design method. This chapter introduces the background of the research. The research objective, the research approach, and the outline of the thesis are also discussed.

1.1 Product design

The chair you're now sitting on, the device that makes your morning coffee, and the car sitting in your driveway. Products are everywhere. They make our lives easier, more pleasurable and more interesting.

Where do all of these products come from? How does an actual thing come from an idea? Products come from designers – those people who have thought about how the chair should feel when we sit in it, how the coffee machine should brew our coffee, and how our car will handle hairpin curves.

And designers don't only think; they also do. Designing is sketching, drawing, modeling, building prototypes, and testing, testing and more testing. All this is meant to ensure that the product works the way it should.

And yet, despite all this thinking and doing, the process still goes awry sometimes. There are many badly designed products in the world. Or do you still think it's your fault that you can't program your VCR? Think again. The fault is in the product.

How is it possible that designers let this happen? Why do they allow badly designed products to enter the market? In fact, creating good products is not an easy thing to do. There are usually many different people who have an interest in the product. People such as the user, of course, but also marketing managers, production engineers, maintenance workers, recycling specialists, and government representatives, just to name a few. Each of these stakeholders has his¹ own ideas and agenda, which may conflict with the ideas and agendas of others. Designers have an extremely tough job trying to satisfy the differing needs and desires of all stakeholders. In addition, designers are always confined by time and cost constraints.

And there's another problem – one that comes into play even before the designer considers how to best satisfy everyone's preferences. What exactly *are* those preferences in the first place? Determining other people's preferences sounds like an easy thing to do: just ask what they want and listen to the answers, right? Although this approach will certainly give a first impression, there's a downside to it. Using natural language as the only communication medium can easily lead to misunderstandings – and, therefore, to unreliable conclusions.

A more reliable approach for determining other people's preferences is to supplement the use of natural language with other communication media such as images, movies, simulations or real-world

¹ In this thesis, the words "he", "him" and "his" may also be read as "she", "her" and "her", respectively.

artifacts. This diminishes the risk of misunderstandings influencing the course and the results of the design process. For instance, if a designer wants to know whether coffee drinkers prefer red, blue or black coffee cups, he can show cups of these colors (or images, movies or simulations of them) to a few coffee drinkers and ask which one they like best. To reliably determine people's preferences, it is important to show them the effects of their statements and/or to give them insight into the consequences of decisions. If the designer wants to be even more confident about the results, he can also do some additional objective measurements (for example, by registering the way the coffee drinkers interact with the differently colored cups). A similar approach can be used to deduce coffee drinkers' preferences with regard to other parameters of the cup such as its height and diameter. Although quite a few experiments would be needed to come to a statistically significant conclusion about the best combination of height, diameter and color, conducting such a series of experiments would definitely be feasible.

But what about products that don't exist yet, those of which the parameters are not known yet? Coffee cups exist long enough for designers to be familiar with the parameters that describe them. This offers designers the opportunity to conduct experiments in which the values of these parameters are varied and in which stakeholders are asked for an opinion about the changes. But when the product's parameters are unknown, it is much more difficult to perform such experiments.

And what about more complex products, those that are described by more than only a handful of parameters? Take a modern car, for example. The amount of parameters needed to describe it ranges from 10^5 to 10^6 (Rouibah & Caskey, 2003). Moreover, many of those parameters are interrelated. This means that changing the value of one parameter has an effect on the possible values of other parameters. Deducing stakeholders' preferences in relation to all those parameters would require an enormous and unwieldy amount of experiments. And even if a designer would be prepared to undertake such a series of experiments, how would it be realistically possible to vary all those parameters and let stakeholders experience the consequences of those changes?

Through the years, various methods and tools have been developed that support designers in dealing with these difficulties. Among these are methods that give stakeholders an active role in the design process so that they can defend their own interests. There are also design methods that utilize scenarios in order to explicitly address problems, needs, constraints, and possibilities. An example of a tool that supports in getting insight into the consequences of decisions is virtual reality (VR) simulation. VR simulation can help to avoid misunderstandings, save money and time, and enable the evaluation of candidate designs early in the design process.

But, so far, these methods and tools have only been a band-aid on a wound. Design has essentially remained a process in which designers are forced to make assumptions about what other people want. This is especially true when designing products that are new, that are complex, and that involve many different stakeholders. For such products, there is no method that adequately supports designers in determining stakeholders' preferences and finding the best compromise between those preferences.

1.2 Objective

The goal of this research was the development of a new product design method that adequately supports designers in determining stakeholders' preferences and finding the best compromise

between those preferences. A method that gives stakeholders insight into the consequences of their decisions and enables them to express their preferences. A method that provides designers with the information necessary to create a good design. A method that specifically supports the design of products that are new, that are complex, and that involve many different stakeholders.

1.3 Approach

Reliably determining stakeholders' preferences in relation to all parameters of a complex product traditionally requires an unwieldy amount of experiments. The new product design method should make this process more manageable by offering a new approach for determining stakeholders' preferences. On the other hand, the new method shouldn't be incompatible with the way designers actually work, and it shouldn't require tools that are unavailable to designers.

To reduce the risk of developing a method that will never be used, the product design method outlined in this thesis is based on elements already present in current design practice. The research began with an analysis of how designers work and a review of currently available design tools. The trends identified through this analysis were then used as a basis for the new product design method. Finally, the new method was evaluated. This was done by applying it to a design case, and, at the same time, collecting and analyzing data about the design process that emerged.

1.4 Outline

While pursuing the goal of this research, four different processes were performed in parallel. Performing these processes required fulfillment of the following roles:

1. Researcher
2. Design method developer
3. Analyst
4. Designer

Because this thesis is a reflection of the research, these roles also appear in the thesis. Each chapter in this thesis is written from the perspective of one specific role. Figure 1.1 shows the outline of the thesis and illustrates the perspective from which each chapter is written. The arrows indicate how the results of one chapter become the input of another.

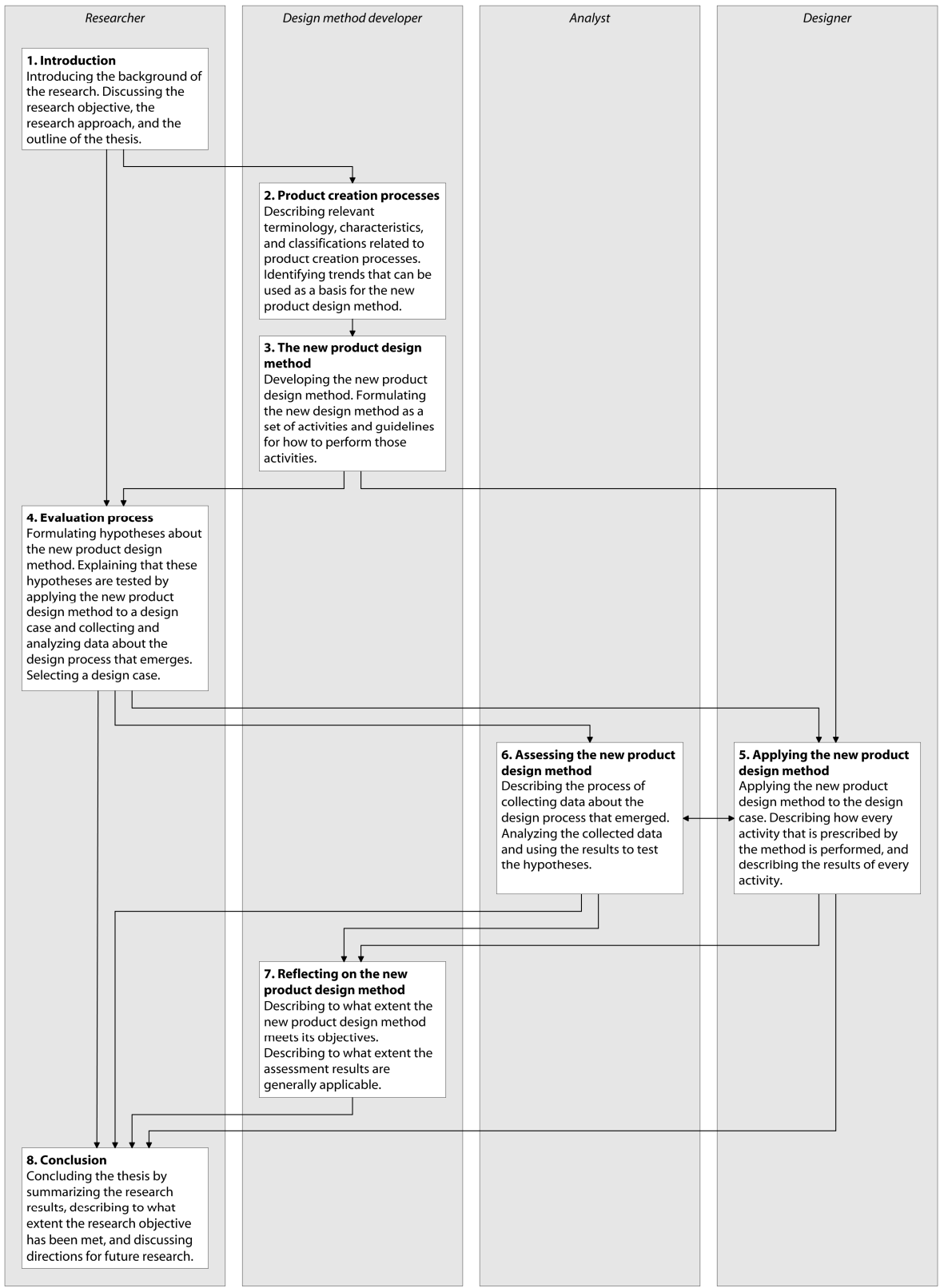


Figure 1.1: Outline of the thesis

PRODUCT CREATION PROCESSES

2

This chapter gives an introduction to product creation processes. First, relevant terminology is introduced, some key characteristics of product creation processes are described, and a classification of product creation processes is proposed. Next, methods and tools that support product design processes are described. From these descriptions, trends are identified that can be used as a basis for the new product design method. The chapter is concluded with formulating requirements for the new product design method.

2.1 Introduction

2.1.1 Products and their creation processes

The world we live in today is much more a man-made, or artificial, world than it is a natural world. Almost every element in our environment shows evidence of human artifice (Simon, 1996). All these man-made, artificial, elements can be called “products”. So a product can be a physical object, such as a pencil, a car, or a football stadium. But it can also be a non-physical process, such as a remedy for a sick patient, a sales plan for a company, or a social welfare policy for a state (Simon, 1996). In this thesis, however, products are defined to be “all discrete physical objects created by humans”.

The creation of a product is instigated by certain recognized needs and/or by certain recognized technological potential. Product creation processes prompted by recognized needs are often referred to as “market pull processes”. Such processes are aimed at finding a solution to a problem. Product creation processes instigated by recognized technological potential are usually referred to as “technology push processes”. The goal of these processes is to find a problem to a solution. In this thesis, however, emphasis will lie on “market pull processes”.

A product should be both effective and efficient. A product creation process should also be both effective and efficient. These two statements imply four different requirements with regard to products and product creation processes (see Table 2.1).

	<i>“A product...”</i>	<i>“A product creation process...”</i>
<i>...should be effective”</i>	A product should adequately fulfill actual needs and adequately exploit actual technological potential.	A product creation process should result in a product that adequately fulfills recognized needs and adequately exploits recognized technological potential.
<i>...should be efficient”</i>	A product should adequately fulfill actual needs and adequately exploit actual technological potential. Also, the product’s price and delivery time should be acceptable.	A product creation process should result in a product that adequately fulfills recognized needs and adequately exploits recognized technological potential. Also, the process’ costs and the product’s time-to-market should be acceptable.

Table 2.1: Requirements to products and requirements to product creation processes

At first glance, the terms “effectiveness of a product” and “effectiveness of a product creation process” seem to be mutually interchangeable. Similarly, the terms “efficiency of a product” and “efficiency of a product creation process” seem to be mutually interchangeable. However, there are subtle differences between these respective terms: it is possible for a specific product creation process to be effective and efficient, while the resulting product is ineffective and inefficient. This is the case, for example, when the *recognized* needs that are input into the product creation process differ from the *actual* needs that the product should fulfill. In such a case, a product creator may find an effective and efficient solution for a problem. However, because he was working on the wrong problem, this effective and efficient solution does not result in an effective and efficient product.

This example shows that product creators must ensure that *recognized* needs coincide with *actual* needs. Similarly, it is important that the *recognized* technological potential coincides with the *actual* technological potential. Theoretically, this would guarantee that an effective and efficient product creation process also results in an effective and efficient product.

2.1.2 Product design processes

A product creator can immediately produce an object that should fulfill certain recognized needs and exploit certain recognized technological potential. However, currently, for the majority of product creation processes, the physical production of an object is preceded by a phase in which it is designed: the product design process. Performing a product design process is aimed at creating a more effective and efficient product compared to when a product design process is not performed.

Figure 2.1 illustrates how the different higher-level processes within a product creation process relate to each other and what the output of each process can be. Its purpose is to prevent possible confusion of the terms “product creation process”, “product design process”, “production planning process” and “production process” as they are used in this thesis.

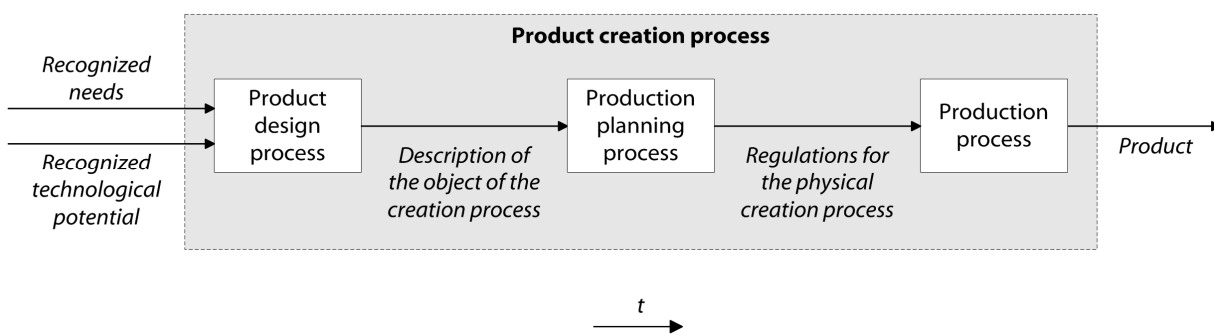


Figure 2.1: The higher-level processes within a product creation process

Figure 2.1 shows that:

- The input to a product creation process is formed by recognized needs and recognized technological potential;
- The output of a product creation process is a product;
- The output of a product design process is a description of the object of the creation process. During the production planning process, this description is translated to regulations for the

physical creation process. During the production process, the product is physically created from its material constituents.

Performance of a product design process is an investment that should pay off. A product design process always costs extra time and resources, but these additional expenses should be regained during later stages of the product creation process. This can be either directly (time and resources are saved during the remainder of the product creation process) or indirectly (the product more adequately fulfills actual needs and/or more adequately exploits actual technological potential).

2.2 Key characteristics of product creation processes

2.2.1 Introduction

This section describes three key characteristics of product creation processes: uncertainties, trade-offs, and human actors. The descriptions are meant to give a sense of “the intrinsic nature” of product creation processes. They also illustrate some difficulties that exist during product creation processes. Finally, the descriptions are used to derive a product creator’s objectives during a product creation process.

2.2.2 Uncertainties

A key characteristic of any product creation process is the presence of uncertainties. Uncertainties may range from *a falling short of certainty* to *an almost complete lack of conviction or knowledge*. In product creation processes, uncertainties exist on different levels. For example, on the highest level, every product design process stems from uncertainty about what to create. After all, if a product creator is absolutely certain about what to create, a product design process would be redundant and he could immediately start the production planning process. In this respect, a product design process is a way to become more certain about what to create.

Not only are there uncertainties about the *output* of a product creation process, but there is also uncertainty about the *inputs*. For example, on a higher-level, there is uncertainty about whether the *recognized* needs that are input into the product creation process coincide with the *actual* needs that should be fulfilled by the product. Those actual needs cannot be known during the product creation process. Similarly, there is uncertainty about whether the *recognized* technological potential that is input into the product creation process coincides with the *actual* technological potential that could be exploited by the product. An example of a lower-level uncertainty is, while creating a car, lack of knowledge about the failure rate of a specific windscreen wiper motor.

2.2.3 Trade-offs

Another key characteristic of product creation processes is that trade-offs must be made (Keeney, 2005). Making a trade-off is defined as giving up one thing in return for another. A *technical trade-off* indicates how much additional achievement *can be attained* on one objective if the level of achievement on another objective is changed. A *value trade-off* indicates how much a person *is willing to* have the achievement decrease on one objective if the achievement can simultaneously increase on another objective *by a specified amount* (Keeney, 2005). An example of a technical trade-off is how much a designer can increase the potential usability of a product by spending a specific amount of time and money to perform a usability test with a physical prototype. The corresponding value trade-off in this situation concerns whether spending that amount of time and money would be worth the potential

increase in usability. One of the most difficult aspects of product development is recognizing, understanding and managing trade-offs in a way that maximizes the potential success of the product (Ulrich & Eppinger, 1995).

Similar to the uncertainties present on different levels of the product creation processes, trade-offs also exist on different levels. For example, a higher-level trade-off may exist between the price of a product, its delivery time, and how adequately it fulfills actual needs. A lower-level trade-off may for example exist between the failure rate and the size of a specific windscreen wiper motor.

2.2.4 Human actors

A third key characteristic of product creation processes is the presence of human actors. Every product creation process involves at least one human actor: the designer. The designer is the person whose direct task it is to describe the object of the creation process (i.e. the design). Coming to such a description involves two alternating processes: synthesis (generating ideas, information, drawings, models, prototypes, etc.) and analysis (establishing evaluation criteria, evaluating what has been generated, and deciding how to proceed). Alternatively, instead of a single designer, a design team may be employed during a product creation process. A design team is two or more people that share the responsibility of creating a design. In addition to performing synthesis and analysis processes, the members of a design team must also communicate, collaborate and negotiate with each other.

In addition to the designer², many different human actors may have a direct or indirect interest in the final product and/or in its creation process. Such human actors are called "stakeholders in a product creation process" (or, in short, "stakeholders"). By definition, every individual stakeholder has a unique view (i.e. a unique set of opinions, beliefs and preferences) on the product and/or on its creation process. However, there are groups of stakeholders with similar views on the product and/or on its creation process. Examples of such groups are "marketing managers", "production engineers", "maintenance workers", "recycling specialists", "government representatives", and "users". Still, within each stakeholder group, views on the product may vary.

2.2.5 The relationship between uncertainties, trade-offs and human actors

The three key characteristics of product creation processes (i.e. uncertainties, trade-offs, and human actors) are interrelated:

A trade-off implies a decision that is made with comprehension of both the positive and negative consequences of a particular choice. Therefore, in order to make a trade-off:

- *Uncertainty about the consequences of a particular choice should be eliminated;*
- *Human actors should be consulted for their opinion on how positive and negative consequences should be weighed.*

In the above statement, the relationship between uncertainties, trade-offs and human actors is considered "from the viewpoint of trade-offs". However, the relationships can also be considered "from the viewpoint of uncertainties". This leads to the following formulation:

² Unless explicitly indicated, in the remainder of this thesis, the word "designer" may also be read as "design team".

In product creation processes, there are uncertainties about trade-offs and human actors. Therefore, in order to eliminate uncertainties:

- *Trade-offs should be recognized and the positive and negative consequences of choices should be understood;*
- *Human actors should be identified and their opinions about how to weigh positive and negative consequences should be understood.*

The relationship between uncertainties, trade-offs and human actors during product creation processes can be illustrated:

- Consider a specific product creation process that involves one designer and two groups of stakeholders: users and government representatives. During the design process, the designer must decide which material will be used to create the product.
- In order to make this decision, the designer must first understand the consequences of choosing a specific material. Theoretically, this means that for every existing material, the designer investigates the consequences of its application to the product's price, time-to-market, environmental friendliness, failure rate, safety, lifespan, aesthetics, usability, etc. A possible outcome is that using aluminum rather than wood is better for the product's aesthetics, but detrimental for its environmental friendliness.
- After identifying the consequences of all choices, the designer then must investigate how positive and negative consequences should be weighed. This means asking stakeholders their opinions about how the positive and negative consequences relate to each other. One possible outcome of this investigation could be that the users would rather have the final product be aesthetically attractive than environmental friendly. In contrast, the government representatives may consider environmental friendliness as the most important objective of the product creation process.
- Finally, the designer must make a decision that satisfies all stakeholders as much as possible. A possible outcome of this decision could be that the designer selects stainless steel as a material, as a compromise between the preferences of the users and the government representatives.

2.2.6 Conclusion

The above example shows that it is difficult to completely eliminate all the uncertainties during a product creation process. Therefore, the designer's objective is to eliminate as many uncertainties as possible for a specific amount of invested time and money. For a specific amount of invested time and money, the designer must:

- Obtain insight into the needs that the product should fulfill and the technological potential that the product could exploit;
- Recognize trade-offs and understand the positive and negative consequences of choices;
- Identify stakeholders and understand their opinions about how positive and negative consequences should be weighed.

2.3 A classification of product creation processes

2.3.1 Introduction

Although every product creation process is unique, product creation processes can be usefully categorized. Numerous different classifications exist. For example, product creation processes can be

classified according to the production quantity, the customer order decoupling point, and the type of design (Lutters, 2001). However, a classification that is based on the three key characteristics that were described in section 2.2 (i.e. uncertainties, trade-offs, and human actors) does not yet exist. Therefore, in this section, such a classification will be proposed.

In general, the properties of a *product creation process* are interrelated with the properties of the *product* that results from this creation process. For example, the design of a product generally determines its possible production methods, and the production method dictates batch size (Lutters, 2001). Therefore, the new classification will not only concern *product creation process properties*, but also *product properties*.

2.3.2 The new classification of product creation processes

The new classification is presented in Table 2.2. Two distinct types of product creation processes are discerned.

<i>Type</i>	<i>Description</i>
1	The problem can be clearly and reliably described in the early stages of the design process, and subsequent stages are aimed at finding an adequate solution. Only a single designer or a small design team is needed to find this solution, while working within the time and cost constraints.
2	The problem cannot be clearly and reliably described in the early stages of the design process. Throughout the entire product design process, "problem describing activities" and "solution finding activities" occur concurrently. A relatively large, often multi-disciplinary, design team is needed to describe the problem and find a solution, while working within the time and cost constraints.

Table 2.2: The two distinct types of product creation processes

In the descriptions in Table 2.2, "the early stages of the design process" are defined as "the timeframe between start of the product design process and creation of the first physical prototype of the product". A "physical prototype" is a "preliminary physical embodiment of (parts of) the design, used for evaluating its properties before the production process is started".

The new classification is purely theoretical in the sense that, in practice, a product creation process will never completely comply with one of the distinct process types. The descriptions represent extremities on a continuous scale. In other words, the more a description matches a specific product creation process, the more the process can be said to be of a certain type. However, a product creation process may be predominately of one type or the other, rather than an equal mix of both.

For each respective distinct process type, sections 2.3.3 and 2.3.4 will describe general characteristics and how these define the process type. Also, examples will be given of product creation processes that conform (mostly) to the distinct process type.

2.3.3 Type 1 product creation processes

General characteristics of type 1 product creation processes are:

- Similar product creation processes and similar results (i.e. similar products) already exist for quite some time. In other words, the product's creation process and its end result are relatively well known. The designer has a good insight into the needs that should be fulfilled by the product and the technology that could be used in the product. The designer generally knows

- who the stakeholders are and what opinions they have about how positive and negative consequences should be weighed. During the product creation process, the degree of uncertainty is therefore relatively low;
- The product creation process and its result (i.e. the product) are neither complex, nor part of a complex system. In other words, there are relatively few parts and aspects related to the product and its creation process, and there exist relatively few interactions between those parts and aspects. This implies that it is relatively easy for the designer to understand the consequences of a particular choice. Therefore, during the product creation process, relatively few trade-offs exist, and it is relatively easy to recognize and understand them;
 - The product creation process and its result (i.e. the product) involve few different groups of stakeholders and the views within each stakeholder group are rather similar. This implies that there are relatively few different opinions among stakeholders about how positive consequences and negative consequences should be weighed. It is therefore relatively easy to make trade-offs such that every stakeholder is sufficiently satisfied.

A result of this relatively low degree of uncertainty, low number of trade-offs, and few different views on how trade-offs should be made is that it is not very difficult to clearly and reliably formulate the problem in the early stages of the product design process. Therefore:

- Subsequent stages of the product design process are aimed at finding an adequate solution for the formulated problem;
- A single designer or a small design team is sufficient to find such a solution, while working within the time and cost constraints.

Examples of products of which the creation processes largely comply with the characteristics of type 1 processes are *a pencil, a hammer, a pair of jeans, and an umbrella*.

2.3.4 Type 2 product creation processes

General characteristics of type 2 product creation processes are:

- Similar product creation processes and similar results (i.e. similar products) do not yet exist. In other words, the product's creation process and its end result are relatively not well known. The designer does not yet have a very good insight into the needs that should be fulfilled by the product and the technological potential that could be exploited by the product. The designer does not yet have a very good insight into who the stakeholders are and what opinions they have about how positive and negative consequences should be weighed. Therefore, during the product creation process, there are relatively many uncertainties and the degree of uncertainty is relatively high;
- The product creation process and its result (i.e. the product) are complex and/or part of a complex system. In other words, there are relatively many parts and aspects related to the product and its creation process, and there exist relatively many interactions between those parts and aspects. This implies that it is relatively difficult for the designer to understand the consequences of a particular choice. Therefore, during the product creation process, relatively many trade-offs exist, and it is relatively difficult to recognize and understand them;
- The product creation process and its result (i.e. the product) involve many different groups of stakeholders and/or the views within each stakeholder group are rather different. This implies that there are relatively many different opinions among stakeholders about how positive

consequences and negative consequences should be weighed. It is therefore relatively difficult to make trade-offs such that every stakeholder is sufficiently satisfied.

A result of this relatively high degree of uncertainty, high number of trade-offs, and many different views on how trade-offs should be made is that it is very difficult to clearly and reliably formulate the problem in the early stages of the product design process. Therefore:

- The design process (i.e. the solution finding process) is started with a tentative problem formulation. Every proposed solution - either on a conceptual or on a detailed level - leads to new insights and associations with regard to the problem. And vice versa: the updated problem formulation leads to new associations and insights with regard to the solution. As a result, activities aimed at formulating the problem and activities aimed at defining the solution occur concurrently throughout the entire product design process;
- There is a relatively high risk of overlooking parts and aspects related to the problem and/or the solution - as well as a high risk of overlooking interactions between those parts and aspects. Therefore, a relatively large, usually multidisciplinary, design team is required to come to an adequate problem formulation and an adequate solution definition, while working within the time and cost constraints. Moreover, human actors who have an either direct or indirect interest in the final product and/or in its creation process (i.e. stakeholders) are often also required to be involved in the product design process.

It is difficult to give examples of products of which the *current* creation processes largely comply with the characteristics of type 2 processes. After all, one of the characteristics is that similar product creation processes and/or similar results (i.e. similar products) do not yet exist. Therefore, examples of products of which the *original* creation processes largely complied with the characteristics of type 2 processes are given: *a microwave, a cell phone, an Anti-lock Braking System, and a GPS navigation system.*

An example of a not yet existing product of which the creation process is expected to largely comply with the characteristics of type 2 processes is an *Automated Highway System (AHS)*. An AHS consists of vehicles and roadways that will provide fully autonomous computer controlled driving. Although such a system will be partly created from products that already exist for some time (e.g. vehicles, roadways, computers), the creation of an AHS-as-a-whole will still largely comply with the characteristics of type 2 processes.

2.3.5 Trends in product creation processes

Current trends have made it so that an ever-increasing number of product creation processes has characteristics of type 2 processes. The most important trends will be discussed, examples will be given, and it will be explained why these trends contribute to the fact that more product creation processes have characteristics of type 2 processes.

The first trend is that new technology is entering the market more quickly. The time span between discovery and/or the invention of a new solution principle and its application to products is decreasing. For example, more than a century passed between the first steam engines and their wide application to products (a major cause for the Industrial Revolution). In the late 19th and early 20th century, it took a few decades between invention of the Otto engine and its wide application to products (a major cause for the Personal Mobility Revolution). More recently, less than a decade passed between creation of the

first microprocessor and its wide application to PCs (a major cause for the Internet Revolution). A general result of new solution principles being more quickly applied to products is that the designer has less time to become familiar with the new technology before it is brought to the market. As argued in section 2.3.4, this leads to more uncertainties and a higher degree of uncertainty during the product creation process.

The second trend is that more functions are combined into single products. For example, microwaves used to be only capable of heating food and drinks using electromagnetic waves. Today, they also function as an oven and a grill. The first cell phones provided a means to wirelessly send and receive voice messages in real time. Today, cell phones take pictures and capture video, e-mail, play music, act as an organizer, etc. Motor vehicles used to get us from point A to point B by means of an engine, four wheels and a steering wheel. Although they still do that, the amount of sub-functions onboard vehicles has increased dramatically. It is not unusual for a current passenger car to have 50 Electronic Control Units (ECUs). These are the computers that control one or more subsystems such as the engine, the gearbox, the braking system, electric windows, air-conditioning, airbags, the infotainment system, etc. And this development is continuing: examples of subsystems that are *currently* being introduced into motor vehicles are parking assistants, adaptive cruise controls, lane departure warning systems, and lane keeping systems. The function of such *driver support systems* is to take over aspects of driving that were previously fulfilled by the human driver. A general result of this trend is that the product and its creation process become more complex. As argued in section 2.3.4, more complexity makes it more difficult for the designer to understand the consequences of a particular choice. In other words, during the product creation process, more trade-offs exist, and it is more difficult to recognize and understand them.

The third trend is that globalization - a general term for increasing global connectivity, integration and interdependence - affects product creation processes and their results (i.e. the products). For example, in the past, production companies used to create products that were primarily aimed at meeting the demands of consumers in their own town, region, or country. Today, the objective of many companies is to create products that meet the demands of consumers around the world. A parallel and interrelated development is that suppliers, production facilities, marketing departments, and maintenance organizations of production companies are more globally distributed. Because of globalization, the product creation process and the resulting product involve more groups of stakeholders. As argued in section 2.3.4, this makes it more difficult for the designer to make trade-offs such that every stakeholder is sufficiently satisfied.

The fourth and final trend is that mass-produced products are becoming more customized to the needs and preferences of individual consumers. This trend is called "mass-customization", and it is closely related to customers becoming more demanding. They not only want effective and efficient products (implying mass-production), but they also want those products to meet their unique individual needs and preferences (implying customization). For example, in the early days of mass-production, a customer could order a T-Ford "in any body-color as long as it was black." Nowadays, two exact same cars leaving a production line is a rarity. This fourth trend is correlated with the first three trends (i.e. new technology faster entering the market, more functions being combined into single products, and globalization affecting product creation processes and their results). Accordingly, the result of mass-customization is also threefold: more uncertainties and a higher degree of uncertainty, more trade-offs

and more difficulty to recognize and understand them, and more difficulty in making trade-offs such that every stakeholders is sufficiently satisfied.

2.4 Product design process support

2.4.1 Introduction

Product design processes can be supported by applying product design methods and product design tools. These methods and tools are aimed at realizing a more effective and more efficient product compared to when they are not applied. Application of product design methods and product design tools is an investment that should pay off. It always costs extra time and additional resources, but these additional expenses should be regained during later stages of the product creation process. This can be either directly (time and resources are saved during the remainder of the product creation process) or indirectly (the product more adequately fulfills actual needs and/or more adequately exploits actual technological potential).

2.4.2 Product design methods

A product design method specifies activities and provides guidelines for how to perform those activities. It offers a framework for gathering and structuring information, which, in turn, offers a basis for communication and decision making during a product design process.

A product design method is always based on a specific reference model of the product design process (i.e. a specific paradigm to consider the product design process). Therefore, a one and only “best” product design method does not exist. After all, it can always be argued that the paradigm on which this product design method is based is incorrect (or not representative for all design cases). Deciding which product design method can be best applied within a product design process depends on the design case at hand (i.e. on factors such as product type, composition of the design team, the involved stakeholders, available resources, desired time-to-market, etc.).

However, generally, a “good” product design method stimulates and enables the designer to work more effectively and more efficiently during a specific product creation process. A “good” product design method fulfills the needs of the designer in gathering and structuring information during the product design process. It protects the designer from making mistakes in communication and decision making during the product design process.

2.4.3 Product design tools

Whereas a product design method supports the designer in *specifying* activities, a product design tool supports the designer in actually *performing* activities. A product design tool can be a technique or an algorithm, but also a piece of hardware or a software application. In describing product design tools, there are:

- Tools for supporting the *generation* of design information (such as creativity techniques);
- Tools for supporting the *representation* of design information (such as sketchbook, pencil, CAD systems and VR simulation systems);
- Tools for supporting the *evaluation* of design information (such as analysis and decision techniques).

Deciding which product design tool can be best applied during a specific activity depends on the design case at hand. However, generally, a “good” product design tool stimulates and enables the designer to work more effectively and more efficiently during performance of a specific activity. A “good” product design tool fulfills the needs of the designer with regard to design information generation, design information representation and/or design information evaluation during performance of a specific activity. Therefore, it protects the designer from making mistakes in communication and decision making during performance of that particular activity.

2.4.4 Product design process support for the two types of product creation processes

As described in section 2.3.2, two main types of product creation processes are distinguished. Both types of processes require different types of support (i.e. different types of product design methods and tools) to stimulate and enable the designer to work more effectively and more efficiently. Both types of processes require different types of support to fulfill the needs of the designer and to prevent the designer from making mistakes. This section gives a brief overview of the product design process support that is available for each of the two types of product creation processes.

There is a lot of type 1 design process support available³. Examples are the design methods of Pahl & Beitz (1984) and Suh (1990). This type of support is typically based on the assumption that it is not very difficult to clearly and reliably formulate the problem in the early stages of the design process. Accordingly, this type of support is typically aimed at stimulating and enabling the designer to effectively and efficiently find the most suitable solution for the formulated problem. Moreover, this type of support doesn't focus on ensuring reliable decision making or communication between members of the design team.

In contrast, type 2 design process support has traditionally been absent. As described in section 2.3.2, in type 2 creation processes, it is difficult to clearly and reliably formulate the problem in the early stages of the design process. As argued, this difficulty is related to the number and degree of uncertainties that exist in a product creation process of this type. Until recently, the only way to eliminate or reduce these uncertainties was to make an initial assumption about the problem, about its most suitable solution, create prototypes of this solution, put them out into the world, and analyze what happens. The results of this analysis were then used to adapt the initial assumption about the problem and the initial assumption about the solution, etc. However, generally speaking, such unsupported trial-and-error-like processes are not very effective and efficient.

Only recently (approximately from the 1980s onwards) have design methods and design tools been developed that are specifically dedicated to supporting type 2 product design processes⁴. Examples of type 2 design methods can be found in the work of Sohlenius (1992), Lu (2003), and Lonchamp et al. (2004). These authors see a product design process as a group activity in which communication and collaboration plays a central role, and in which “problem describing activities” and “solution finding activities” occur concurrently throughout the entire process. Examples of type 2 design tools can be found in the work of Ehn & Sjögren (1991) and Iacucci et al. (2000). These authors developed several

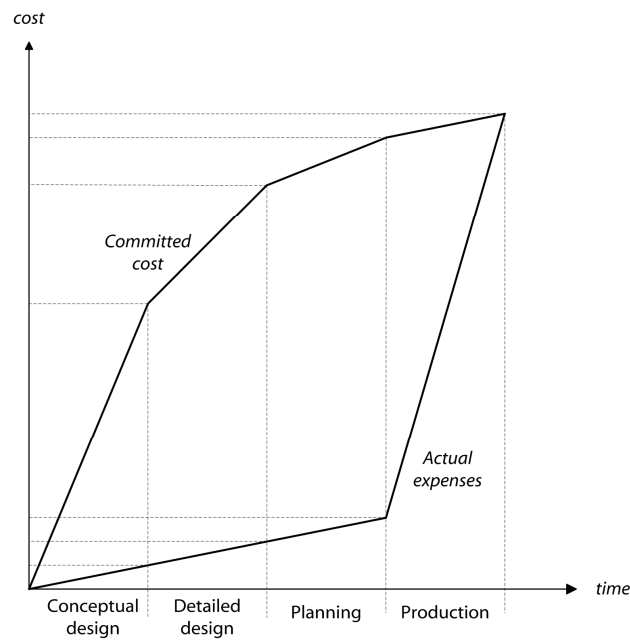
³ For the sake of readability, “design process support for type x product creation processes” will be called “type x design process support”.

⁴ For the sake of readability, a “product design process during a type x product creation process” will be called a “type x product design process”.

different games to be used for design purposes. This provided the means for discussing the existing reality and for investigating future visions. From this, the requirements of the proposed product could be specified.

2.4.5 The market for type 2 design process support

The four trends that were identified in section 2.3.5 (i.e. new technology faster entering the market, more functions being combined into single products, globalization affecting product creation processes and their results, and mass-customization) make that an increasing percentage of product creation processes has characteristics of type 2 processes. This implies that there is an increasing need for type 2 design process support. In other words, the “market” is now bigger for type 2 design methods and tools.



**Figure 2.2: Different costs during product development stages
(adapted from Sohlenius (1992))**

Figure 2.2 shows a typical cost break-down for a product development process. The lower line shows the actual expenses of product development activities. The upper line shows the costs that are committed by product development activities. This upper line can be understood as the cost of the final product becoming established by decisions made throughout the various phases of a product creation process. It can be seen that the early stages of a product creation process are relatively cheap. However, at the same time, a majority of the final product cost is established in these early stages. In later stages, there are only small opportunities for cost improvements.

Figure 2.2 is especially true for type 2 product creation processes. Generally speaking, the more a specific product creation process has type 2 characteristics, the more costs are committed in the early stages, and the less opportunities there are for cost improvements in later stages. Accordingly, the “market” for type 2 product design process support is primarily located in the early stages of the design process.

2.5 State of the art in type 2 design process support

2.5.1 State of the art in type 2 design methods

All currently existing methods for supporting type 2 product design processes stem from the *concurrent engineering paradigm* (Sohlenius, 1992). Within this paradigm, a product design process is no longer a sequence of phases that are executed in a predefined order, as it is within a *sequential engineering paradigm* (e.g. Pahl & Beitz, 1984; Suh, 1990). In fact, within this paradigm, there is no need to predefine all the phases that *can* occur within a product design process. All activities with regard to the design of the product - and the processes that play a role during the product's life cycle - can be performed simultaneously.

Recently, Stephen Lu (Lu et al., 2000; Lu & Cai, 2001; Lu, 2003) has taken the concurrent engineering paradigm one step further. He sees the product design process as a group activity in which communication and collaboration plays a central role and in which the result is not only determined by technical decisions, but also by the social interaction between the various human actors involved. He considers conflicts as a resource for driving the social construction process between stakeholders. The design method that Lu proposes is aimed at managing conflicts by investigating, understanding and manipulating the perspectives of stakeholders. Differing from the long iterations of *sequential engineering* or the shorter iterations of *concurrent engineering*, his design method attempts to completely replace *design iterations* with *negotiations*. The name that Lu proposes for his paradigm is *engineering as collaborative negotiation* (ECN).

One of the stakeholders within the negotiation process proposed by Lu could be "users" of the product. Thus, his method can be associated with another trend in supporting type 2 product design processes: allowing intended users of the product to be a part of the product design process to ensure that the product will function satisfactorily in different use situations. Involving users in the design process can be done in many different ways. For example, performing market research aims at discovering reasons for buying, using, possessing and discarding products. Applying Quality Function Deployment (QFD) aims at translating "customer requirements" into "technical requirements" (Akao, 1990). Asking users to give feedback on concepts or prototype designs is aimed at making a correct decision about how to proceed. The largest degree of user participation is achieved by applying Participatory Design (PD). This method prescribes that users be involved in all stages of the design process for constant evaluation of ideas, concepts and prototypes (e.g. Ehn & Sjögren, 1991).

A final trend in methods for supporting type 2 product design processes originates from the discipline of software engineering (Carroll, 2000): scenario based design methods. Scenario based design is a general term for techniques that apply scenarios to bring products, environments and their interactions into harmony (Miedema et al., 2007). Scenarios are explicit descriptions of hypothetical events concerning a product during a certain phase of its life cycle. A scenario may be expressed by means of a written or spoken storyline. It may also be visual or auditory (for example, images, movies or animations). A scenario can also be expressed by displaying a prototype (either real or virtual) in an environment (either real or virtual). Within design processes, scenarios are used in order to address problems, needs, constraints and possibilities. This not only stimulates communication, coordination and collaboration, but also avoids misunderstandings between the involved human actors. Furthermore, because information is represented in an understandable, easily accessible, and often

contextual form, using a scenario based design method allows for the inclusion of non-experts (such as intended users of the product) into the design process.

2.5.2 State of the art in type 2 design tools

As described in section 2.4.3, in describing product design tools, there are tools for supporting the *generation* of design information (such as creativity techniques), tools for supporting the *representation* of design information (such as sketchbook, pencil, CAD systems and VR simulation systems), and tools for supporting the *evaluation* of design information (such as analysis and decision techniques).

Traditionally, within product design processes, there is an emphasis on using tools from the second and third category. Today, however, it is understood that “creativity” is not a static personal characteristic, but rather one that can be stimulated. As a result, a current trend for tools that support type 2 product design processes is a more frequent application of design tools that stimulate creativity and thereby support the generation of design information.

Another trend in tools for supporting type 2 product design processes can be attributed to rapid developments in computer hardware and software. Today, a CAD system is considered to be the default tool for representing the design’s geometry, whereas a wide range of additional tools has emerged that can be used for simulation of the design’s behavior (Van Houten, 2001). A VR simulation system makes it possible for a human to have lifelike interaction with a computer model of a potential design. By using VR simulation, misunderstandings between human actors are less likely to occur compared to when using more abstract or symbolic representations of design information (such as natural language, sketches and CAD drawings). Another benefit of using VR simulation is that it eliminates the necessity to make physical prototypes. It not only saves money and time, but also allows for evaluation of potential designs in an earlier phase of the design process (Tideman et al., 2004).

A final trend in supporting type 2 product design processes is the use of games as design tools. For example, Ehn & Sjögren (1991) developed several different games to be used for design purposes. Within the rules of the game, players (intended users) had to interact with functions and artifacts that were represented by cards. Users could develop alternatives for original designs and discuss changes. When all participants agreed, new functions and artifacts could be introduced, and the rules of the game could be changed. By playing these games, a common language was developed between designers and users. This provided the means for discussing the existing reality and for investigating future visions. From this, the requirements of the proposed product could be specified. Iacucci et al. (2000) tested the principle of “design by playing games” as well. From their experiments, they conclude that playing games is a way to generate ideas in a situated and participative way. Moreover, the culture of players and the context of use of the proposed product is made explicit.

Due to rapid developments in the gaming industry, the trend of using games as a design tool no longer means just board games and card games, but also computer games. In the past couple of years, the serious game genre has emerged as a more entertaining way of revealing processes to adults (Bakie, 2005). Because computer games provide insight into the possible consequences of real-world decisions, they are a potentially useful product design tool. Within a computer game, information is simultaneously generated, represented and evaluated. Therefore, design iterations could be performed

very quickly. Moreover, the objective of playing a game coincides with the objective of a product design process: finding a solution to a problem within constraints.

The enormous potential of using computer games for problem solving purposes is well demonstrated by Von Ahn & Dabbish (2004). In a period of only a few weeks, their games have accurately labeled most images present on the World Wide Web; not by using excessive computer processing power, nor by using superior image recognition algorithms, but by means of a simple - and addictive - online game.

2.6 Conclusion

2.6.1 Trends

In section 2.5, the state of the art in type 2 design process support was described. Table 2.3 gives an overview of the trends that were identified.

<i>Trend</i>	<i>Description</i>
T.1	Application of product design methods that allow simultaneous performance of tasks and activities with regard to the design of the product and the processes that play a role during the product's life cycle.
T.2	Application of product design methods that consider the product design process as a group activity in which communication and collaboration play a central role and in which the result is not only determined by technical decisions, but also by the social interaction between the various human actors involved.
T.3	Application of product design methods that involve intended users of the product during the product design process to ensure that the product will function satisfactorily in as many situations as possible.
T.4	Application of product design methods that are based on the use of scenarios to explicitly show and address problems, needs, constraints and possibilities; thereby not only stimulating communication, coordination and collaboration, but also avoiding misunderstandings and managing conflicts between the various human actors involved.
T.5	Application of product design tools that generate design information by stimulating creativity.
T.6	Application of product design tools based on VR simulation to avoid misunderstandings, to save money and time, and to evaluate candidate designs in an early phase of the design process.
T.7	Application of product design tools based on gaming principles to provide insight into the consequences of decisions and to perform very quick design iterations.

Table 2.3: The identified trends in type 2 design process support

Each of the seven trends contributes to the potential effectiveness and efficiency of type 2 product design processes. However, within contemporary type 2 product design processes, the trends appear to "co-exist". Elements of the identified trends are sometimes combined in individual product design processes, but only in an ad-hoc manner. A product design method that integrates elements of *all seven* trends does not exist.

As described in section 1.2, the goal of this research is the development of a new product design method that adequately supports designers in determining stakeholders' preferences and finding the best compromise between those preferences. A method that allows all stakeholders to obtain insight into the consequences of decisions, that enables them to express their preferences, and that provides designers with the information necessary to draw a reliable conclusion about what would be a good design. A method that specifically supports the design of products that are new, that are complex, and that involve many different stakeholders. It is expected that this goal can be achieved by combining the essence of all seven trends into one product design method.

2.6.2 Requirements for the new product design method

Each of the seven trends is translated into a requirement for the new product design method (see Table 2.4).

<i>Requirement</i>	<i>Description</i>
R.1	It should stimulate and enable the designer to simultaneously perform tasks and activities with regard to the design of the product and the processes that play a role during the product's life cycle.
R.2	It should stimulate and enable the designer to consider the product design process as a group activity in which communication and collaboration play a central role and in which the result is not only determined by technical decisions, but also by the social interaction between the various human actors involved.
R.3	It should stimulate and enable the designer to involve intended users of the product during the product design process to ensure that the product will function satisfactorily in as many situations as possible.
R.4	It should stimulate and enable the designer to use scenarios that explicitly show and address problems, needs, constraints and possibilities; thereby not only stimulating communication, coordination and collaboration, but also avoiding misunderstandings and managing conflicts between the various human actors involved.
R.5	It should stimulate and enable the designer to generate design information by stimulating the creativity of stakeholders.
R.6	It should stimulate and enable the designer to use tools that provide realistic simulations of a design's behavior to avoid misunderstandings, to save money and time, and to evaluate candidate designs in an early phase of the design process.
R.7	It should stimulate and enable the designer to use gaming principles to provide insight into the consequences of decisions and to perform very quick design iterations.

Table 2.4: Requirements for the new product design method (1)

Table 2.5 depicts some more requirements for the new product design method. These arise from the designer's objectives during a product creation process (see section 2.2.6), and from the fact that the "market" for type 2 product design process support is primarily located in the early stages of the design process (see section 2.4.5).

<i>Requirement</i>	<i>Description</i>
R.8	It should stimulate and enable the designer to obtain insight into the needs that the product should fulfill and the technological potential that the product could exploit in the early stages of the product design process.
R.9	It should stimulate and enable the designer to recognize trade-offs and understand the positive and negative consequences of choices in the early stages of the product design process.
R.10	It should stimulate and enable the designer to identify stakeholders and understand their opinions about how positive and negative consequences should be weighed in the early stages of the product design process.

Table 2.5: Requirements for the new product design method (2)

THE NEW PRODUCT DESIGN METHOD

3

This chapter presents a new product design method for supporting type 2 product design processes. First, the basic mechanism of the new product design method is specified. This includes a functional specification of the method and a conceptual description of the design process that should emerge as a result of using the method. It also includes a specification of the activities that should be performed while applying the method. Next, guidelines for how to perform those activities are specified. Finally, remarks are made about the applicability of the method.

3.1 Conceptual design of the new product design method

3.1.1 Functional specification

Table 3.1 presents the functions of the new product design method. These follow from the requirements for the new product design method, as they were specified in Table 2.4 and Table 2.5.

<i>Function</i>	<i>Description</i>
F.1	Stimulating and enabling the designer to simultaneously perform tasks and activities with regard to the design of the product and the processes that play a role during the product's life cycle.
F.2	Stimulating and enabling the designer to consider the product design process as a group activity in which communication and collaboration play a central role and in which the result is not only determined by technical decisions, but also by the social interaction between the various human actors involved.
F.3	Stimulating and enabling the designer to involve intended users of the product during the product design process to ensure that the product will function satisfactorily in as many situations as possible.
F.4	Stimulating and enabling the designer to use scenarios that explicitly show and address problems, needs, constraints and possibilities; thereby not only stimulating communication, coordination and collaboration, but also avoiding misunderstandings and managing conflicts between the various human actors involved.
F.5	Stimulating and enabling the designer to generate design information by stimulating the creativity of stakeholders.
F.6	Stimulating and enabling the designer to use tools that provide realistic simulations of a design's behavior to avoid misunderstandings, to save money and time, and to evaluate candidate designs in an early phase of the design process.
F.7	Stimulating and enabling the designer to use gaming principles to provide insight into the consequences of decisions and to perform very quick design iterations.
F.8	Stimulating and enabling the designer to obtain insight into the needs that the product should fulfill and the technological potential that the product could exploit in the early stages of the product design process.
F.9	Stimulating and enabling the designer to recognize trade-offs and understand the positive and negative consequences of choices in the early stages of the product design process.
F.10	Stimulating and enabling the designer to identify stakeholders and understand their opinions about how positive and negative consequences should be weighed in the early stages of the product design process.

Table 3.1: Functions of the new product design method

3.1.2 Conceptual design

There are multiple ways to translate a set of functions into a conceptual design. One approach is to find a solution principle for every function, and then combine all these principles into one concept. Another, somewhat more holistic, approach is to reformulate the set of functions so that they all concern the same aspect of the solution, and then find one concept that covers all reformulated functions together.

Compared to the second approach, an advantage of the first approach is that it is straightforward and easily understandable. On the other hand, a drawback of the first approach is that the influence of each solution principle on the performance of the concept-as-a-whole is initially unknown. This yields the risk of creating a concept that contains two or more solution principles that are incompatible. To evade this risk, the second approach is followed.

The ten functions (see Table 3.1) all concern different aspects of the new product design method. However, despite the differences, two groups can be discerned: functions that concern mental processes (functions F.1, F.2, F.8, F.9 and F.10), and functions that concern physical means (functions F.3, F.4, F.5, F.6 and F.7). Accordingly, there would be two ways of reformulating the functions. One way would be to make them concern *how* design information is dealt with within the new product design method. The other way would be to make them concern the *means* that are used for generating, representing and evaluating design information.

Because a product design method is primarily a framework for gathering and structuring information (see section 2.4.2), the first approach is followed. Therefore, functions F.1, F.2, F.8, F.9 and F.10 are reformulated so that they all concern *how* design information is dealt with within the new product design method (see Table 3.2). Functions F.3, F.4, F.5, F.6 and F.7 are translated to prerequisites for how the reformulated functions should be fulfilled (see Table 3.3).

<i>Function</i>	<i>Description</i>
RF.1	Stimulating and enabling the designer and all stakeholders to generate design information.
RF.2	Stimulating and enabling the designer to represent the generated design information such that it is easily accessible for all stakeholders.
RF.3	Stimulating and enabling the designer to make sure that the represented design information is consistent.
RF.4	Stimulating and enabling all stakeholders to give opinions about the represented design information.
RF.5	Stimulating and enabling all stakeholders to verify their opinions about the represented design information.
RF.6	Stimulating and enabling all stakeholders to weigh positive and negative consequences of choices.
RF.7	Stimulating and enabling the designer to find a compromise between the preferences of all stakeholders.

Table 3.2: Reformulated functions of the new product design method

<i>Prerequisite</i>	<i>Description</i>
P.1	Intended users of the product should be involved during the product design process to ensure that the product will function satisfactorily in as many situations as possible.
P.2	Scenarios that explicitly show and address problems, needs, constraints and possibilities should be used; thereby not only stimulating communication, coordination and collaboration, but also avoiding misunderstandings and managing conflicts between the various human actors involved.
P.3	Design information should be generated by stimulating the creativity of stakeholders.
P.4	Tools that provide realistic simulations of a design's behavior should be used to avoid misunderstandings, to save money and time, and to evaluate candidate designs in an early phase of the design process.
P.5	Gaming principles should be used to provide insight into the consequences of decisions and to perform very quick design iterations.

Table 3.3: Prerequisites for how the reformulated functions should be fulfilled

Now the functions all concern the same aspect of the solution, it is possible to search for a concept that covers the entire set of functions. This process consists of looking around in the world, and trying to discover an existing concept or artifact that fulfills a similar set of functions.

A concept that fulfills a set of functions similar to the set in Table 3.2 is the working mechanism of “wiki” websites. The most well-known and largest wiki is the online encyclopedia Wikipedia. Practically anyone can access and edit the contents of wiki websites, which appears to result in the generation of a large body of consistent information. There are still questions about the final quality of the information created by wiki websites. For example, critics have questioned Wikipedia's reliability and accuracy. The site has also been criticized for its susceptibility to vandalism, uneven quality, systemic bias, and for favoring consensus over credentials in its editorial process. However, scholarly studies have concluded that vandalism is generally short-lived (Priedhorsky et al., 2007) and that Wikipedia is roughly as accurate as other encyclopedias (Giles, 2005).

The working mechanism of wiki websites comes from the combined presence of the following characteristics (Wikipedia, 2007):

- It is open to anyone. The entire body of information is accessible to anyone and anyone can propose and implement changes and additions;
- It has a large contributor base. Information stems from a large number of people from different backgrounds;
- It is written by consensus according to editorial guidelines and policies. There are some basic requirements regarding the contents and the form of information to ensure accessibility and consistency;
- A history of all edits and changes is kept. Information can never “vanish” or “be lost”.

Section 3.1.3 describes the design process that emerges as a result of using a product design method that fulfills the functions and meets the prerequisites, and that is loosely based on the working mechanism of wiki websites.

3.1.3 Description of the design process

The backbone of the design process is a simulation model. This simulation model consists of two elements – an environment database and a technology database. The environment database contains the set of elements that represent the world relevant to the product. The technology database contains the set of technology that might be relevant to the product (i.e. the technological potential that could be exploited by the product). Both databases are created and maintained by the designer. By means of a VR simulation system, stakeholders can have lifelike interaction with the contents of both databases. By means of configuration panels, stakeholders can adapt parameters of both databases, thus generating candidate designs and test environments for the candidate designs. The simulation model, the VR simulation system, and the configuration panels together form the design environment.

A scenario is formed by a combination of elements from the environment database together with a task description. A stakeholder experiences a scenario by trying to perform the task in the simulated environment. From these experiences, the stakeholder identifies what he needs and/or wants. By combining elements from the technology database, the stakeholder can configure a candidate design with which he expects to fulfill his needs and desires.

By applying a self-configured design to a self-configured scenario, the stakeholder can assess whether his expectations about the functionality, behavior and performance of the design were correct. By applying the design to a different scenario (i.e. a different combination of elements from the

environment database together with a different task description), the stakeholder can test whether it also functions satisfactorily under different circumstances or whether new needs emerge. At any point during the session, the stakeholder is allowed to alter the configuration of the design or even to start all over again with a completely different design. Similarly, at any point during the session, the stakeholder is allowed to alter the configuration of the scenario or even to start all over again with a completely different scenario.

The design process is split into two separate phases. The first phase is aimed at developing the design environment into a valid representation of the world relevant to the product and the technology that may be usefully applied to the product. During the second phase, the design environment - as it was created during the first phase - is used to specify a good design.

The first phase starts with activities such as observing the real-world, reading literature and talking to stakeholders. Based on the results of such activities, the designer makes an initial assumption about the necessary contents of both the environment database and the technology database. In other words, the designer attempts to identify all aspects of the world relevant to the product as well as all technology that may be usefully applied to the product. Based on the results from this identification process, the designer creates an initial simulation model. Simultaneously, the designer creates a VR simulation system that enables stakeholders to have lifelike interaction with the simulation model, as well as configuration panels that give stakeholders the possibility to generate candidate designs and test environments.

After the initial design environment has been created, its validity is tested. More specifically, the designer tests whether all relevant aspects of the design case are present and whether they are correctly modeled. This is done by inviting stakeholders for reflection sessions. During a reflection session, a stakeholder is told that the goal is to create the most satisfying "personal design" of the proposed product. By generating designs and scenarios, and evaluating those designs in the scenarios, the stakeholder is able to iteratively work towards this goal. In the meantime, the designer observes the stakeholder's behavior and asks the stakeholder for opinions about the generated designs. However, the designer only performs these activities in order not to reveal the true purpose of the session. This true purpose (i.e. collecting feedback on the quality of the design environment) is only accomplished at the end of the reflection session when the stakeholder is interviewed. The feedback from all stakeholders is used to create a list of required adaptations to the design environment.

The designer implements the required adaptations into the design environment. Subsequently, the same people that participated in the reflection sessions are invited again, but now for verification sessions. During a verification session, a stakeholder is confronted with the adaptations to the design environment that he explicitly or implicitly proposed. The stakeholder is asked whether he agrees to the adaptation or whether something else was intended. Additionally, the stakeholder is confronted with adaptations that were proposed by others. This time, the stakeholder is not asked whether he agrees to this adaptation. Instead, the stakeholder is asked whether he rejects the adaptation; not rejecting an adaptation is considered sufficient for acceptance of the specific adaptation.

By performing this cycle of reflection sessions, implementation of the required adaptations and verification sessions, the design environment evolves. Initially, the design environment will evolve

rapidly. After a certain number of cycles, the speed of evolution will decrease. Ultimately, the evolution of the design environment will practically stop – stakeholders will only be able to confirm the completeness and correctness of the design environment. The design environment has become “saturated”. It will contain the “problem-solution space” of the design case in a form that is both verifiable and controllable. When this state of saturation is achieved, the first phase of the new product design method has come to an end.

During the second phase of the design process, the design environment - as established during the first phase - no longer changes. There is now an emphasis on the quality of the proposed product, instead of on the quality of the design environment. Stakeholders are invited for design sessions. The activities of the stakeholders during these design sessions are quite similar to the activities during the reflection sessions of the first phase of the design process. A stakeholder is given the assignment to iteratively work towards the “most attractive design” by generating designs and scenarios, and evaluating those designs in the scenarios. In the meantime, the designer observes the stakeholder’s behavior and asks the stakeholder for opinions about the generated designs. In contrast to during the first phase of the design process, the designer now actually uses the collected information. For every stakeholder, the designer creates a “personal report”. This personal report contains both objective information (i.e. personal information and a specification of the “most attractive design”) and subjective information (i.e. reasons for why the specified design is so attractive and why other product features are less desirable). Based on these personal reports, the designer specifies (an) attractive design(s) for each stakeholder.

Because of the large amount of parameters that stakeholders could adapt to generate candidate designs, it is unlikely that all “attractive designs” are identical. It is therefore likely that the designer has to search for a compromise between the preferences of all stakeholders. Based on the subjective information in the personal reports, the designer identifies relevant themes and organizes these into a hierarchy. Every theme can be thought of as a group of parameters that, from a stakeholder’s perspective, is meaningful. Because of the hierarchical organization, the designer can easily “zoom in” and “zoom out” on the entirety of information - both on the objective information and the subjective information, and both on the “technology information” and the “environment information”. By performing quantitative and qualitative analyses, the designer can specify a good design (i.e. a compromise between the preferences of all stakeholders).

3.1.4 Specification of activities

Figure 3.1 shows the higher-level processes during application of the new product design method. It shows that:

- While applying the new product design method, recognized needs and recognized technological potential are converted into a specification of a good design;
- From recognized needs, an image of the world relevant to the product is created (activity 1.a). This image consists of an environment database and a VR simulation system to have lifelike interaction with the contents of the database. Also, an interface is created with which stakeholders can generate test environments by adapting environment parameters (activity 1.b);
- Recognized technological potential is used to create an overview of the technology relevant to the product (activity 1.c). This image consists of a technology database and a VR simulation system to have lifelike interaction with the contents of the database. Also, an interface is

created with which stakeholders can generate candidate designs by adapting technology parameters (activity 1.d);

- The image, the overview, and both interfaces together form the design environment;
- The design environment is used to specify a good design (activity 2).

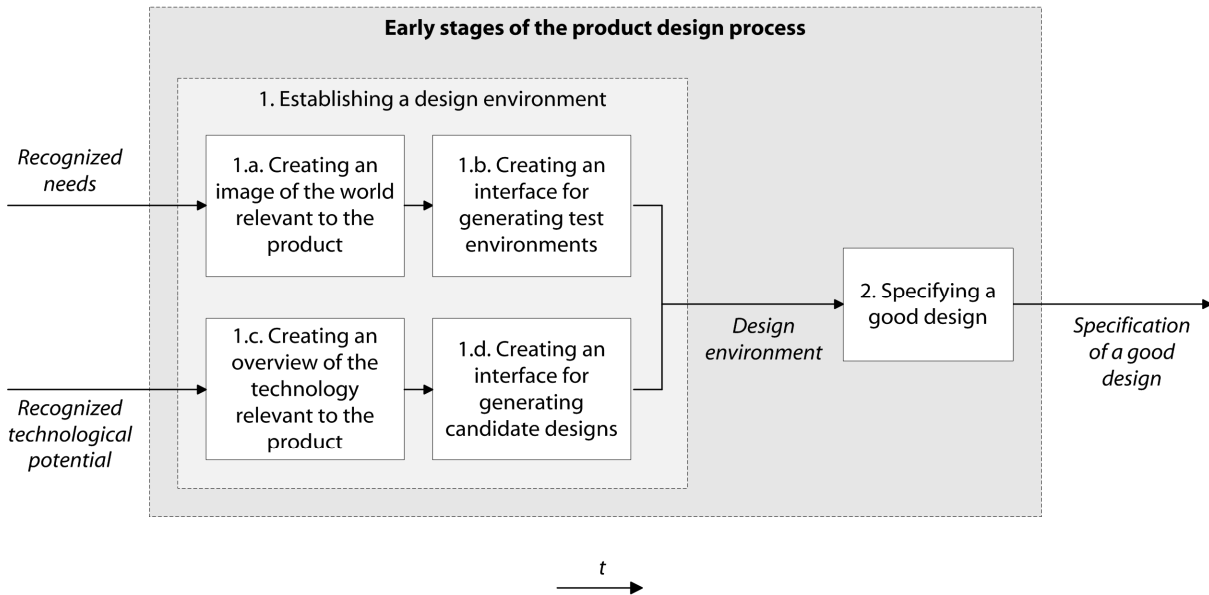


Figure 3.1: The higher-level processes during application of the new product design method

Table 3.4 and Table 3.5 present detailed specifications of the respective activities.

Activity 1: Establishing a design environment

1.1	Based on an initial assumption about the needs of stakeholders that should be fulfilled by the product and the technological potential that could be exploited by the product, the designer creates a design environment that is easily accessible for all stakeholders.
1.2	All stakeholders interact with the design environment and reflect on it.
1.3	The designer registers the behavior of stakeholders while interacting with the design environment, and registers the opinions of stakeholders while reflecting on it.
1.4	The designer uses the registered information to verify the initial assumption about the world and the technology relevant to the product and to reveal desired changes and additions to the design environment.
1.5	The designer updates the design environment based on new insights, such that it is kept consistent and that new insights are easily accessible for all stakeholders.
1.6	All stakeholders interact with the updated design environment and reflect on the updates.
1.7	The designer registers the behavior of stakeholders while interacting with the updated design environment, and registers the opinions of stakeholders while reflecting on the updates.
1.8	The designer uses the registered information to verify the updates and to reveal new desired changes and additions to the design environment.
1.9	The designer and all stakeholders repeat activities 1.5 to 1.8 until no more desired changes and additions are revealed.

Table 3.4: Detailed specifications of activity 1

Activity 2: Specifying a good design

2.1	All stakeholders adapt technology parameters, thus generating candidate designs.
2.2	All stakeholders adapt environment parameters, thus generating test environments for the candidate designs.
2.3	All stakeholders test the candidate designs in the test environments, and reflect on the degree to which they fulfill their needs.
2.4	The designer registers the behavior of stakeholders while generating candidate designs, generating test environments, and testing the candidate designs in the test environments. The designer also registers the opinions of stakeholders while reflecting on the degree to which the candidate designs fulfill their needs.
2.5	The designer uses the registered information to specify attractive designs for each stakeholder.
2.6	If not all “attractive designs” are identical, the designer organizes the registered information into a hierarchy that is meaningful from a stakeholder’s perspective.
2.7	The designer uses the hierarchy to specify a compromise between the preferences of all stakeholders.

Table 3.5: Detailed specifications of activity 2

3.2 Detailed design of the new product design method

3.2.1 Introduction

Table 3.4 and Table 3.5 present the activities that human actors should perform while applying the new product design method. Sections 3.2.2 to 3.2.15 present guidelines for how to perform the respective activities.

3.2.2 Guidelines for creating an initial design environment (activity 1.1)

Creating an initial design environment is a “product creation process” of its own. Accordingly, there are many ways to proceed, and there are many methods and tools that can be used to support the process. A priori, one way of proceeding is not necessarily better than another way of proceeding. Therefore, the guidelines in this section should be read as *suggestions*, in the sense that deviating from them might still result in a good initial design environment.

A first step in creating a design environment is to become familiar with the design case. This can, for example, be done by performing activities such as observing the real-world, reading literature and talking with stakeholders. It is recommendable to document these processes for later reference. This can, for example, be done in the form of a report. The conclusion of such a report should contain an overview of all stakeholders that have an interest in the product as well as an overview of all parameters that might be relevant to the design case. For every parameter, there should also be a specification of its possible values as well as a specification of which stakeholder(s) should have a say about its value.

While writing such a report, an important question to address for every identified parameter is whether it should become a part of the environment database or a part of the technology database. Much of the world that surrounds us consists of technology (i.e. human-made artifacts). Therefore, inevitably, the environment database will often not only contain natural elements (i.e. objects not created by humans), but also technology. However, a specific element should only be inserted into the technology database if the constraints of the design case allow this element to be altered. All other elements should automatically become part of the environment database. For example, while designing a bicycle, a relevant element would be a bicycle shed with attributes such as “capacity”, “entrance size” and “material”. Suppose the assignment would be *to design a new bicycle and, at the same time, investigate whether there are possibilities to introduce an accompanying shed*, the bicycle shed with all its attributes

should become a part of the technology database. Within the constraints of the design case, the designer would be allowed to have an influence on “bicycle shed technology”. However, if the assignment would be *to design a new bicycle that will fit into as many as possible existing sheds*, the bicycle shed would clearly belong to the environment database.

After having become familiar with the design case, a simulation model, a VR simulation system, and interfaces for generating test environments and candidate designs should be created. Because all these elements of the design environment are interrelated, it is advisable to develop them in parallel. Moreover, because of the multi-disciplinary character of the development work (i.e. both hardware and software), it is advisable to consult domain experts or to even form a multi-disciplinary design team. While performing such parallel processes within such a multi-disciplinary design team, avoiding misunderstandings is top-priority. Keeping everybody on the same page can, for example, be done by using scenarios as a communication tool.

While creating the simulation model and the VR simulation system, an important question to address is which part of the “problem-solution space” should be simulated and which part should be physically present within the design environment. The benefit of physical objects is that they reduce simulation complexity in the sense that they don’t have to become a part of the simulation model. On the other hand, physical objects have the disadvantage that their parameters cannot be adapted during the sessions. Therefore, elements are only allowed to be physically present in the design environment if they cannot change, if they are not allowed to change within the constraints of the design case, or if a change is not expected to have an influence on the “problem-solution space”. The remainder of the elements should be integrated into the simulation model.

While creating interfaces for generating test environments and candidate designs, two different requirements have to be met. Firstly, stakeholders should be able to understand and operate the interfaces. This means that the way parameters are represented, as well as the way stakeholders can specify values for the parameters, should be in line with the abilities of the “target group” (i.e. the specific stakeholder group for whom the interfaces are meant). Secondly, to make sure that there is sufficient time to perform a number of iterations during every session, generating a test environment and generating a candidate design each shouldn’t take longer than a couple of minutes. This might mean that not all parameters that are present in the simulation model can actually be offered to stakeholders to adapt, and that some parameters should be assigned a default value. The assumption about what would be the proper set of parameters for stakeholders to adapt, as well as what would be proper default values for the non-adaptable parameters, should be tested during the reflection sessions. Possible imperfections can always be corrected during the remainder of the first phase of the design process.

3.2.3 Guidelines for reflecting on the initial design environment (activity 1.2)

Ideally, all stakeholders are invited to reflect on the initial design environment. However, in practice, this will often be infeasible – especially, when the group of users is very large. Therefore, only representatives from each stakeholder group have to be invited. The guideline for the selection of participants is twofold:

1. Representatives from every stakeholder group should be invited to participate. This is to make sure that the design environment will facilitate the perspectives of all stakeholder groups;

2. The group of people that is invited to represent a specific stakeholder group does not necessarily have to be a “cross-section” of that stakeholder group. To efficiently gather much information from every stakeholder group, participants that have little difficulty in getting familiar with new computer interfaces are preferred above participants that have much difficulty in getting familiar with new computer interfaces. People that have little difficulty in getting familiar with new computer interfaces spend less time getting used to the design environment, spend less effort operating the design environment, and therefore have more attention for the contents of the environment database and the technology database.

There is no strict guideline for the number of representatives per stakeholder group that should be involved in every iteration of the first phase of the design process. The most efficient number of representatives per iteration is typically design case specific. To get a first impression, 8 to 12 representatives from every stakeholder group are reasonable. This number is sufficient to get an image of whether the entire stakeholder group considers the design environment as valid, while the process is still kept manageable. The benefit of having more representatives is that more information is delivered and that more corrections and additions to the design environment are proposed. On the other hand, a drawback of inviting more representatives is that more time and effort are spent on the reflection and verification sessions, whereas not much added value is created. As the number of representatives increases, the amount of unique information that is delivered (i.e. corrections and additions that have not been mentioned by somebody else) decreases.

There is also no strict guideline for the number of design iterations that every representative should perform during a reflection session. The more design iterations, the better the stakeholder’s image of the design environment, and the better he will be able to give feedback on this design environment. On the other hand, to keep the stakeholder focused, a reflection session shouldn’t take more than approximately two hours. The number of design iterations that can be performed in those two hours is design case specific.

It is important not to reveal the real purpose of the reflection session to stakeholders. This could distract them from their designing and testing activities. It could also prompt them to nitpick because they feel they are supposed to give feedback. Finally, it would add another level of complexity to the reflection session procedure, which is already difficult enough for stakeholders to understand. In order not to reveal the real purpose, during a reflection session, the stakeholder’s behavior should be observed and the stakeholder should be asked for opinions about the generated designs. These observations and questions are meant to give stakeholders the illusion that they are actually participating in a design process. Asking for feedback on the design environment should be saved for the concluding interview.

3.2.4 Guidelines for registering the behavior and opinions of stakeholders (activity 1.3)

During the concluding interview, stakeholders should be asked about the validity of the simulation model, the interfaces, and the design environment as-a-whole. More specifically, they should be asked whether:

- All situations that are relevant for the product are represented in the environment database;
- All technology that can be usefully exploited by the product is represented in the technology database;
- All situations represented in the environment database are relevant for the product;

- All technology represented in the technology database can be usefully exploited by the product;
- All situations represented in the environment database are correctly modeled;
- All technology represented in the technology database is correctly modeled;
- The interfaces for generating test environments are sufficiently usable;
- The interfaces for generating candidate designs are sufficiently usable;
- The validity of the design environment as-a-whole is sufficiently high.

Stakeholders' opinions should be registered both by notes and by audio/video recordings. Notes are particularly useful during the interview itself, in the sense that they help the designer to structure the conversation. The audio/video recordings are particularly useful after the interview, when analyzing what exactly has been said by the stakeholder. Moreover, they function as a backup since it is sometimes difficult to immediately register all relevant information in the form of notes.

3.2.5 Guidelines for verifying the initial assumptions (activity 1.4)

The feedback from all stakeholders should be used to create a list of proposed adaptations to the design environment. The proposed adaptations to the interfaces for generating test environments and candidate designs, as well as the proposed adaptations to the design environment as-a-whole, automatically become required adaptations. This means that these adaptations should be implemented. However, the proposed adaptations to the simulation model (i.e. the environment database and the technology database) do not automatically become required adaptations.

It could occur that a proposed adaptation to the environment database falls outside the scope of the design case. It could also occur that a proposed adaptation regards removing elements that are considered superfluous by a specific stakeholder, whereas, at the same time, others find these elements to be relevant for the design case. Furthermore, proposed adaptations to the environment database could be based on expectations about other stakeholders that appear to be untrue. Proposed adaptations could also consider altering elements or situations that were experienced to be unrealistic but that were deliberately introduced to provoke specific behavior. Finally, proposed adaptations to the environment database could consider introducing elements that are already present in the scenarios, but that were not noticed by the specific participant. If one or more of these cases apply to a specific proposed adaptation to the environment database, it shouldn't become a required adaptation.

Similarly, it could occur that a proposed adaptation to the technology database falls outside the scope of the design case, that it regards removing elements that are considered useful by others, or that it is based on expectations about other stakeholders that appear to be untrue. Proposed adaptations to the technology database could also make the configuration of a candidate design considerably more complex or time-consuming, to the point at which it is disproportional to the added value that is offered by those specific adaptations. If one or more of these cases apply to a specific proposed adaptation to the technology database, it shouldn't become a required adaptation.

3.2.6 Guidelines for updating the design environment (activity 1.5)

Similar to during creating the initial design environment, there are also many ways to proceed during updating it. Furthermore, there are many methods and tools that can be used to support the updating process. In any case, one way or the other, the required adaptations have to be implemented. This

might only require making some minor adaptations to the existing hardware and software, but this might also require a complete redesign of the design environment. Regardless of the degree to which the design environment is altered, it is recommendable to document the updating process for future reference.

3.2.7 Guidelines for reflecting on the updated design environment (activity 1.6)

The verification sessions should involve the same group of people that participated in the reflection sessions. At the beginning of a verification session, the stakeholder should be told that some changes have been made to the design environment, and that the session is aimed at obtaining opinions about the adaptations. Subsequently, the stakeholder should be allowed to perform a number of iterative cycles of generating candidate designs, generating test environments, and testing the candidate designs in the test environments. This is aimed at becoming familiar with the updated design environment. Optionally, the designer may point out specific adaptations to stakeholders. The number of iterations necessary to get the stakeholder familiar with the updates typically depends on the degree to which the design environment was altered. However, just as a reflection session, a verification session should not take longer than approximately two hours.

3.2.8 Guidelines for registering the behavior and opinions of stakeholders (activity 1.7)

At the end of a verification session, every adaptation that was implemented into the design environment should be discussed with the stakeholder. For every adaptation that the stakeholder in question personally proposed, he should be asked whether he agrees to the adaptation or whether something else was intended. This is to check whether the specific adaptation has been correctly implemented. For all other adaptations (i.e. the adaptations that were proposed by others), he should be asked whether he rejects the adaptation or not. This is to check whether the stakeholder “can live with” the specific adaptation. Additionally, for every adaptation, it should be asked whether the stakeholder noticed it during the verification session. Finally, every stakeholder should also be asked whether he has ideas on how to improve the updated design environment even further. Similar to during the reflection sessions, stakeholders’ opinions should be registered both by notes and by audio/video recordings.

3.2.9 Guidelines for verifying the updates (activity 1.8)

The feedback from all stakeholders should be used to perform a couple of different analyses. Firstly, it should be checked whether stakeholders agree to the way their “personally proposed adaptations” have been implemented. If a stakeholder doesn’t agree to a specific personally proposed adaptation, it should be undone. Secondly, for every adaptation that was proposed by others, it should be checked whether stakeholders don’t reject it. In order to accept a specific adaptation as a valuable addition or correction to the design environment, it is not by definition necessary that nobody rejects it. However, for a specific adaptation to be accepted, the number of rejections of this adaptation should be very limited. Moreover, there should be an explanation to every rejection. If such an explanation is absent, the adaptation in question should be undone.

Having no opinion about an adaptation does not mean that it is rejected. However, if a high percentage of stakeholders has no opinion about a specific adaptation, it should be analyzed how often it was noticed during the verification sessions. A high percentage of people not noticing it could be an explanation for a high percentage of people having no opinion about it.

Finally, from the ideas on how to improve the design environment even further, a new list of required adaptations to the updated design environment should be created.

3.2.10 Guidelines for performing another iteration (activity 1.9)

If some implemented adaptations have to be undone and/or there are some new required adaptations to the updated design environment, another iteration should be performed. Such an iteration should start with implementing the newly proposed adaptations and inviting a new group of stakeholders to reflect on the design environment. Since such an iteration would consist of repeating activities 1.5 to 1.8, the guidelines that should be observed are identical to the guidelines that were described in sections 3.2.6 to 3.2.9.

3.2.11 Guidelines for generating and testing candidate designs (activities 2.1, 2.2 and 2.3)

Ideally, all stakeholders participate during the second phase of the design process. However, in practice, this will often be infeasible – especially, when the group of users is very large. Therefore, only representatives from each stakeholder group have to be invited. The guideline for the selection of participants is twofold:

1. Representatives from every stakeholder group of which the perspective is facilitated by the design environment should be invited to participate. In other words, for every category of aspects that is represented by the design environment (e.g. use aspects, production aspects, marketing aspects, maintenance aspects), representatives from the corresponding stakeholder group should be invited (e.g. users, production engineers, marketing managers, maintenance workers). This is to make sure that the opinions of all stakeholder groups on how positive and negative consequences of choices should be weighed are taken into account;
2. To reliably identify designs that best fulfill stakeholders' needs, the group of people that is invited to represent a specific stakeholder group should be a "cross-section" of that stakeholder group. In other words, the group of representatives from every stakeholder group should be a reliable representation of the total group of people that belong to that stakeholder group.

There is no strict guideline for the number of representatives per stakeholder group that should be involved during the second phase of the design process. As a result of the large amount of parameters that can be adapted, by definition, the number of participants required to be allowed to draw a statistically significant conclusion would be unmanageably large. To get a first impression, 16 to 24 representatives from every stakeholder group are reasonable. This number is sufficient to get an image of the needs, desires and preferences of the entire stakeholder group, while the process is still kept manageable. When preferences within a specific stakeholder group are expected to correlate with personal characteristics of its representatives, the group of representatives should be split according to those personal characteristics. In such cases, the second phase of the design process should preferably be performed with 16 to 24 representatives from every subgroup. However, when a specific design case involves too many subgroups to keep the design process manageable, it is allowed to bring the number of representatives per subgroup down to minimally 8.

There is also no strict guideline for the number of design iterations that every representative should perform during a design session. The more iterations, the better the stakeholder can specify the "most attractive design", and the better he can explain why this design is so attractive and other designs are

less attractive. On the other hand, to keep the stakeholder focused, a design session shouldn't take more than approximately two hours. The number of design iterations that can be performed in those two hours is design case specific.

When the design environment facilitates the perspectives of multiple different stakeholder groups, it is an option to perform multi-actor sessions. These are sessions in which representatives from two or more stakeholder groups are invited at the same time. The procedure during such a multi-actor session can be shaped in multiple different ways. One approach would for example be to let one stakeholder generate a candidate design and a test environment, to let him experience this design in the test environment, and to have the other stakeholders assess the performance of the design from their own perspectives. Then the roles would switch, and the same activities are performed again. This would go on until a compromise is found between the preferences of all involved stakeholders.

A benefit of performing multi-actor sessions would be that specifying a compromise between the preferences of all stakeholders (activity 2.7) is directly performed by the stakeholders instead of indirectly by the designer. On the other hand, a drawback of performing multi-actor sessions would be that the complexity of the procedure is increased. Moreover, it would only be individual representatives that together specify a compromise. There would be no guarantee that another group of representatives is also going to be satisfied with it.

3.2.12 Guidelines for registering the behavior and opinions of stakeholders (activity 2.4)

During a design session, the interactions with the interfaces should be automatically stored so that the specifications of the generated candidate designs and test environments can be easily deduced. Also, the stakeholder's behavior should be observed and, after every design iteration, the stakeholder should be asked for an opinion about the design that he just evaluated. Such a conversation helps the stakeholder to "organize" the experiences he just acquired, and to make a plan for his next candidate design and his next test environment. However, during these conversations, the designer should be careful not to steer the stakeholder in a specific direction. At the end of the design session, the stakeholder should be interviewed. This is aimed at getting a final opinion about the designs that were created, and to get a final specification of the "most attractive design". Similar to during the reflection and verification sessions, stakeholders' opinions should be registered both by notes and by audio/video recordings.

3.2.13 Guidelines for specifying attractive designs for each stakeholder (activity 2.5)

For every stakeholder, the designer should create a "personal report" that contains both objective information (i.e. personal information and a specification of the "most attractive design") and subjective information (i.e. reasons for why the specified design is so attractive and why other product features are less desirable). These personal reports are a means to check the consistency of the information that was gathered from stakeholders. The level of consistency between the objective and the subjective information is an indicator for the level of reliability of the information that is represented in the personal reports.

For each stakeholder whose personal report doesn't contain any inconsistency, there is no reason to assume that the specified "most attractive design" will not function satisfactorily in all scenarios for this stakeholder. The absence of inconsistencies means that, under all circumstances, all orally expressed

preferences are in accordance with the specified “most attractive design”. However, for each stakeholder whose personal report contains inconsistencies, the specification of the “most attractive design” shouldn’t be considered definite right away. First, the inconsistencies in question should be managed.

There are three possible causes for inconsistencies in the personal reports:

1. Limited possibilities of the technology database and the interface for generating candidate designs. For example, a stakeholder saying to desire a specific product feature, whereas this feature is not present in his “most attractive design”;
2. Different preferences in different scenarios. For example, a stakeholder saying to desire different product features in different scenarios, whereas his “most attractive design” only has one set of features;
3. Slips during the design sessions. These are discrepancies between the stakeholder’s behavior and verbally-expressed preferences that were not noticed or not resolved during the design session.

Inconsistencies due to the first cause should be managed by analyzing them for recurring themes. A recurring theme is defined to be a similarity between two or more inconsistencies that stem from different participants. Every inconsistency that is not part of a recurring theme must be managed by removing the subjective information from the personal report of the stakeholder in question. However, when a recurring theme is discovered (i.e. when two or more inconsistencies relate to the same aspect of the product), the personal reports of the stakeholders in question must be extended with a note. The original specifications of these stakeholders’ “most attractive designs” remain intact. However, the notes reflect the probable choice of the stakeholders in case the desired product functionality would have been available in the technology database during the design sessions.

Inconsistencies due to the second cause should be managed by extending the specification of the “most attractive design” with a specification of the scenarios in which this design is attractive to the stakeholder. Furthermore, in each personal report, one or more alternative designs should be specified that, together with the “most attractive design”, are expected to function satisfactorily in all scenarios for the stakeholder. Each alternative design should also come with a specification of the scenarios in which it is expected to be attractive for the stakeholder.

Inconsistencies due to the third cause should be managed by assuming that the objective specification of the “most attractive design” is true and that the subjective verbally- expressed preference is false. Accordingly, the subjective information that is assumed to be false should be removed from the personal reports. However, before doing this, it should be made sure that the inconsistency in question is truly a slip from the designer. The inconsistency in question may only regard a small detail of the product.

After the personal reports have been made consistent, the specifications of all “most attractive designs” should be compared with each other. If they are all identical, apparently, all stakeholders want the same design. Accordingly, the design process should stop. If not all “most attractive designs” are identical, there has to be searched for a compromise between the preferences of all stakeholders. A first step is to

organize the registered information into a hierarchy that is meaningful from a stakeholder's perspective.

3.2.14 Guidelines for organizing the information into a hierarchy (activity 2.6)

Organizing the information into a hierarchy should be done by following an approach similar to "grounded theory" (Glaser & Strauss, 1967). Originally, the aim of grounded theory is to develop a theory that fits a set of collected data. However, it has also become increasingly popular in product design processes to answer specific questions and address design concerns (Sharp et al., 2007). Within grounded theory, identification of themes, and organizing these into a hierarchy, is achieved by "coding" the data (i.e. marking it up according to the emerging themes).

A random sample of personal reports should be used to make a first assumption about the set of codes from which the coding system should be made up. For every statement in these personal reports, one or more codes should be defined, and these defined codes should be combined into a list. A trained rater should be asked to assign one or more codes from the list to every statement in the sample of personal reports. Next, the average inter-rater reliability per statement (the percentage of the assigned keywords per statement that matches between the designer and the rater) should be calculated. A reliability of 75% would be sufficient to accept the coding system as a definition of relevant themes. However, if the reliability is less than 75%, the rating results should be discussed. During this discussion, the designer and the rater together create a new coding system. To test the new coding system, a new random sample of personal reports is used.

The above described cycle of activities should be repeated until the average inter-rater reliability per statement reaches 75%. The resulting coding system should be used to code the subjective information in all personal reports and re-organize the objective information into categories that are meaningful from a stakeholder's perspective. Because the coding system has a hierarchical structure, this results in a hierarchy of information that represents the preferences of all stakeholders. A hierarchy of which the structure is meaningful from a stakeholder's perspective, and that consists of both objective information and subjective information. A hierarchy in which, for every stakeholder, the objective information is fully consistent with the subjective information.

3.2.15 Guidelines for specifying a compromise between the preferences of all stakeholders (activity 2.7)

For every product feature present in the coding system, it should be analyzed how often stakeholders desire it (i.e. how often the product feature appears in the set of "most attractive designs"). Furthermore, an analysis should be made of correlations between desired product features (in the form of "IF the stakeholder prefers value A for design parameter p THEN he is likely to prefer value B for design parameter q"). It should also be analyzed how personal characteristics of a stakeholder correlate with his preferences. Finally, an analysis should be made of stakeholders' reasons for considering product features to be desirable/undesirable, and how this relates to the events in the scenarios. By combining the findings from these analyses, a compromise between the preferences of all stakeholders can be specified. It is recommendable to document this process for future reference.

3.3 Applicability of the method

The new product design method is developed to support type 2 product design processes. As follows from table 2.2, these are processes in which:

1. The problem cannot be clearly and reliably described in the early stages of the design process;
2. "Problem describing activities" and "solution finding activities" occur concurrently throughout the entire product design process;
3. A relatively large, often multi-disciplinary, design team is needed to describe the problem and find a solution, while working within the time and cost constraints.

For each of the three characteristics, it is briefly described how the new product design method is expected to offer added value:

1. The environment database contains a description of the problem. The VR simulation system makes that this description is clear (i.e. easily accessible for all stakeholders). All stakeholders are asked for feedback on the problem description, new insights are implemented, and the updates are verified by all stakeholders. This cycle of activities makes that the problem description becomes reliable (i.e. agreed upon by all stakeholders);
2. The technology database evolves concurrently with the environment database - according to the same cycle of activities. The design environment therefore facilitates concurrent occurrence of "problem describing activities" and "solution finding activities" throughout the entire product design process;
3. The configuration panels make that every stakeholder can explore the "problem-solution space" from his own perspective. At the same time, because of the VR simulation system, results from these explorations can be clearly and reliably communicated to all others. These others may include members of a large multi-disciplinary design team.

It is expected that application of the new product design method asks for a considerable investment (i.e. time, money, other facilities). It depends on the design case whether or not this investment is worth the added value that may result from applying the new product design method. Generally speaking, the more a product creation process has type 2 characteristics, the higher the chance of "return on investment". This chance is expected to become even higher when the new product design method is applied to the design of:

- Products that are used in a partly unknown and potentially dangerous environment;
- Products in which the functionality is partly determined by the behavior of the human operator (and his behavior is likely to change as a result of using the product).

However, above all, the new product design method is expected to be generally applicable. This means that, theoretically, it can be applied to the design of every product.

EVALUATION PROCESS

4

This chapter describes how the new product design method is evaluated. First, the evaluation framework is established. Next, the evaluation process is specified into detail. The chapter ends with the selection of a design case, which will be used to perform two experiments.

4.1 Evaluation framework

The object of analysis is the new product design method. A product design method specifies activities and provides guidelines for how to perform those activities. These specifications and guidelines are interpreted by the designer against the background of a design case (i.e. an initial problem formulation and/or an initial solution definition). As a result of this interpretation process, the designer will have certain thoughts and associations, make certain decisions and perform certain actions. The ultimate result is a description of the object of the creation process (i.e. a description of the product).

As described in section 2.4, application of a product design method is aimed at better meeting the objectives of a product creation process (i.e. realizing a more effective and more efficient product). However, it is impossible to make a reliable comparison between the results of applying a specific product design method and applying *another* product design method (or applying *no* product design method). Product development is a historic process that cannot be repeated. It is therefore difficult to prove afterwards that other methods would have led to other results. Moreover, the success of new product development depends on many more factors than only the product designed, and it is not easy to separate the effect of a certain design method from other factors (Roozenburg & Eekels, 1995).

Consequently, learning how the new product design method performs in practice must be done by examining the *design processes* that emerge as a result of applying it, rather than examining the *products* that result from applying it. More specifically, it must be done by testing whether the new product design method meets its objectives in the sense that it is viable and that it fulfills its functions. Therefore, the framework for examining the design processes that emerge as a result of applying the new product design method consists of the following two elements:

- A set of general criteria that a product design method should meet in order to be viable;
- The set of functions that the new product design method should fulfill.

Table 4.1 depicts the set of general criteria that a product design method should meet in order to be viable. Testing whether these criteria are met implies addressing the question whether human actors are able to perform the specified activities, whether the specified activities yield actual results, and whether the guidelines for the selection of participants are correct. It also implies addressing the question whether the guidelines are unambiguous, whether they provide guidance under all circumstances, and whether they are generic.

<i>Criterion</i>	<i>Description</i>
GC.1	Application of the product design method should be feasible. Human actors (i.e. designers and stakeholders) should be able to perform the specified activities.
GC.2	Application of the product design method should yield actual results. Human actors (i.e. designers and stakeholders) should generate output by performing the specified activities.
GC.3	The guidelines for the selection of participants for specific activities should be correct. It should not be possible that a stakeholder group with a unique view on the product is left out of consideration.
GC.4	The guidelines for how to perform the activities prescribed by the design method should be unambiguous. The guidelines should be formulated such that they cannot be interpreted in many different ways.
GC.5	The guidelines for how to perform the activities prescribed by the design method should provide guidance under all circumstances. The guidelines should specify the possible outcomes of each activity, and, for every possible outcome, the guidelines should provide directions about how to proceed.
GC.6	The guidelines for how to perform the activities prescribed by the design method should be generic. The guidelines should be formulated such that they provide guidance to the designer, independent of specific characteristics of the design case.

Table 4.1: General criteria that a product design method should meet in order to be viable

Table 4.2 depicts the set of functions that the new product design method should fulfill. It is a copy of Table 3.2. Testing whether these functions are fulfilled implies addressing the question whether human actors are stimulated and enabled to generate design information, to represent the generated design information such that it is easily accessible, and to make sure that the represented design information is consistent. It also implies addressing the question whether human actors are stimulated and enabled to give opinions about the represented design information, to verify their opinions about the represented design information, to weigh positive and negative consequences of choices, and to find compromises.

<i>Function</i>	<i>Description</i>
RF.1	Stimulating and enabling the designer and all stakeholders to generate design information.
RF.2	Stimulating and enabling the designer to represent the generated design information such that it is easily accessible for all stakeholders.
RF.3	Stimulating and enabling the designer to make sure that the represented design information is consistent.
RF.4	Stimulating and enabling all stakeholders to give opinions about the represented design information.
RF.5	Stimulating and enabling all stakeholders to verify their opinions about the represented design information.
RF.6	Stimulating and enabling all stakeholders to weigh positive and negative consequences of choices.
RF.7	Stimulating and enabling the designer to find a compromise between the preferences of all stakeholders.

Table 4.2: Functions that the new product design method should fulfill

The requirements for the new product design method (see Table 2.4 and Table 2.5) are excluded from the evaluation framework, because the functions in Table 4.2 already cover those

4.2 Method

4.2.1 Conceptual experimental design

Testing whether the new product design method is viable and whether it fulfills its functions requires applying it to a couple of different design cases and, while doing so, collecting and analyzing data about the design processes that emerge. However, limited availability of resources for this research makes that the new product design method can only be applied to one design case. Limited availability of resources also makes that the design process can only be performed by a single designer, rather than

by a design team. The designer may consult others and delegate tasks to others. However, the responsibility of successfully completing the design case will be solely his.

4.2.2 Two parallel processes

A designer is given the assignment to apply the new product design method to a design case. This designer should perform the activities that are prescribed by the method (as specified in section 3.1.4). While doing so, he should also observe the guidelines for how to perform those activities (as specified in section 3.2). In the meantime, an analyst is given the assignment to collect data about the design process that emerges, to analyze the collected data, and to use the results to test whether the criteria are met and the functions are fulfilled. So, during performance of the design case, two processes run in parallel:

- The design process (i.e. the process of applying the new product design method to a design case). This process is performed by the designer.
- The assessment process (i.e. the process of collecting and analyzing data about the design process). This process is performed by the analyst.

In principle, the assessment process and the design process run independently of each other. The designer is not influenced by the assessment process. However, it may be that the designer is asked to consider the needs of the analyst by, for example, answering questions after performance of a specific activity. It may also occur that the designer is asked to deviate from the guidelines to enable the analyst to perform certain measurements. An example of this could be selecting additional stakeholders than as prescribed by the guidelines. At all times, the analyst should make sure that the “original” design process is not influenced by such measurements.

4.2.3 Fulfillment of roles

Due to practical reasons, the role of *designer* and the role of *analyst* are fulfilled by the same person. This person is also the one who fulfills the roles of *design method developer* and *researcher* (see also section 1.4).

4.2.4 Experimental setup

As explained in section 3.1.3, when using the new product design method, the design process is split into two separate phases. Since the assessment process runs in parallel with the process of performing the design case, it is logical to split the assessment process into two separate experiments. Thus, each experiment coincides with one of the two phases of the product design process.

However, those two experiments will not facilitate a reliable verification of whether criteria GC.4, GC.5 and GC.6 (see Table 4.1) are met. Since the role of *design method developer*, the role of *designer* and the role of *analyst* are fulfilled by the same person, it is impossible to reliably verify whether the guidelines are unambiguous (GC.4). Since the new product design method is only applied to one design case, it is impossible to reliably verify whether the guidelines provide guidance under all circumstances (GC.5) and whether they are generic (GC.6). This makes that testing these criteria falls outside of the scope of the evaluation process, and that only criteria GC.1, GC.2 and GC.3 will be tested.

4.2.5 Hypotheses

Table 4.3 and Table 4.4 show the hypotheses that are tested during the two respective experiments. Hypotheses HY.1, HY.2 and HY.3 concern criteria GC.1, GC.2 and GC.3, respectively. Hypothesis HY.4 concerns the functions RF.1 to RF.7. Each hypothesis has an “a-version” and a “b-version”. The “a-versions” are tested during the first experiment, and the “b-versions” are tested during the second experiment.

<i>Hypothesis</i>	<i>Description</i>
HY.1.a	Human actors are able to perform activity 1 (as it was specified in section 3.1.4).
HY.2.a	Activity 1 yields actual results.
HY.3.a	The guideline for the selection of participants for activity 1 (as it was formulated in section 3.2.3) is correct.
HY.4.a	Functions RF.1, RF.2 and RF.3 (see Table 4.2) are fulfilled.

Table 4.3: The hypotheses that are tested during the first experiment

<i>Hypothesis</i>	<i>Description</i>
HY.1.b	Human actors are able to perform activity 2 (as it was specified in section 3.1.4).
HY.2.b	Activity 2 yields actual results.
HY.3.b	The guideline for the selection of participants for activity 2 (as it was formulated in section 3.2.11) is correct.
HY.4.b	Functions RF.4, RF.5, RF.6 and RF.7 (see Table 4.2) are fulfilled.

Table 4.4: The hypotheses that are tested during the second experiment

4.2.6 Dependent variables and measurement instruments

Table 4.5 depicts the variables that are used to accept or reject the hypotheses. Table 4.6 specifies the measurement instruments that are used during the two experiments. Table 4.6 also specifies for which variables each instrument is used.

<i>Variable</i>	<i>Description</i>
V.1	The extent to which stakeholders act according to the instructions given by the designer
V.2	The extent to which stakeholders answer the questions of the designer
V.3	The opinion of stakeholders about their own abilities
V.4	The opinion of the designer about the abilities of stakeholders
V.5	The opinion of the designer about his own abilities
V.6	The design information that is generated
V.7	The behavior of stakeholders during the reflection sessions
V.8	The type of design information that is generated by stakeholders during the reflection sessions
V.9	The amount of design information that is generated by stakeholders during the reflection sessions
V.10	The ease of stakeholders in getting familiar with new computer interfaces
V.11	The opinions of stakeholders about how positive and negative consequences of choices should be weighed
V.12	The opinion of stakeholders about the extent to which they felt stimulated to perform activities
V.13	The opinion of stakeholders about the extent to which they felt enabled to perform activities
V.14	The opinion of the designer about the extent to which stakeholders seemed stimulated to perform activities
V.15	The opinion of the designer about the extent to which stakeholders seemed enabled to perform activities
V.16	The opinion of the designer about the extent to which he felt stimulated to perform activities
V.17	The opinion of the designer about the extent to which he felt enabled to perform activities

Table 4.5: The dependent variables

<i>Instrument</i>	<i>Description</i>	<i>Variables</i>
I.1	Questionnaires	V.3, V.4, V.5, V.10, V.12, V.13, V.14, V.15, V.16, V.17
I.2	Direct observations	V.1, V.2, V.7
I.3	Indirect observations (i.e. audio/video recordings)	V.1, V.2, V.7
I.4	Design information (e.g. notes, documents, the design environment, etc.)	V.6, V.8, V.9, V.11

Table 4.6: The measurement instruments and the variables for which they are used

4.2.7 Criteria

Table 4.7 and Table 4.8 specify the criteria for acceptance of the hypotheses that are tested during the two respective experiments.

<i>Hypothesis</i>	<i>Criteria for acceptance</i>
HY.1.a	For every activity, V.1 and V.2 should be high for at least 80% of the stakeholders. For every activity, V.3 and V.4 should be positive for at least 80% of the stakeholders. For every activity, V.5 should be positive.
HY.2.a	For every activity, V.6 should be in line with one of the possible outcomes that is specified by the guidelines.
HY.3.a	V.7 and/or V.8 should differ between stakeholder groups. V.9 should correlate with V.10
HY.4.a	For every function, V.14 and V.15 should be positive for at least 80% of the stakeholders. For every function, V.16 and V.17 should be positive.

Table 4.7: The criteria for acceptance of the hypotheses that are tested during the first experiment

<i>Hypothesis</i>	<i>Criteria for acceptance</i>
HY.1.b	For every activity, V.1 and V.2 should be high for at least 80% of the stakeholders. For every activity, V.3 and V.4 should be positive for at least 80% of the stakeholders. For every activity, V.5 should be positive.
HY.2.b	For every activity, V.6 should be in line with one of the possible outcomes that is specified by the guidelines.
HY.3.b	V.11 should differ between stakeholder groups.
HY.4.b	For every function, V.12, V.13, V.14 and V.15 should be positive for at least 80% of the stakeholders. For every function, V.16 and V.17 should be positive.

Table 4.8: The criteria for acceptance of the hypotheses that are tested during the second experiment

4.2.8 Simplifications

A general guideline for performing experiments is that they should not be more complex than necessary. Therefore, two simplifications are implemented.

First of all, activity 1.b (creating an interface for generating test environments; see Figure 3.1) will not be performed. Accordingly, activity 2.2 (all stakeholders adapt environment parameters, thus generating test environments for the candidate designs; see Table 3.5) will also not be performed. During the experiments, the designer will generate test environments. This simplification reduces the complexity of the design environment that should be created. For a conclusion about whether human actors are able to perform activity 1.b – and whether this activity yields actual results - the conclusion about activity 1.d will be extrapolated. Similarly, the conclusion about activity 2.2 will be extrapolated from the conclusion about activity 2.1.

Secondly, the design process will only be performed for the *use aspects* of product design. The design environment will be solely aimed at representing the use aspects of the product, whereas other aspects (such as production, marketing, maintenance, etc.) will not be represented. The use aspects are “most critical” in the sense that – of all stakeholder groups - the way users communicate is expected to differ

most from the way the designer communicates. Therefore, it is assumed that if the experiments yield positive results for the use aspects (or for the stakeholder group “users”) this may be extrapolated to all imaginable aspect types (or to all imaginable stakeholder groups). An additional consequence of this simplification is that no multi-actor sessions will be performed during the second phase of the design process.

The impacts of these two simplifications on the general applicability of the experimental results will be discussed in chapter 7.

4.2.9 Participants

From combining the descriptions in section 4.2.1 with the second simplification (see section 4.2.8) follows that the participants in both experiments should be a designer and a group of users. The designer is a 25 year old Mechanical Engineer who is familiar with the new product design method and who has experience in virtual reality simulation and usability research.

In principle, this designer selects the users that participate in the design process according to the guidelines that are described in section 3.2.3 (for the first phase of the design process) and section 3.2.11 (for the second phases of the design process). However, to test hypothesis HY.3.a (see Table 4.3), the group of users that participates during the first phase of the design process should be divided according to the scales “view on the product” and “ease of getting familiar with new computer interfaces”, respectively. Theoretically, this yields four conditions. In practice, however, the number of conditions is three: “developers who have much difficulty in getting familiar with new computer interfaces” do not exist. Therefore, when inviting users to participate in the first phase of the design process, the designer should take into account that:

- 1/3 of the participants should be *consumers* that have *much difficulty* in getting familiar with new computer interfaces;
- 1/3 of the participants should be *consumers* that have *little difficulty* in getting familiar with new computer interfaces;
- 1/3 of the participants should be *developers* that have *little difficulty* in getting familiar with new computer interfaces.

4.2.10 Outlook

In section 4.3, the design case for the two experiments is selected. Chapter 5 describes the application of the new product design method to the design case. This chapter is written by the author in the role of *designer*. Next, chapter 6 describes the process of collecting data about the design process that emerges, analyzing the collected data, and using the results to test the hypotheses. It is written by the author in the role of *analyst*. Finally, chapter 7 describes to what extent the new product design method meets its objectives, and to what extent the results are generally applicable. This chapter is written by the author in the role of *design method developer*.

4.3 Selection of a design case

4.3.1 Requirements

The new product design method is expected to be generally applicable. However, it is also expected that the more a product creation process has type 2 characteristics (see section 2.3.4), the higher the

chance that it is a worthy investment to apply the new product design method. Therefore, the design case should involve a type 2 product creation process. This leads to requirements RDC.1, RDC.2 and RDC.3 in Table 4.9. Requirements RDC.4 and RDC.5 follow from the descriptions about the applicability of the new product design method (see section 3.3).

<i>Requirement</i>	<i>Description</i>
RDC.1	Similar product creation processes and similar results (i.e. similar products) do not yet exist.
RDC.2	The product creation process and its result (i.e. the product) are complex and/or part of a complex system.
RDC.3	The product creation process and its result (i.e. the product) involve many different stakeholders.
RDC.4	The product is used in a partly unknown and potentially dangerous environment.
RDC.5	The product's functionality is partly determined by the behavior of the human operator (and his behavior is likely to change as a result of using the product).

Table 4.9: Requirements for the design case

In addition to the requirements in Table 4.9, there is a prerequisite for the design case. It should be technically possible to create a design environment that reflects the “problem-solution space” of the design case such that it can be easily understood by all stakeholders. In other words, it should be technically possible to create interfaces for stakeholders to generate candidate designs and test environments, and to offer simulations of those designs in those environments such that stakeholders can make a reliable assessment of the designs' properties.

4.3.2 Selection process

There is a theoretically unlimited amount of (future) products that meet the requirements in Table 4.9. However, the prerequisite narrows the set of possible products down to fields in which VR simulation technology has reached a sufficient level of maturity. At this point in time, these fields are driving simulation and flight simulation. This means that the design case should concern a product that has something to do with either car driving or flying an airplane. Such products also automatically meet the requirements about the complexity level of the product (RDC.2) and the danger level of the environment (RDC.4).

When considering the requirements about the novelty of the product (RDC.1), the number of different stakeholders that are involved (RDC.3), and functionality that is partly determined by the behavior of the human operator (RDC.5), an AHS (as introduced in section 2.3.4) could be a suitable design case. An Automated Highway System consists of vehicles and roadways that will provide fully autonomous computer controlled driving. Although such a system will be partly created from products that already exist (e.g. vehicles, roadways, computers), the creation of an AHS-as-a-whole will still largely comply with the characteristics of the second process type.

However, an AHS cannot be realized overnight. It takes a transition process in which existing roadways are adapted and the current fleet of vehicles is renewed so that they support computer controlled driving. This transition process has already started with the introduction of *driver support systems*. Such systems fulfill parts of the driving task previously fulfilled by the human driver. Examples of driver support systems are parking assistants, adaptive cruise controls, lane departure warning systems, and lane keeping systems. Despite the fact that such systems are already on the market, some are still immature enough to function as a design case within this research.

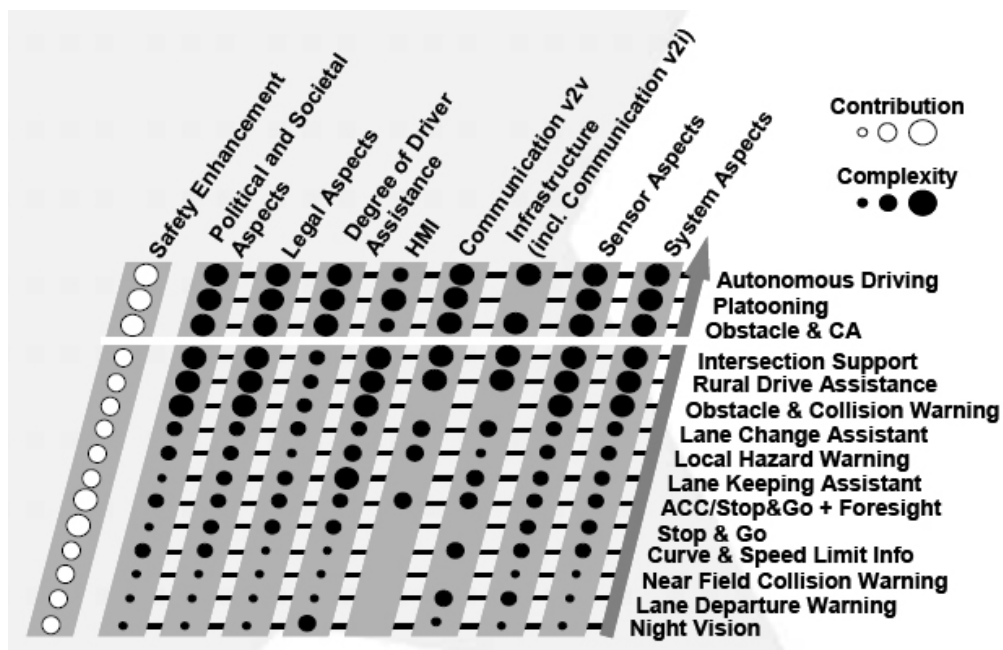


Figure 4.1: ADASE2 roadmap
(adapted from Ehmans & Spannheimer (2004))

Figure 4.1 depicts the ADASE2 roadmap (Ehmans & Spannheimer, 2004). This roadmap is meant to identify technological gaps and future research needs in the field of advanced driver assistance in Europe. For every driver support system function, the roadmap shows the expected complexity level of realizing the various different system aspects.

4.3.3 Selected case

A lane change support system would be a suitable design case. Figure 4.1 shows that every aspect of such a system is considered to be intermediately complex. Therefore, the design case will not be too easy, but also not too difficult. A too easy design case would yield the risk of only generating trivial results – results that were already known or could have been easily predicted. A too difficult design case would yield the risk of not finishing the design case within the available time, thereby generating no results at all. Moreover, a lane change support system meets all requirements in Table 4.9:

- Requirements RDC.1 is met because no lane change support system is yet on the market (Note: no lane change support system was on the market when the design case was started in January 2005. In the meantime, some car manufacturers have created simple implementations);
- Requirement RDC.2 is met because a lane change support system is part of a complex system that consists of many different parts and many interactions between those parts: the traffic system. Moreover, a lane change support system can be implemented in many different ways: the circumstances under which it provides support, the contents of the provided support, and the form of the provided support may all vary independently of each other. Theoretically, this yields literally millions of potential lane change support system designs;
- Requirement RDC.3 is met because there are many car drivers in the world, each having their own personal way of making lane change maneuvers. Each country or city has its own specific rules, regulations and social norms. For example, the absence of speed limits on German

highways imposes other requirements on lane change behavior than lane changing in Cairo or Beijing, where lane markers are ignored and drivers will use their horns to indicate that neighboring vehicles come too close (Tideman & Spengelink, 2005). Moreover, lane changing is performed as a part of various maneuvers and/or as a response to various traffic conditions, roadway characteristics, or environment characteristics. Lane change maneuvers may occur during urban driving, rural driving, and highway driving. They may occur during passing, entering traffic, leaving traffic, parking, negotiating intersections, and entering on-ramps and off-ramps. Furthermore, lane change maneuvers may be initiated by environmental circumstances such as the road surface, obstructions, intersections, turnabouts and toll plazas (McKnight & Adams, 1970);

- Requirement RDC.4 is met because lane changing is performed in a potentially dangerous environment. In 2005, 817 people were killed on Dutch roads (Stipdonk et al., 2006). Worldwide, an estimated 1.2 million people are killed in road crashes each year and as many as 50 million are injured (WHO, 2004);
- Requirement RDC.5 is met because a lane change support system fulfils some of the tasks that were previously fulfilled by the human driver. A new task division between a human and a machine implies new behavior of the human (Tideman & Spengelink, 2005).

4.3.4 Constraints

While applying the new product design method to the design case, only lane change support systems in which the driver is "in the loop" will be considered. This means that fully automatic control systems, in which the driver has no way to overrule the system's actions, are excluded from the technology database. This is because, due to legal constraints, fully automatic control systems are not likely to enter the market in the near future.

Another constraint is that only *highway* lane change support systems will be considered. A lane change support system is expected to be particularly useful on highways and less so in cities and on rural roads (Tideman & Spengelink, 2005). Although it will be possible to create designs that also function in cities and on rural roads, the structure and the contents of the technology database will be geared to facilitating the generation of lane change support systems that are used on highways. Accordingly, the environment database will only need to contain *highway* traffic scenarios. This constraint is applied to reduce the complexity of the technology database and the environment database.

APPLYING THE NEW PRODUCT DESIGN METHOD

5

In this chapter, the new product design method is applied to the design case. For every activity that is prescribed by the method, it is described how it is performed and what the results are. The chapter is split into two sections; each describing one of the two phases of the design process.

5.1 Performing the first phase of the design process

5.1.1 Introduction

This section describes the first phase of the design process that emerged as a result of applying the new product design method to the design of a lane change support system. According to the descriptions in section 3.1.4, this phase consists of performing activities 1.a, 1.b, 1.c and 1.d. However, the first simplification in section 4.2.8 made that activity 1.b was not performed. Consequently, the descriptions in this section only concern activities 1.a, 1.c and 1.d.

5.1.2 Creating an initial design environment (activity 1.1)

Basic layout

The results from observing the world, reading literature and talking to stakeholders were converted into a report on supporting spatial-temporal cognition and control during lane change tasks (Tideman & Spengelink, 2005). The findings in this report were used to create an initial design environment. This design environment consisted of the following main elements:

- An environment database filled with highway traffic scenarios;
- A technology database filled with lane change support system technology;
- A lane change support system configurator that enabled a user to generate lane change support system designs;
- A driving simulator that enabled a user to control a vehicle within the traffic scenarios, thereby realistically experiencing them. The driving simulator also allowed the user to realistically experience the behavior of the lane change support system designs within the traffic scenarios.

Figure 5.1 shows the initial design environment. It consisted of a mock-up of a vehicle, a large curved screen that displays the traffic environment, and a sound-system that displays sounds from the traffic environment. The mock-up itself consisted of a force feedback steering wheel and a pedal set, a driver's seat equipped with vibrating elements, four flat screens that together form a dashboard, three flat screens that offer rearview mirror functionality, and an in-car sound system. In the middle console, a touch screen was integrated as an interface for the lane change support system configurator. The hardware interfaces in the design environment were connected to a network of six high-end PCs that run on Windows XP. The simulations were controlled by two software packages: ST Software (www.stsoftware.nl) and Pilgrim Pro 3D (www.pilgrim-visuals.com). ST software is dedicated driving simulator software. Pilgrim Pro 3D is a generic 3D engine. Each software package "owned" three PCs in

the network. The two software packages communicated with each other through an UDP channel. Technical details about the initial design environment's layout can be found in Appendix A.

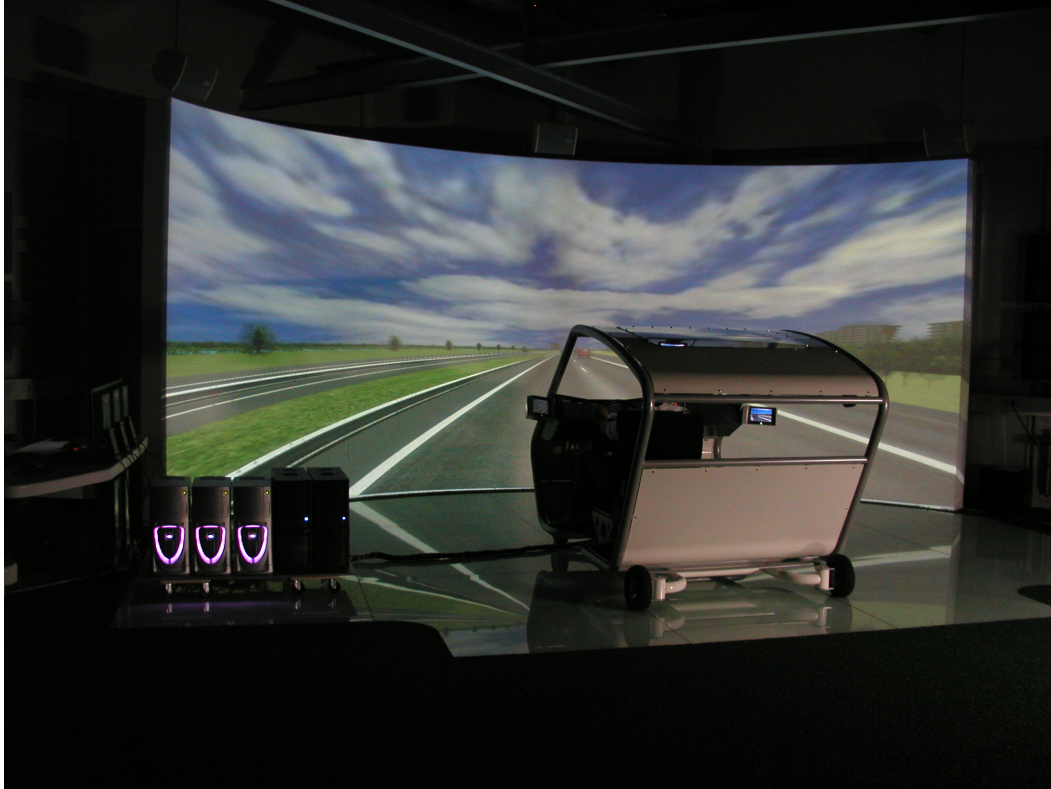


Figure 5.1: The initial design environment

The environment database

The environment database was filled with a set of five traffic scenarios. Every scenario covered a distance of 6 km, and every scenario started and stopped when the vehicle was at rest. The scenarios provoked natural driving behavior and they confronted the user with a number of different situations that might occur on Dutch highways in which lane change maneuvers can - or sometimes even must - be performed. These situations were derived from Table 5.1, which gives an overview of possible motivations for initiating a lane change maneuver.

<i>Situation</i>	<i>Motivation</i>	<i>Description</i>
SI.1	Slow lead vehicle	Lane change to pass a slower vehicle
SI.2	Return	Lane change to return to preferred driving lane
SI.3	Enter	Lane change to enter a road (e.g. from on-ramp)
SI.4	Exit	Lane change to exit a road (e.g. to an off-ramp)
SI.5	Lane drop	End of driver's lane (e.g. road goes from 3 to 2 lanes)
SI.6	Added lane	Addition of a lane (e.g. road goes from 2 to 3 lanes)
SI.7	Tailgating vehicle	Another vehicle following too closely or approaching quickly
SI.8	Merging vehicle	Another vehicle entering the road (e.g. from an on-ramp)
SI.9	Obstacle avoidance	Maneuver to avoid an obstacle or rough road surface

Table 5.1: Possible motivations for initiating a lane change maneuver (adapted from Lee et al. (2004))

A distinction was made between situations that occur very frequently (situations SI.1 to SI.4) and situations that occur less frequently (situations SI.5 to SI.9). Since the traffic scenarios were meant to provoke driving behavior that is as natural as possible, all scenarios contained situations SI.1 to SI.4. In addition, each of the five traffic scenarios contained one of the less frequently occurring situations. The less frequently occurring situation can be considered the “theme” of the scenario. This situation occurred at a random moment during the scenario. Table 5.2 gives an overview of the themes of the five initial traffic scenarios and the situations from which they were made up.

<i>Scenario</i>	<i>Theme</i>	<i>Very frequently occurring situations</i>	<i>Less frequently occurring situations</i>
SC.1	Lane drop	SI.1, SI.2, SI.3, SI.4	SI.5
SC.2	Added lane	SI.1, SI.2, SI.3, SI.4	SI.6
SC.3	Tailgating	SI.1, SI.2, SI.3, SI.4	SI.7
SC.4	Merging vehicle	SI.1, SI.2, SI.3, SI.4	SI.8
SC.5	Obstacle avoidance	SI.1, SI.2, SI.3, SI.4	SI.9

Table 5.2: Themes of the five initial traffic scenarios and the situations from which they were made up

The first column of Table 5.3 specifies the scenario attributes that were expected to have an influence on the lane change behavior of a driver and on his needs for lane change support (Tideman & Spengelink, 2005). Thus, these attributes should have been made available for users to adapt. However, as a result of the first simplification (not creating an interface for generating test environments; see section 4.2.8), this possibility was not implemented. Instead, variations in the value of each attribute were “pre-programmed” into each scenario. The last column of Table 5.3 specifies the values of each attribute during the scenarios.

<i>Attribute</i>	<i>Description</i>	<i>Values</i>
A.1	Traffic intensity	{light, medium, heavy}
A.2	Number of driving lanes	(1, 2, 3)
A.3	Preferred speed of a traffic participant coming from behind the subject vehicle	A random number between 20 km/h and 90 km/h faster than the subject vehicle, but minimal 100 km/h
A.4	Preferred speed of a traffic participant in front of the subject vehicle	A random number between 25 km/h slower and 10 km/h faster than the subject vehicle, but minimal 80 km/h

Table 5.3: Influential scenario attributes and their values

The order in which the different traffic intensities appeared during a scenario was random. However, the frequently occurring situations (i.e. situations SI.1 to SI.4) all arose at least three times in every scenario: once in light traffic, once in medium traffic and once in heavy traffic. Most of the time, there were two driving lanes. Only scenario SC.1 contained a stretch with one driving lane (i.e. the stretch after the “lane drop”), and scenario SC.2 contained a stretch with 3 driving lanes (i.e. the stretch after the “added lane”). Traffic participants were autonomous agents with their own set of behavioral rules which they activate depending on the situation. Within a scenario, their preferred speeds were randomly distributed within a range that depended on the speed of the subject vehicle.

Figure 5.2 shows a user experiencing a traffic scenario.



Figure 5.2: Experiencing a traffic scenario

The technology database

Figure 5.3 displays the higher-level structure of the technology database. This structure followed from the dimensions that determine the working principle of a lane change support system from a user's perspective (Tideman & Spengelink, 2005). The next pages will describe these dimensions into detail.

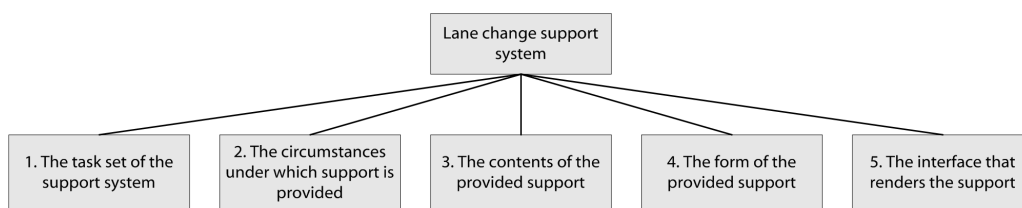


Figure 5.3: The higher-level structure of the technology database

Figure 5.4 depicts the structure of the technology database for the task set of a lane change support system.

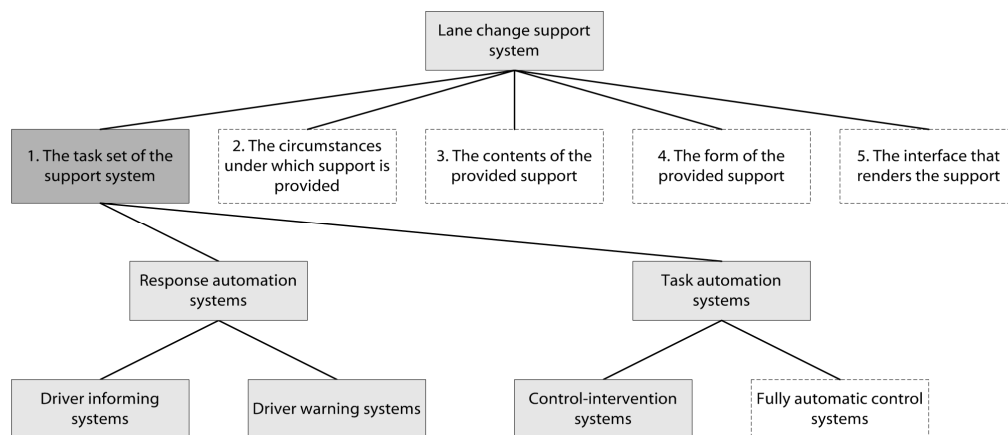


Figure 5.4: The technology database structure for the task set of a lane change support system

Response automation systems pre-empt human decision making and control. They initiate a task, thereby giving the driver assistance in attention management (Boer & Hoedemaeker, 1998). In task automation systems, on the other hand, the task is automated in order to reduce physical or mental workload (Goodrich et al., 2001).

Response automation systems are further subdivided into driver informing systems and driver warning systems. Driver informing systems continuously provide information about the state of the traffic environment. By interpreting this information, the driver is supported in making judgments about the safety of a situation or maneuver (Chovan et al., 1994). In case of driver warning systems, the system itself makes interpretations about the safety of a situation or maneuver. It generates a warning when some threshold condition is met or exceeded. However, the system's interpretations are meant to enhance the driver's own interpretations about the traffic environment. The driver's interpretations dominate the system's interpretations in the sense that he remains fully responsible for the vehicle control task (Chovan et al., 1994).

Just like driver warning systems, task automation systems also make interpretations about the safety of a situation or maneuver. They act when some threshold condition is met or exceeded. They are further subdivided into control-intervention systems and fully automatic control systems. In control-intervention systems, the system's interpretations are meant to enhance the driver's own interpretations about the traffic environment. The driver's interpretations dominate the system's interpretations in the sense that he can overrule the interventions that the system imposes (Chovan et al., 1994). In fully automatic control systems, on the other hand, the system generates and executes a plan of action. The driver's interpretations about the traffic environment are irrelevant, since there is no means for the driver to overrule the system's actions (Chovan et al., 1994).

As follows from section 4.3.4, the design case concerns a lane change support system in which the driver is "in the loop". This means that he remains fully responsible for controlling the vehicle. Therefore, fully automatic control systems are not incorporated in the technology database. This is indicated in Figure 5.4 by the dotted line around the box.

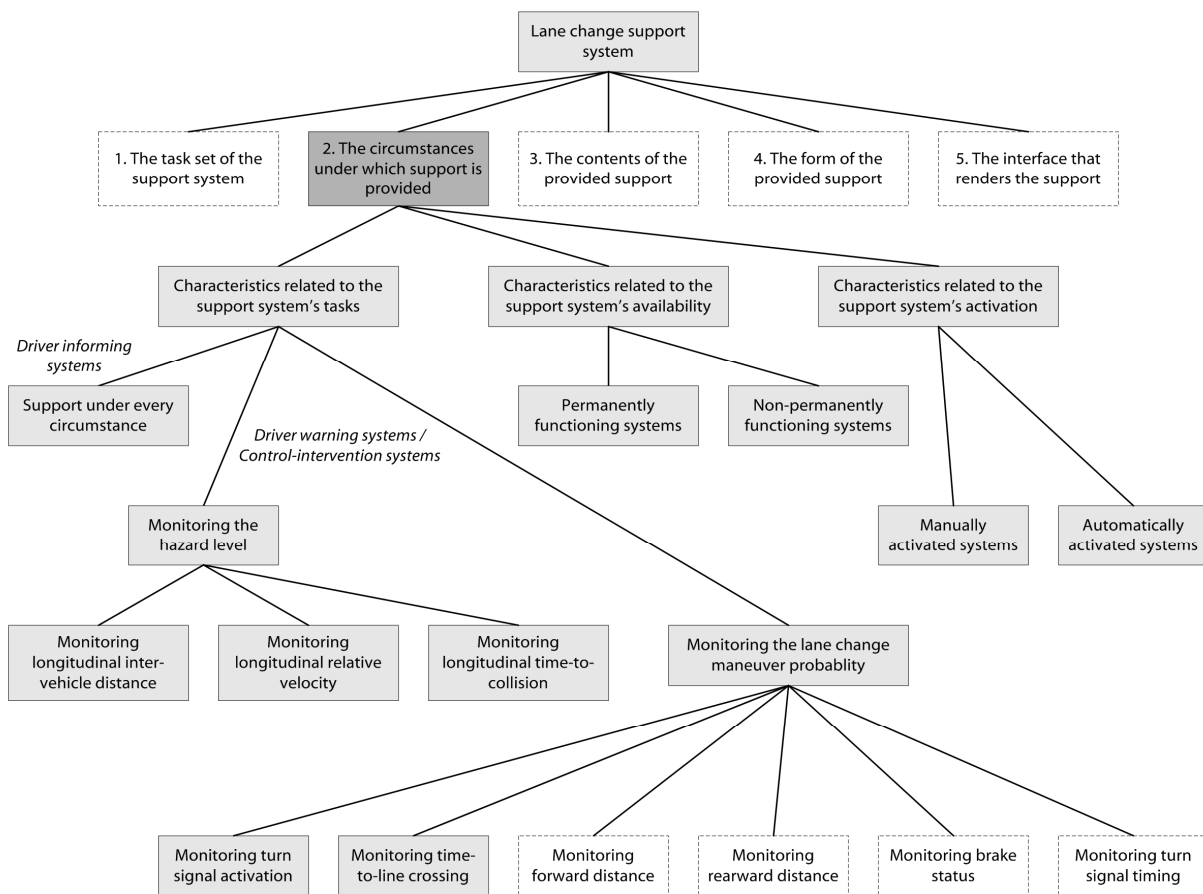


Figure 5.5: The technology database structure for the circumstances under which support is provided

Figure 5.5 depicts the structure of the technology database for the circumstances under which support is provided. As can be seen, these circumstances may vary depending on three types of system characteristics: those related to the support system’s tasks, the support system’s availability, and the support system’s activation.

Characteristics related to the support system’s tasks refer back to Figure 5.4. Driver informing systems continuously provide information about the state of the traffic environment, so they provide support *under every circumstance*. Driver warning systems and control-intervention systems, on the other hand, only act *when some threshold condition is met or exceeded*. For the specific case of a lane change support system, these actions are based on combining results from monitoring the hazard level (i.e. would a lane change maneuver result in a possibly hazardous situation?) and monitoring the lane change maneuver probability (i.e. is a lane change maneuver to be expected in the short term?).

The signals that are issued by a lane change support system can be prompted by, theoretically, a limitless amount of objects. The most relevant objects are *adjacent* vehicles – vehicles that travel in the lane directly left of the subject vehicle or in the lane directly right of the subject vehicle. Normally, it is only these vehicles in these lanes which impose an immediate hazard in case of a lane change maneuver. Furthermore, *trailing* vehicles traveling in these adjacent lanes are more relevant than

leading vehicles. The driver has a clear view of the vehicles in front of him, whereas retrieving information about trailing vehicles is more difficult as it requires glancing in the mirrors and checking the blind spots. Therefore, while monitoring the hazard level, only *trailing adjacent* vehicles are taken into account.

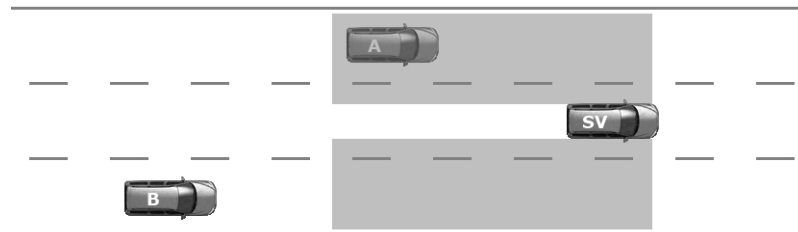


Figure 5.6: The zones that are monitored by the “virtual sensors” in the technology database (length of the zones can be adapted by users)

Figure 5.6 shows the zones that are monitored by the “virtual sensors” in the technology database. These sensors cover the adjacent lanes behind the front bumper of the subject vehicle. As it is drawn in Figure 5.6, vehicle A will be covered by the sensors, but vehicle B will not be covered. As it is drawn in Figure 5.6, the zones are approximately 20 m long. However, this length can be adapted by users (possible values range from 5 to 50 m). Monitoring the hazard level of trailing adjacent vehicles can be done by monitoring longitudinal inter-vehicle distance, longitudinal relative velocity and longitudinal time-to-collision, and comparing the monitored quantities with some threshold condition (Bascunana, 1995; Jula et al., 2000).

Monitoring the lane change maneuver probability can be done in multiple ways. As a result of field observations, Hetrick (1997) hypothesizes that the ideal warning onset rule would be a combination of monitoring turn signal activation and monitoring time-to-line-crossing. If the threshold condition for any of these checks is met or exceeded, then the system should assume that there is a lane change maneuver coming up in the short term. Based on experimental results, Van Winsum et al. (1999) hypothesize that a time-to-line crossing of 1 second would be suitable for discriminating between lane changes and straight-ahead driving. Olsen (2003) also developed a model that discriminates between lane changes and straight-ahead driving. It includes monitoring turn signal activation, time-to-line-crossing, forward distance, rearward distance, brake status and turn signal timing. However, because Olsen’s model is expected to offer little added value compared to Hetrick’s model - and integration of his model into the technology database makes it more difficult for users to specify an indicator for the lane change maneuver probability - Olsen’s model is left out of the technology database. This is indicated in Figure 5.5 by the dotted lines around the respective boxes.

The functionality of a lane change support system can be either permanently available or only available when some threshold condition is met or exceeded (e.g. the support system’s functionality is only available above a speed of 70 km/h).

Finally, a lane change support system can either be manually activated (the driver can manually activate/de-activate the system), or automatically activated (the system activates/de-activates when

some threshold condition is met or exceeded). An example of an automatically activated system is a system that activates above 70 km/h and de-activates below 70 km/h.

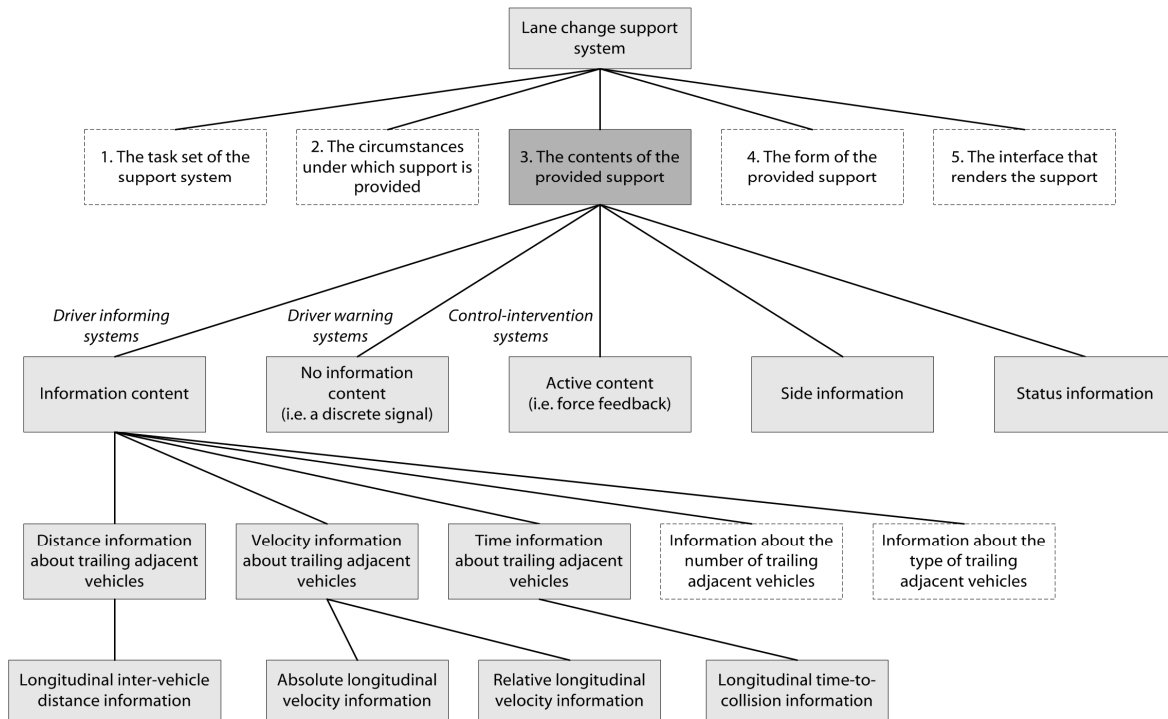


Figure 5.7: The technology database structure for the contents of the provided support

Figure 5.7 depicts the structure of the technology database for the contents of the provided support. A support signal can have “information content”. This information gives an indication about what is going on in the traffic situation. When a support signal does not have “information content”, it is a discrete signal (i.e. a warning). Such a signal tells that some threshold condition is met or exceeded. A support signal can also have “active content” (i.e. force-feedback). Active content not only tells that some threshold condition is met or exceeded, but also gives an indication about what is considered to be the proper driver control input. Additionally, side information and status information can be communicated. Side information tells the driver whether the vehicle about which a support signal is issued travels in the left or in the right adjacent lane. Status information tells the driver whether the system is active or not (Campbell et al., 1996).

Relevant information about trailing adjacent vehicles could be distance information, velocity information or time information. Distance information is the longitudinal inter-vehicle distance with a trailing vehicle in the adjacent lane (i.e. information about the size of the inter-vehicle gap). Velocity information is the absolute longitudinal velocity of a trailing vehicle in the adjacent lane or information about the relative longitudinal velocity with a trailing adjacent vehicle (i.e. information about the changing rate of the inter-vehicle gap). Time information is the longitudinal time-to-collision with a trailing adjacent vehicle. Other relevant information that could be communicated to the driver is information about the number of trailing adjacent vehicles or information about the type of trailing adjacent vehicles (Cody, 2005). However, this information is less important than information about

distance, velocity and time. In order to reduce complexity, this information is left out of the technology database. This is indicated in Figure 5.7 by the dotted lines around the respective boxes.

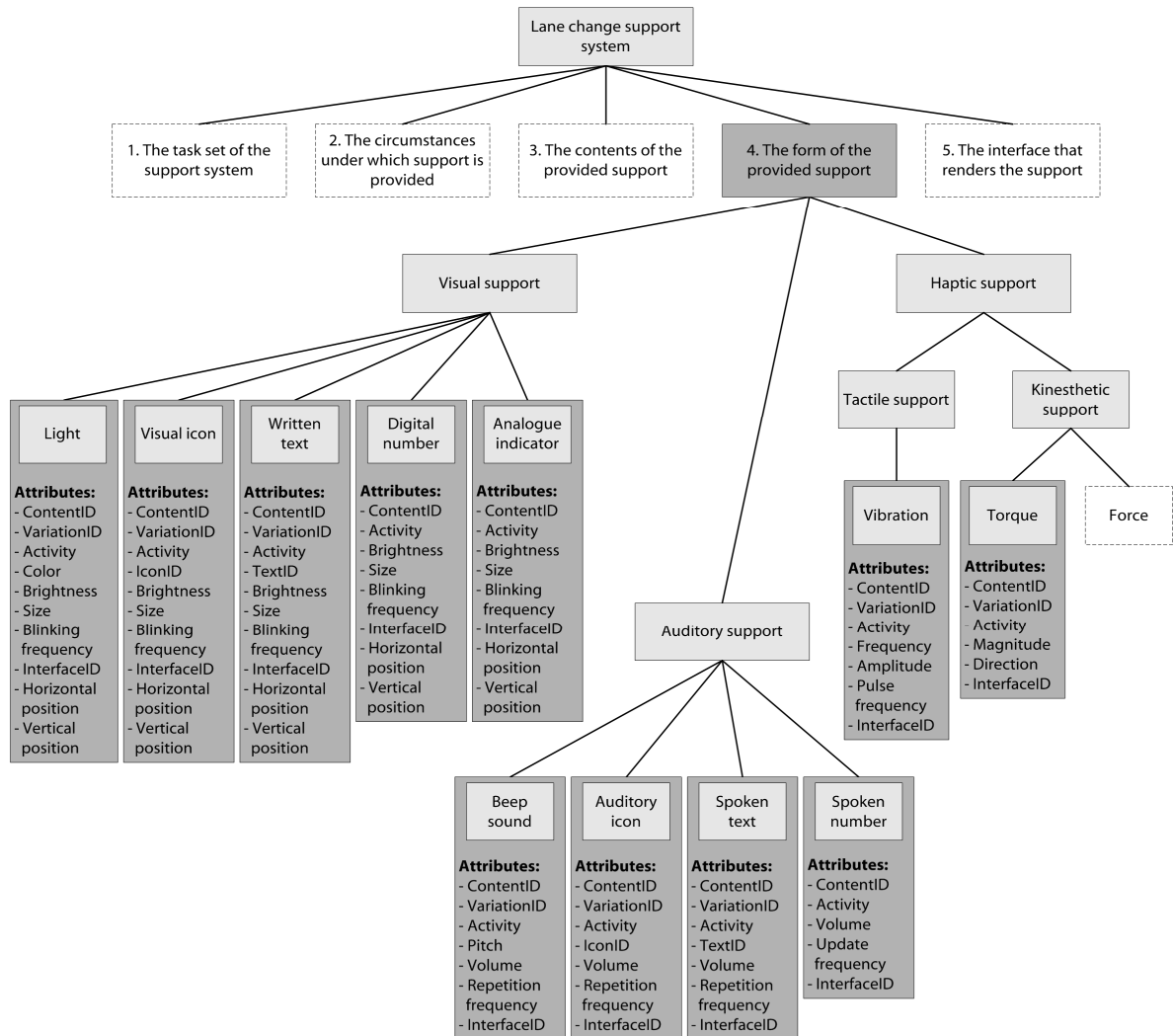


Figure 5.8: The technology database structure for the form of the provided support

Figure 5.8 depicts the structure of the technology database for the form of the provided support. The support modality can be visual, auditory or haptic; haptic support is further subdivided into tactile support and kinesthetic support.

Visual support can be given in the form of a light, a visual icon (e.g. an image of a triangle or an arrow), a written text (e.g. “adjacent vehicle left” or “caution!”), a digital number, or an analogue indicator. Auditory support can be given in the form of a beep, an auditory icon (e.g. a horn sound or the sound of driving on a rumble strip), a spoken text (e.g. “adjacent vehicle left” or “caution!”), or a spoken number. Tactile support is always a vibration (e.g. a vibration in the seat or in the steering wheel). Kinesthetic support can either be a torque or a force (e.g. a torque on the steering wheel or a force on the gas pedal). As kinesthetic support will directly affect vehicle control, it can only be present in control-

intervention systems. A force can only be rendered on the pedals. Since operating the pedals has an effect on the vehicle's *longitudinal* position and velocity - and this is considered less relevant in case of providing lane change support – forces are left out of the technology database. In Figure 5.8, this is indicated by the dotted box.

Figure 5.8 illustrates that every support form has a number of attributes. One of the attributes that every support form - either visual, auditory or haptic - shares is the "ContentID". This attribute refers to the "information content" that should be expressed by the signal: information about the size of the inter-vehicle gap, about the speed of a trailing adjacent vehicle, or about the longitudinal time-to-collision with a trailing adjacent vehicle (see also Figure 5.7).

In case of a digital number, an analogue indicator or a spoken number, the information content is expressed by universal symbols (i.e. by numbers). However, in case of a light, a visual icon, a written text, a beep, an auditory icon, a spoken text, a vibration or a torque, the information content cannot be expressed by such symbols. Therefore, these support forms all have the attribute "VariationID". This VariationID specifies the attribute that is varied to express the information content. For example, if a light should give information about the size of the inter-vehicle gap, the user could opt for selecting the attribute "Color" as VariationID. This means that the color of the light will change as the distance with another vehicle becomes shorter. Alternatively, the user could also select the attributes "Brightness", "Size" or "Blinking frequency" as VariationIDs.

Although the *support form* is generally independent of the *support content*, a particular ContentID might not be compatible with a particular support form. The following constraints apply:

- In a driver informing system, only a light, digital number, analogue indicator, beep, spoken number or a vibration can be used to communicate the desired information to the user;
- In a driver warning system, only a light, visual icon, written text, beep, auditory icon, spoken text or a vibration can be used to express the warning signal;
- In a control-intervention system, the only support form that can be used is torque on the steering wheel.

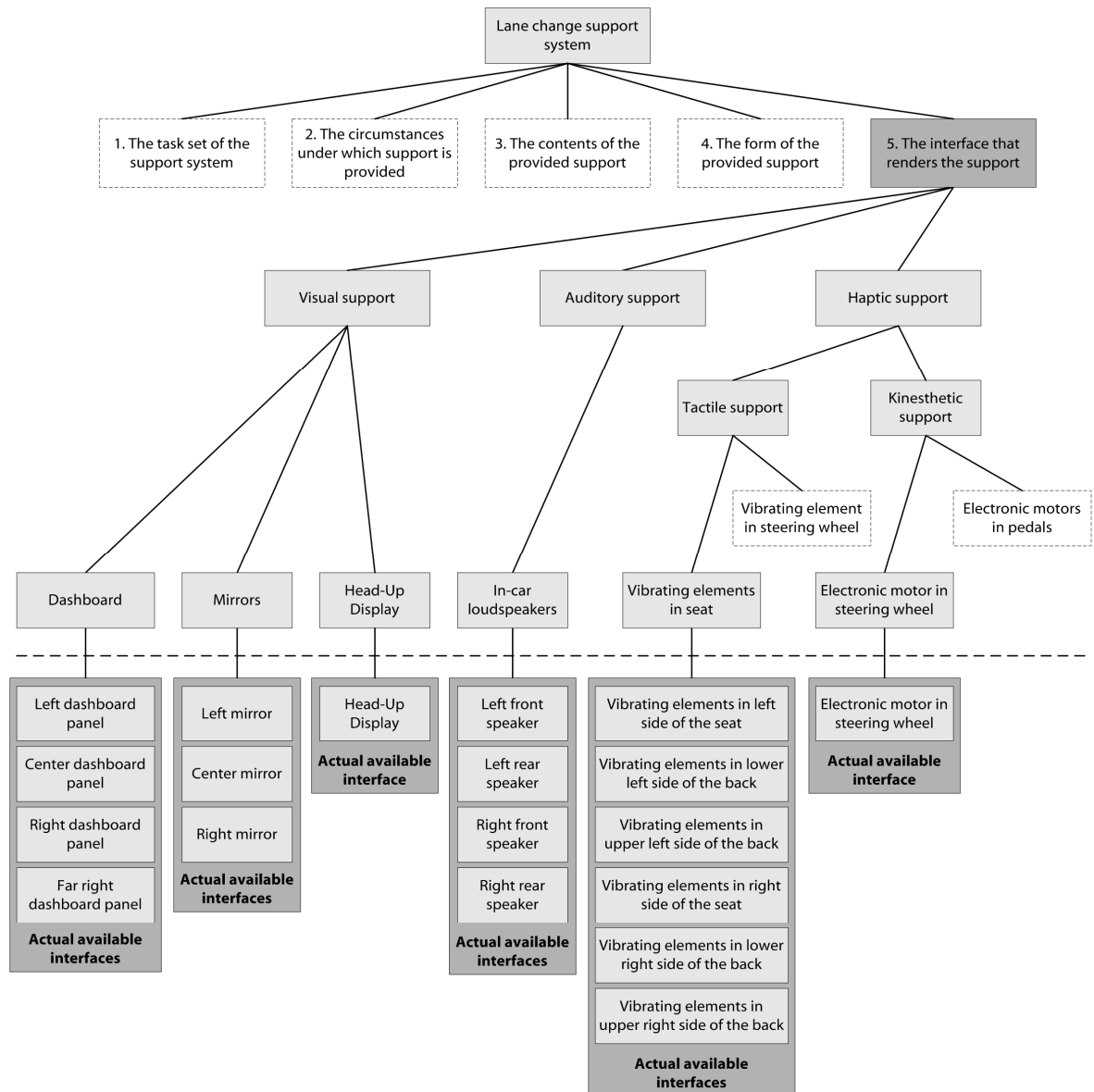


Figure 5.9: The technology database structure for the interface that renders the support

Figure 5.9 depicts the structure of the technology database for the interface that renders the support. The interfaces that can render visual support are the dashboard, the mirrors and a Head-Up Display (HUD). The interfaces that can render auditory support are in-car loudspeakers. The interfaces that can render tactile support are vibrating elements in the seat and a vibrating element in the steering wheel. The interfaces that can render kinesthetic support are an electronic motor in the steering wheel and electronic motors in the pedals.

Below the dotted line in Figure 5.9, is an overview of interfaces that are actually available within the design environment. As can be seen, the dashboard consists of a left dashboard panel, a center dashboard panel, a right dashboard panel and a far right dashboard panel. There is a left mirror, a

center mirror and a right mirror. Furthermore, a Head-Up Display, four in-car loudspeakers and six vibrating elements in the seat are available. As follows from Figure 5.8, kinesthetic support via the pedals is left out of the technology database. This is indicated by a dotted line around this box in the figure. Also, a vibrating element in the steering wheel is not present within the design environment (indicated by a dotted box in Figure 5.9). If desired, tactile support in the steering wheel can be rendered by the electronic motor in the steering wheel.

The lane change support system configurator

Figure 5.10 shows the functional architecture of a lane change support system from a user’s perspective.

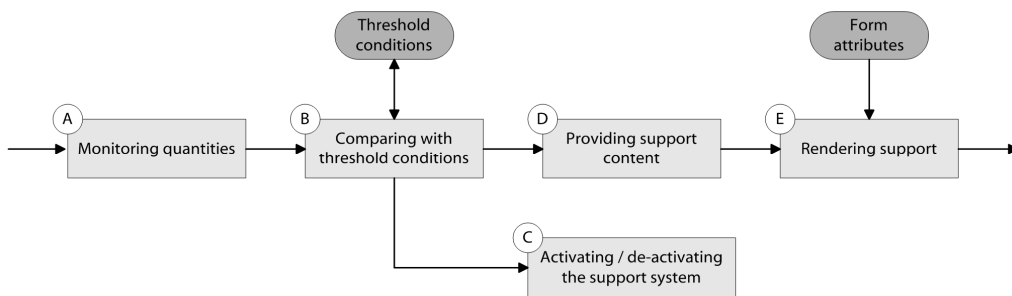


Figure 5.10: The functional architecture of a lane change support system from a user’s perspective

The lane change support system configurator offered users the possibility to generate lane change support system designs by:

- Making a selection out of the sub functions in categories A, B, C, D and E;
- Specifying values for the threshold conditions that are required to fulfill the sub functions in category B;
- Specifying values for the attributes that determine the way the sub functions in category E are fulfilled.

The configurator was an electronic questionnaire that ran on a touch screen in the middle console of the mock-up. In the questionnaire, the set of lane change support system technology was represented by descriptions in natural language, images, and previews of the behavior of the technology. The technology was organized into categories that are meaningful from a user’s perspective. By operating the configurator (i.e. reading the questions, looking at the images, experiencing the previews, and giving answers to the questions), users would form a mental model of a lane change support system’s functional architecture in an effective and efficient way. The specific implementation of the electronic questionnaire made it impossible for users to “forget” to define crucial values. It was therefore guaranteed that the generated candidate designs actually work.

Figure 5.11 shows a user operating the lane change support system configurator.



Figure 5.11: The lane change support system configurator

In order to create a questionnaire that could be completed within a couple of minutes, the following assumptions were made:

- The support system is *either* a driver informing system *or* a driver warning system *or* a control-intervention system: a hybrid system is not possible;
- If there is more than one trailing vehicle in a specific adjacent lane, a warning or a control-intervention is only based on the *closest* (i.e. the most dangerous) trailing vehicle;
- The *task set* of the support system – the *circumstances* under which support is provided and its contents – is *symmetric*. This means that vehicles in the left adjacent lane are “treated” in the same way as vehicles in the right adjacent lane. Only the *form* of the provided support and/or the *interface* that renders the support might differ between vehicles traveling in the left adjacent lane and vehicles traveling in the right adjacent lane;
- The threshold condition for “monitoring the lane change maneuver probability” cannot be specified by the user. It is determined to be a combination of “monitoring turn signal activation” and “monitoring time-to-line crossing”. If the turn signal is activated *or* the time-to-line crossing drops below 1s, it is assumed that a lane change maneuver will soon be made;
- Characteristics related to the support system’s availability are *not* taken into account. It is assumed that the support system is a permanently functioning system;
- If a manually activated system is chosen, the default interfaces for activating and de-activating the support system are the two buttons on the steering wheel;
- If the user chooses for receiving status information, this information is displayed via a standard visual icon rendered on the center dashboard panel (i.e. near the speedometer).

The lane change support system configurator does not allow users to choose the mirrors or the HUD as interfaces for rendering visual support. Also, in the case of tactile support, users cannot adjust the amplitude or frequency of vibrations. These restraints result from incompatibilities between the two software packages that control the simulations (i.e. ST Software and Pilgrim Pro 3D). It is technically possible to solve these incompatibilities but not within the timeframe and money allotted for this project.

5.1.3 Reflecting on the initial design environment (activity 1.2)

Participants

Twelve users were invited for a reflection session in which they access the design environment. A reflection session involved one user at a time, so twelve sessions were performed in total. All users had at least five years of driving experience and drove at least 10.000 km per year. This parameter was set to ensure that possible problems with controlling the vehicle in the traffic scenarios were not caused by lack of driving experience. Within the group of users, variations existed in gender, age and education level.

Instruction

At the beginning of a reflection session, the user received a written instruction. This instruction did not reveal the purpose of the session (i.e. checking the design environment for completeness and correctness). Rather, the instruction explained that the session was aimed at finding out which lane change support system design is most desirable.

The practicing phase

After the user read the instruction, he was offered the opportunity to familiarize himself with the design environment. First, the user was asked to drive a route with the driving simulator. This route was set on a simulated Dutch highway with light – and calm - traffic. Navigation instructions were given by a computer generated humanlike voice. Next, the user was offered the opportunity to explore the lane change support system configurator. The user was asked to create a support system that complies with written instructions. Finally, the user was asked to re-drive the route, but now with the newly created lane change support system design. In this way,, the user gets an impression about the working principles of lane change support systems. Moreover, the user discovered the relationships between choices made during configuration of the system and the actual behavior of the system. If necessary, the user's questions about the design environment were answered.

Generating and testing designs

After the "practicing phase", the user was asked to create a lane change support system design. Then, the user was asked to assess this design by using it within a simulated traffic scenario. At the end of the assessment, the user was asked for an opinion about the design. Next, the user was asked to create a new design that might better meet his needs. This series of activities was performed five times in total. For every "design iteration", a traffic scenario was offered for assessment of the lane change support system. If the user found everything to be satisfactory before these five iterations were over, it was stressed that it is important that several different options be tried during the session.

Interview

After the five design iterations were finished, the user was interviewed. This interview was aimed at checking whether:

- All situations that are relevant while using a lane change support system were represented in the environment database;
- All technology that could be usefully exploited by a lane change support system was represented in the technology database;
- All situations represented in the environment database are relevant while using a lane change support system;
- All technology represented in the technology database could be usefully exploited by a lane change support system;
- All situations represented in the environment database were correctly modeled;
- All technology represented in the technology database was correctly modeled;
- The lane change support system configurator was sufficiently usable;
- The validity of the design environment was sufficiently high.

Finally, the user was asked what he liked or disliked about the different designs that he configured and assessed. Also, he was asked which design he liked most. These questions didn't address the quality of the design environment. They were solely asked to not reveal the true purpose of the session. The questions that were asked during the interview are depicted in Appendix B.

5.1.4 Registering the behavior and opinions of users (activity 1.3)

The behavior of the users while using the design environment, and their opinions afterwards, were registered by audio/video recordings and by notes. In addition, the interactions with the lane change support system configurator (i.e. the design choices of users) were also automatically stored in data files.

5.1.5 Verifying the initial assumptions (activity 1.4)

Adaptations to the environment database

22 adaptations to the environment database were proposed. 17 of them complied to the guideline for accepting a *proposed adaptation* as a *required adaptation* (see section 3.2.5). This means that these adaptations didn't fall outside the scope of the design case, didn't regard removing superfluous elements that were considered relevant by others, didn't consider altering elements that were deliberately introduced to provoke specific behavior, didn't consider introducing elements that were already present in the scenarios, and were not based on expectations about others that appeared to be untrue. Table 5.4 depicts the required adaptations. They are ordered by the number of times they were proposed. For every adaptation, the participant(s) that proposed it is/are also listed. Table 5.5 shows the 5 proposed adaptations to the environment database that didn't comply to the guideline and therefore didn't become required adaptations.

<i>Adaptation</i>	<i>Description</i>	<i>Proposed by</i>
EDB.1	The enter lanes should be made longer	P1, P4, P9
EDB.2	Vehicles that overtake on the right side should be introduced	P1, P2, P9
EDB.3	The exit lanes should be made longer	P3, P4
EDB.4	The number of "hesitating vehicles" (i.e. vehicles that are continuously changing lanes) should be diminished	P5, P8
EDB.5	Trailing adjacent vehicles should not consequently offer the subject vehicle the opportunity to change lanes whenever the subject vehicle's turn signal is activated	P1
EDB.6	The traffic scenarios should be made longer so that there is more time to evaluate the configured support systems	P1
EDB.7	Vehicles that merge onto the highway with a high velocity should be introduced	P2
EDB.8	The navigation information should be provided earlier	P2
EDB.9	The number of "weird behaving vehicles" (suddenly braking, continuously changing lanes, large velocity fluctuations) should be diminished	P2
EDB.10	A three-lane highway that has faint lane markers under dark lighting conditions should be introduced, because it is difficult to estimate whether an overtaking vehicle is driving in the middle lane or in the left lane	P5
EDB.11	The braking lights of other vehicles should be brighter	P5
EDB.12	Emergency services (e.g. ambulance, police and firefighters) that are passing with high velocities should be introduced	P7
EDB.13	The number of vehicles that offer the opportunity to merge onto the highway by moving to the left lane should be increased	P8
EDB.14	A traffic jam that is present in both lanes of the highway should be introduced	P9
EDB.15	Vehicles that travel with extremely large speed differences should be introduced. (e.g. German-highway-like traffic scenarios)	P10
EDB.16	Ghost drivers (i.e. vehicles driving against traffic) should be introduced	P11
EDB.17	The benches that are placed right next to the highway should be removed, because they are totally unrealistic	P12

Table 5.4: Required adaptations to the environment database

<i>Adaptation</i>	<i>Description</i>	<i>Proposed by</i>
EDB.18	The lane drop should be announced earlier	P1, P12
EDB.19	The stretches with light traffic conditions are superfluous, because in those conditions, the support system cannot be properly evaluated	P2, P4
EDB.20	Lane change scenarios on rural roads - in which the support system gives support about oncoming traffic - should be introduced	P8, P11
EDB.21	The traffic jam is superfluous in testing a lane change support system, because during a traffic jam, no lane changes are performed	P1
EDB.22	A series of overtaking vehicles that drive at a very close distance from each other should be introduced	P1

Table 5.5: Proposed adaptations to the environment database that didn't become required adaptations

Adaptations to the technology database

16 adaptations to the technology database were proposed. Table 5.6 depicts the 8 of them that complied to the guideline for accepting a *proposed adaptation* as a *required adaptation* (see section 3.2.5). This means that these adaptations didn't fall outside the scope of the design case, didn't regard removing superfluous elements that were considered relevant by others, and were not based on expectations about others that appeared to be untrue. It also means that the added value of these adaptations justified the additional time required for generating a lane change support system design.

Table 5.7 shows the 8 proposed adaptations to the technology database that didn't comply to the guideline and therefore didn't become required adaptations.

<i>Adaptation</i>	<i>Description</i>	<i>Proposed by</i>
TDB.1	It should be possible to define conditions for support in the left adjacent lane that differ from the conditions for support in the right adjacent lane	P1, P2, P8, P9, P10, P12
TDB.2	It should be possible to define hybrid systems (i.e. combinations of informing, warning and/or control-intervention systems)	P1, P2, P4, P5, P11
TDB.3	It should be possible to render support in the mirrors	P5, P8, P10
TDB.4	It should be possible to render support in a Head-Up Display	P5, P8
TDB.5	It should be possible to only receive information when the system detects that the driver has the intention to change lanes	P3
TDB.6	The digit in the "digital number display" should be enlarged to make it more readable	P3
TDB.7	The "high volume option" should yield a less loud signal: it is currently too loud	P3
TDB.8	It should be possible to adjust (decrease) the amplitude of vibrations in case of tactile support	P8

Table 5.6: Required adaptations to the technology database

<i>Adaptation</i>	<i>Description</i>	<i>Proposed by</i>
TDB.9	The option to set the brightness of visual support is superfluous and should therefore be removed from the configuration panel: it should be bright by default	P3, P10
TDB.10	The option to automatically activate the support system above a certain velocity is superfluous and should therefore be removed from the configuration panel	P1
TDB.11	The option to choose for seeing a status icon is superfluous and should therefore be removed from the configuration panel: a status icon should be visible by default	P1
TDB.12	The option to select the speaker (front, rear) is superfluous and should therefore be removed from the configuration panel	P2
TDB.13	The options to set size, color and position (both horizontal and vertical) of visual support is superfluous and should therefore be removed from the configuration panel	P2
TDB.14	It should be possible to also configure lane departure warning assistance (LDWA) systems	P5
TDB.15	When users choose for thresholds based on velocity differences or the time-to-collision, they should be provided with a default value (e.g. 15 km/h or 2 s). After a first test, they should be enabled to alter this value. For the average user, it is too difficult to enter this value right away	P5
TDB.16	It should be possible to upload "personal pictures" or "personal sounds" to the vehicle in order to render those as support signals	P10

Table 5.7: Proposed adaptations to the technology database that didn't become required adaptations

The usability of the lane change support system configurator

All users judged the usability of the lane change support system configurator as high. However, 5 users proposed adaptations that would improve the usability even further (see Table 5.8).

<i>Adaptation</i>	<i>Description</i>	<i>Proposed by</i>
CON.1	Less text should be used while formulating the questions	P1
CON.2	Questions should be more concise	P2
CON.3	It should be possible to have a short summary of the choices made when the configuration is finished	P5
CON.4	The text-size should be enlarged	P8
CON.5	The radio-buttons should be enlarged	P10

Table 5.8: Proposed adaptations to the lane change support system configurator

The validity of the design environment

The design environment's level of validity was defined as "the expected level of similarity between opinions about the lane change support system designs in the design environment and opinions about those same designs in the real world". All users judged the validity of the design environment as high. If the various self-configured support systems would be installed in their own private vehicles, all users expected to have similar opinions about those systems. Moreover, all users had the feeling of driving in a real vehicle.

5.1.6 Updating the design environment (activity 1.5)

Updating the environment database

Most required adaptations to the environment database are related to the behavior of traffic participants. As a result of the reflection sessions, three new behavioral rules were created. The first rule enables participants to overtake on the right side. The second rule allows overtaking vehicles in the left adjacent lane to ignore the subject vehicle's turn signal and not give it the opportunity to change lanes. The third rule enables participants to offer other cars the opportunity to merge onto the highway by moving to the left lane. With these new behavioral rules, 50% of all participants were given "social behavior": these participants will never overtake on the right side, will offer the opportunity to change lanes when the turn signal is activated, and will offer the opportunity to merge onto the highway by moving to the left lane. The other 50% were given "less social behavior": these participants will overtake on the right side to maintain speed, will not offer the opportunity to change lanes when the turn signal is activated, and will not offer the opportunity to merge onto the highway by moving to the left lane. Furthermore, 25% of the participants that enter the highway were given a velocity that is 35 km/h faster than the subject vehicle. The other 75% enters with a velocity that is equal to the velocity of the subject vehicle. Finally, the driving behavior of participants was made less "hesitant" by switching off two specific behavioral rules (i.e. the rule that gives participants a preferred driving lane and the rule that gives a participant a new "random behavior" whenever it enters a new road element).

The set of traffic scenarios was based on the motivations for initiating a lane change maneuver. As a result of the reflection sessions, two motivations were added to the original overview: "emergency services" and "ghost driver" (see Table 5.9).

<i>Situation</i>	<i>Motivation</i>	<i>Description</i>
SI.1	Slow lead vehicle	Lane change to pass a slower vehicle
SI.2	Return	Lane change to return to preferred driving lane
SI.3	Enter	Lane change to enter a road (e.g. from on-ramp)
SI.4	Exit	Lane change to exit a road (e.g. to an off-ramp)
SI.5	Lane drop	End of driver's lane (e.g. road goes from 3 to 2 lanes)
SI.6	Added lane	Addition of a lane (e.g. road goes from 2 to 3 lanes)
SI.7	Tailgating vehicle	Another vehicle following too closely or approaching quickly
SI.8	Merging vehicle	Another vehicle entering the road (e.g. from an on-ramp)
SI.9	Obstacle avoidance	Maneuver to avoid an obstacle or rough road surface
SI.10	Emergency services	Maneuver to make way for passing emergency services
SI.11	Ghost driver	Maneuver to avoid a vehicle driving against traffic

Table 5.9: Possible motivations for initiating a lane change maneuver (updated version)

In the original set of traffic scenarios, there was a distinction made between situations that occur frequently and situations that occur less frequently. As a result of the reflection sessions, this classification was made more specific:

- Frequently occurring situations: these are situations that usually occur multiple times during a highway ride;
- Regularly occurring situations: these are situations that occur regularly during highway driving, but not necessarily during every highway ride;
- Rarely occurring situations: these are situations that occur so rarely that some drivers will never even experience them.

Table 5.10 presents the new classification.

		Urgency of a lane change maneuver	
		Essential lane change maneuvers	Nonessential lane change maneuvers
Frequency of occurrence	Frequently occurring situations	Sl.3. Enter Sl.4. Exit	Sl.1. Slow lead vehicle Sl.2. Return
	Regularly occurring situations	Sl.5. Lane drop	Sl.6. Added lane Sl.7. Tailgating* Sl.8. Merging vehicle*
	Rarely occurring situations	Sl.9. Obstacle avoidance Sl.11. Ghost driver	Sl.10. Emergency services*

Table 5.10: A new classification of motivations for initiating a lane change maneuver (motivations marked with * belong to the subcategory “social lane change maneuvers”)

Table 5.10 also makes a distinction between “essential lane change maneuvers” and “nonessential lane change maneuvers”. An essential lane change maneuver is a maneuver that - if it is not performed immediately – has a direct negative consequence for the driver (such as a collision or deviation from the desired route). A nonessential lane change maneuver has no direct negative consequences for the driver (other than possible loss of speed). Moreover, within the category of nonessential lane change maneuvers, a subcategory is discerned: social lane change maneuvers. These are lane change maneuvers primarily made for the benefit of others.

The updated environment database contains a set of six traffic scenarios. Every scenario contains the frequently occurring situations (situations Sl.1 to Sl.4). Situations Sl.5 to Sl.8 occur in pairs once every two scenarios. Each rarely occurring situation (situations Sl.9 to Sl.11) should only occur once within the total set of traffic scenarios. However, implementation of situations Sl.10 and Sl.11 is impossible with the current software architecture of the design environment. Therefore, the only rarely occurring situation that remains is situation Sl.9 (obstacle avoidance). Table 5.11 gives an overview of the “themes” of the six traffic scenarios and the situations from which they are made up.

Scenario	Theme	Frequently occurring situations	Regularly occurring situations	Rarely occurring situations
SC.1	Lane drop + added lane	Sl.1, Sl.2, Sl.3, Sl.4	Sl.5, Sl.6	
SC.2	Tailgating + merging vehicle	Sl.1, Sl.2, Sl.3, Sl.4	Sl.7, Sl.8	Sl.9
SC.3	Lane drop + tailgating	Sl.1, Sl.2, Sl.3, Sl.4	Sl.5, Sl.7	
SC.4	Added lane + merging vehicle	Sl.1, Sl.2, Sl.3, Sl.4	Sl.6, Sl.8	(Sl.10)
SC.5	Lane drop + merging vehicle	Sl.1, Sl.2, Sl.3, Sl.4	Sl.5, Sl.8	
SC.6	Added lane + tailgating	Sl.1, Sl.2, Sl.3, Sl.4	Sl.6, Sl.7	(Sl.11)

Table 5.11: Themes of the six new traffic scenarios and the situations from which they were made up (implementation of situations Sl.10 and Sl.11 is impossible with the current software architecture)

Table 5.12 specifies the new set of scenario attributes that, based on the reflection sessions, were expected to have an influence on the lane change behavior of a driver and on his needs for lane change support. The last column specifies the values of each attribute during the scenarios.

Attribute	Description	Values
A.1	Traffic intensity	{very light, light, medium, heavy, very heavy}
A.2	Number of driving lanes	{1, 2, 3}
A.3	Preferred speed of a traffic participant coming from behind the subject vehicle	A random number between 100 km/h and 170 km/h; Only in "very light traffic conditions": 70 km/h faster than the subject vehicle
A.4	Preferred speed of a traffic participant in front of the subject vehicle	A random number between 70 km/h and 140 km/h
A.5	Weather conditions	{sunny, foggy}

Table 5.12: Influential scenario attributes and their values (updated version)

Compared to the original set of influential scenario attributes (see Table 5.3), more variation exists. These changes are:

- In the original set of traffic scenarios, the traffic intensity could be light, medium or heavy. In the new set of traffic scenarios, the traffic intensity can also be very light (with speeding vehicles) or very heavy (resulting in a traffic jam);
- The preferred speed of a traffic participant coming from behind the subject vehicle was originally set at a random value between 20 km/h and 90 km/h faster than the subject vehicle. The minimum speed of the approaching vehicle was always at least 100 km/h. Now, the speed of the approaching vehicles is set at a random value between 100 km/h and 170 km/h. This change makes the traffic flow more stable and the behavior of the other participants less hesitant. Similarly, the preferred speed of a traffic participant in front of the subject vehicle is now set at a random value between 70 km/h and 140 km/h;
- Originally, the weather was always sunny. From the reflection sessions it is was determined that in order to simulate reduced visibility conditions, rain and darkness should be introduced into the scenario. Since both conditions cannot be simulated with the current software architecture, fog is selected to simulate reduced visibility.

Furthermore, the enter lanes now have a length of 200 m instead of 100 m. The exit lanes now have a length of 150 m instead of 100 m, and the benches next to the highway were removed. Navigation

information is now provided 550 m before an exit instead of 400 m. Each scenario has a length of 7 km instead of 6 km. However, the required adaptation to the braking lights of other vehicles (i.e. making them brighter) was not implemented: this is impossible with the current software architecture of the design environment.

Intermezzo

Written from the viewpoint of the researcher

The implemented adaptations to the environment database are meant to increase its quality. If successful, these adaptations will be noticed and appreciated by users during the verification sessions. This would indicate that the environment database indeed evolves into a better representation of the problem space of the design case. In order to get more evidence for the fact that the quality of the environment database is increased by asking users for feedback on its level of realism, two obviously unrealistic elements are introduced into the set of traffic scenarios: vehicles that drive through the crash barrier at the lane drop, and vehicles that crash into the traffic jam. Users noticing these elements, and bringing them up during the verification sessions, would indicate that the quality of the environment database is indeed increased by asking users for feedback on its level of realism.

Updating the technology database

In order to implement required adaptations TDB.1 (the possibility to define conditions for support in the left adjacent lane that differ from the conditions for support in the right adjacent lane) and TDB.2 (the possibility to define hybrid systems), the structure of the technology database was altered. Figure 5.12 depicts the new higher-level structure of the technology database.

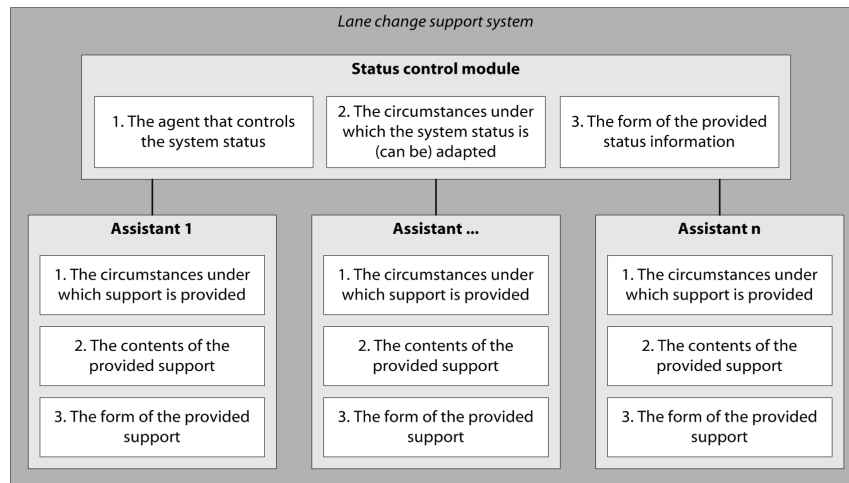


Figure 5.12: The new higher-level structure of the technology database

The most salient feature of the new structure is that a lane change support system is no longer considered as one integrated system, but rather as an assembly of independently functioning - and independently configurable – assistants (i.e. modules). The working principle of the support system as a whole is simply the sum of the working principles of the assistants. In addition to the set of assistants, there is a module that controls the system status.

As can be seen in Figure 5.12, the working principle of an assistant is determined by the “circumstances under which support is provided”, the “contents of the provided support”, and the “form of the provided support”. The “task set of the support system” and the “interface that renders the support” are no longer present in the technology database. From insights acquired during the reflection sessions follows that the task set of a support system (or rather, the task set of *an assistant*) is not an independent dimension. The task set is a higher-level term for the combination of the “circumstances under which support is provided” and the “contents of the provided support”. Similarly, the interface that renders the support is not an independent dimension, but rather an attribute of the “form of the provided support”.

Another important element in the new technology database structure is the status control module. The status control module activates or deactivates the support system (i.e. the set of assistants) as-a-whole. The working principle of the status control module is determined by the agent that controls the system status, the circumstances under which the status is (or can be) adapted, and the form of the provided status information.

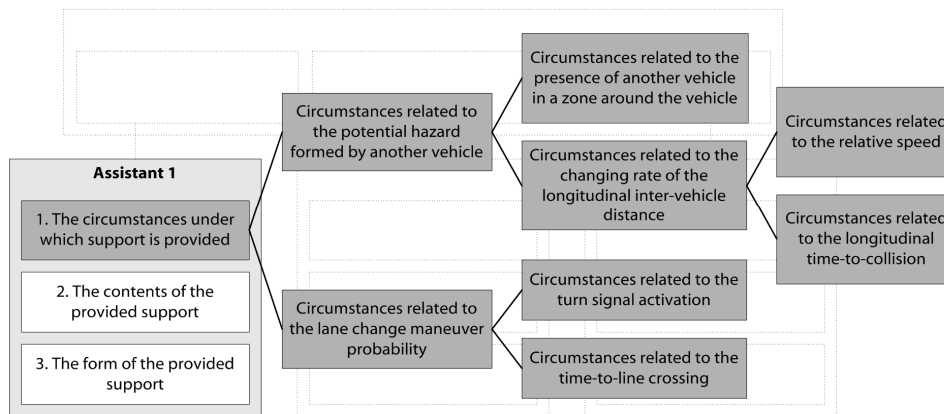


Figure 5.13: The new technology database structure for the circumstances under which an assistant provides support

Figure 5.13 depicts the new structure of the technology database for the circumstances under which an assistant provides support. These circumstances may be in relation to the potential hazard created by another vehicle and the lane change maneuver probability.

An assistant monitors a zone around the vehicle for the presence of another vehicle. A zone is located either at the left side or at the right side of the vehicle, thereby covering either the left or the right adjacent lane. A zone starts at the front bumper of the vehicle and has a certain length. This length determines how close an adjacent vehicle may approach before the assistant provides support concerning this vehicle. Figure 5.14.a shows an example of an assistant that monitors the left adjacent lane. Figure 5.14.b shows an example of an assistant that monitors the right adjacent lane. As it is drawn, in both pictures, vehicles A will be picked up by the respective assistants. Vehicles B, C and D will not be picked up. The length of a zone can be adapted by users.

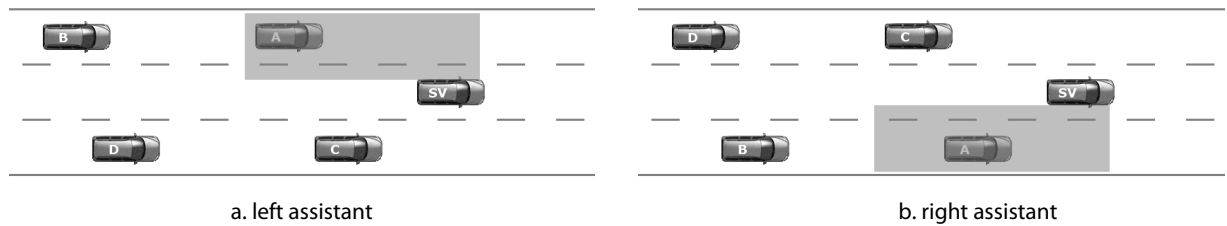


Figure 5.14: Examples of the zone that is monitored by an assistant (the length of a zone can be adapted by users)

When a vehicle is present in the monitored zone, it forms a potential hazard. However, an additional condition may be necessary before the assistant provides support concerning this vehicle. This condition is the changing rate of distance between the vehicles. This changing rate can be expressed by the relative speed between the two vehicles. For example, a condition may be that the assistant only provides support when the relative speed between vehicles is more than 10 km/h. Alternatively, the closing rate of the gap can be expressed by the longitudinal time-to-collision between the vehicles. The time-to-collision is calculated by dividing the distance between vehicles (i.e. the gap-size) by the relative speed between the vehicles. For example, a condition may be that the assistant only provides support when the longitudinal time-to-collision drops below 2 seconds.

In addition to the conditions concerning the potential hazard formed by another vehicle, conditions concerning the lane change maneuver probability (i.e. the probability that a lane change maneuver is going to be performed in the short term) may have to apply before the assistant provides support. This probability can be derived from monitoring the turn signal activation and/or monitoring the time-to-line crossing. For example, a condition may be that the assistant only provides support when the turn signal is activated. Alternatively or additionally, a condition may be that the assistant only provides support when the time-to-line crossing drops below 1 second.

Apart from turn signal activation and time-to-line crossing, a couple of other indicators could be used to discriminate between lane changes and straight ahead driving. For example, the brake status and turn signal timing may also be considered (Olsen, 2003). Within the original technology database, turn signal activation and time-to-line crossing were considered sufficiently accurate indicators. This assumption was based on findings by Hetrick (1997). The results from the reflection sessions did not alter this assumption.

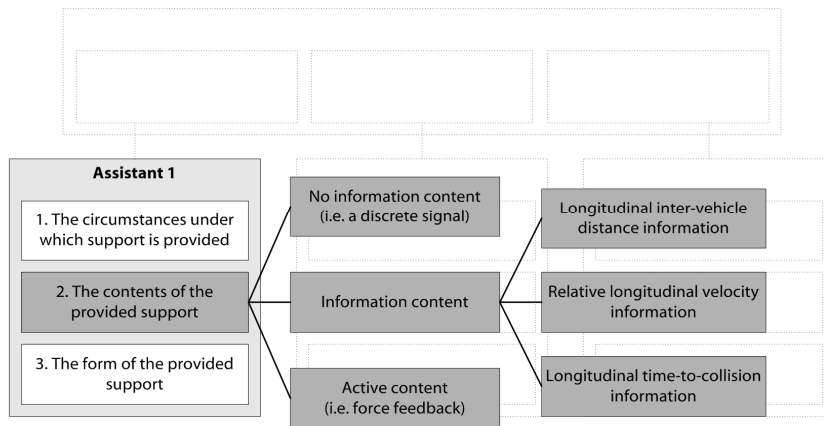


Figure 5.15: The new technology database structure for the contents of the support provided by an assistant

Figure 5.15 depicts the new structure of the technology database for the contents of the support provided by an assistant. When a support signal does not have “information content”, it is a discrete signal (i.e. a warning). A warning tells the driver that some specific circumstances apply. A support signal can also have “active content” (i.e. force-feedback). Force feedback not only tells the driver that some specific circumstances apply, but also gives the driver additional cues about what the proper reaction would be to evade the hazard. Finally, a support signal can have “information content”. When information is issued, the driver is not only told *that* some specific circumstances apply, but he is also given a more detailed indication about *what is going on* in the traffic environment. Useful information that a driver can be provided with is:

- The longitudinal inter-vehicle distance with a trailing adjacent vehicle, or;
- The relative longitudinal velocity with a trailing adjacent vehicle, or;
- The longitudinal time-to-collision with a trailing adjacent vehicle.

In addition to this information, other information could be communicated to the driver. For example, information about the number of trailing vehicles or about the type of vehicles (Cody, 2005). Because this information is considered less relevant, it was not made available to the user within the original technology database. The results from the reflection sessions did not alter this assumption.

A final piece of information that could be given to the driver is information about the absolute longitudinal velocity of a trailing adjacent vehicle. Within the original technology database, this possibility was actually offered to the users. However, during the reflection sessions, it appeared that this information content is not useful - even irrelevant - while performing lane change maneuvers. Therefore, this option is not integrated into the updated technology database.

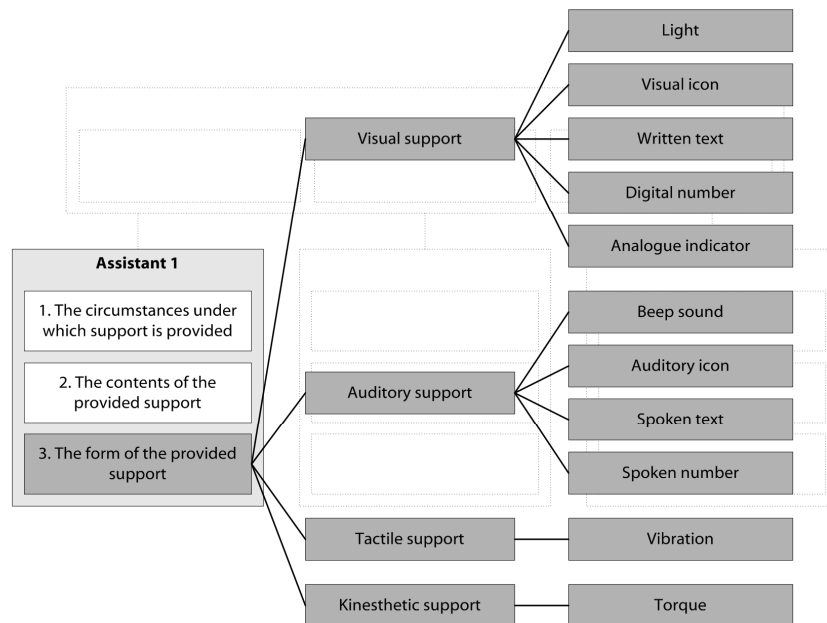


Figure 5.16: The new technology database structure for the form of the support provided by an assistant

Figure 5.16 depicts the new structure of the technology database for the form of the support provided by an assistant. The support modality can be visual, auditory, tactile or kinesthetic.

Visual support can be provided by a light, a visual icon, a written text, a digital number or an analogue indicator. It is rendered by one of the dashboard panels, by one of the mirrors or by the Head-Up Display. Auditory support can be provided by a beep, an auditory icon, a spoken text or a spoken number. It is rendered by one of the in-car speakers. Tactile support is always given in the form of a vibration, rendered by one of the vibrating elements in the driver’s seat. Another way of providing tactile support would be rendering vibrations in the steering wheel. However, within the original technology database, a vibrating element in the steering wheel was not present. Therefore, it was not offered to the user as an option. The results from the reflection sessions did not alter this. Kinesthetic support is always given in the form of torque, rendered on the steering wheel. Another way of providing kinesthetic support would be rendering a force on the pedals. Within the original technology database, this was considered not relevant for a lane change support system. Therefore, it was not offered to the user as an option. The results from the reflection sessions did not alter this assumption.

Although the form of the provided support is generally independent of its contents, a particular support form may not be compatible with particular support contents. The following constraints apply:

- A warning can only be expressed by a light, a visual icon, a written text, a beep, an auditory icon, a spoken text or a vibration;
- Information content can only be expressed by a light, a digital number, an analogue indicator, a beep, a spoken number or a vibration;
- Active content can only be expressed by a torque on the steering wheel.

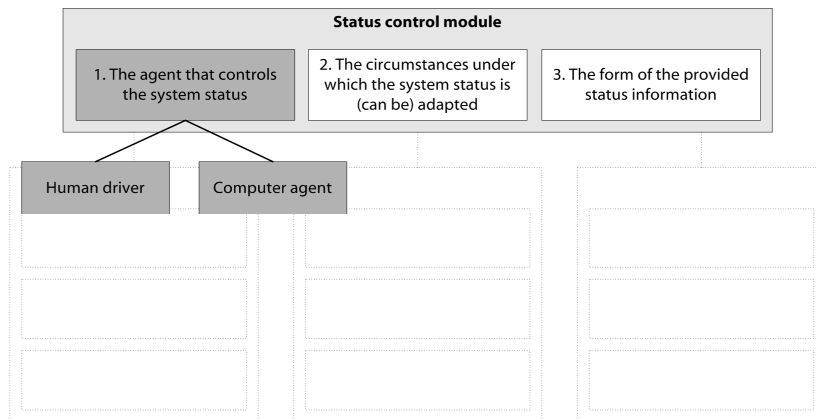


Figure 5.17: The new technology database structure for the agent that controls the system status

Figure 5.17 depicts the new structure of the technology database for the agent that controls the system status. It can either be the human driver or a computer agent. When the support system status is controlled by a computer agent, the driver has no direct influence on the support system status. When the support system status is controlled by the driver, he should have a means to give commands to the system. The most obvious way to give such commands is by a manually operated button. Alternatively, voice commands could be used to activate/deactivate the support system.

Within the original technology database, the possibility to adapt the system status by means of voice commands was not implemented. Voice recognition technology is not completely mature and therefore not reliable. Therefore, in case of a driver controlled system status, there should be the possibility to manually activate and deactivate the support system. That is why the default interfaces for activating and deactivating the support system were the buttons on the steering wheel. The results from the reflection sessions did not alter this assumption.

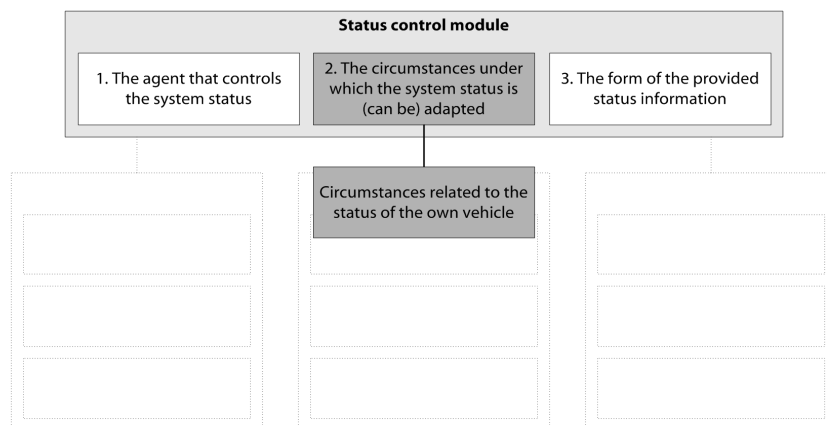


Figure 5.18: The new technology database structure for the circumstances under which the system status is (can be) adapted

Figure 5.18 depicts the new structure of the technology database for the circumstances under which the system status is (or can be) adapted. These regard the status of the subject vehicle.

In case of a driver controlled system status, the driver is able to adapt the status of the support system independently of the status of the subject vehicle (i.e. the driver can always adapt the system status). Alternatively, the driver is able to adapt the support system status when the status of the subject vehicle complies with a specific condition (i.e. when it is safe to activate or deactivate the system). Indicators for the safety level could be the engine status, the handbrake status, the vehicle’s velocity, its acceleration or its heading. For example, conditions could be that the engine should be off or that the vehicle’s velocity should be below 30 km/h in order to be able to manually adapt the system status. Such conditions would force the driver to make a conscious decision about the support system status prior to every ride.

In case the support system status is controlled by a computer agent, the support system could, for example, be automatically activated at engine start and automatically deactivated when the engine stops. Another example: the support system could be automatically activated above a certain velocity and automatically deactivated below a certain velocity. Alternatively, the support system status could also depend on the traffic environment, the driver state, or on the motivation for a lane change maneuver. For example, the system could be activated on the highway, whereas in urban and rural environments it is automatically deactivated. Or the support system could be activated when the driver is tired, whereas it is automatically deactivated when the driver is well-rested. Or the support system could be activated in case of overtaking maneuvers, whereas it is automatically deactivated during entering and exiting maneuvers. However, considering the current state of the art in sensor technology, reliable recognition of the traffic environment, the driver’s state as well as the lane change motivation is difficult, if not impossible. Therefore, these options are not incorporated into the model. Consequently, the circumstances under which the computer agent can adapt the support system status are only concerned with the status of the subject vehicle.

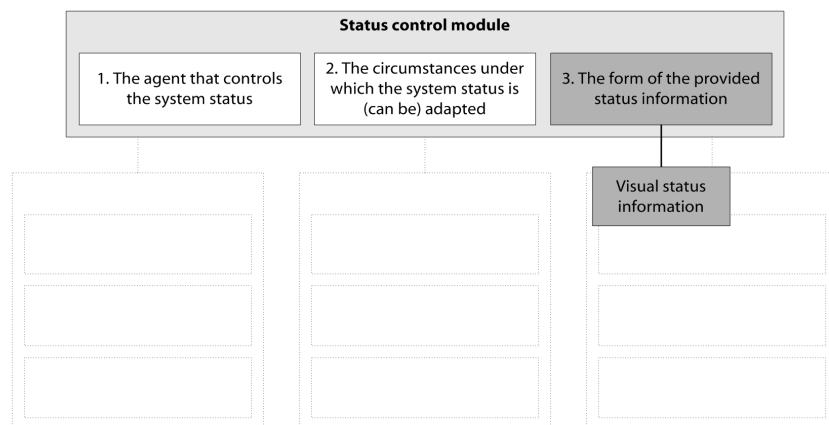


Figure 5.19: The new technology database structure for the form of the provided status information

Figure 5.19 depicts the new structure of the technology database for the form of the provided status information. Status information tells the driver whether the support system is active or not. Within the

original technology database, the driver was offered the option to not receive any status information. During the reflection sessions, users suggested that this option no longer be offered. Instead, status information will always be provided.

As depicted in Figure 5.19, status information is provided visually by default. Theoretically, it can also be provided through auditory or tactile means. Within the original technology database, status information was displayed via a standard visual icon rendered on the center dashboard panel (i.e. near the speedometer). Auditory and tactile status information were considered too intrusive and therefore considered irrelevant options to offer to the user. The results from the reflection sessions did not alter this assumption.

Intermezzo

Written from the viewpoint of the researcher

The implemented adaptations to the technology database are meant to increase its quality. If successful, these adaptations will be noticed and appreciated by users during the verification sessions. This would indicate that the technology database indeed evolves into a better representation of the solution space of the design case. In order to get more evidence for the fact that the quality of the technology database is increased by asking users for feedback on its level of completeness, P5 and P8 received an e-mail two days in advance of the verification session that informed them of existence of the LaneFX system (www.lanefx.com). This is an alternative way of giving blind spot support. It functions by means of an electronic motor that moves the side mirror outward to expose the blind spot. P5 or P8 bringing up the LaneFX system during the verification sessions would indicate that the quality of the technology database is indeed increased by asking users for feedback on its level of completeness.

Updating the lane change support system configurator

The results of the reflection session did not alter the basic idea behind the lane change support system configurator. All users judged its usability as high and none of the users seemed to have problems with completing the electronic questionnaire on the touch screen. Also, the functional architecture of a lane change support system (see Figure 5.10) remained unchanged. The only thing that was adapted was the formulation of the questions in the electronic questionnaire so that they match the new structure of the technology database. While reformulating the questions, the tips from users on how to improve the usability (see Table 5.8) were taken into account.

The new set of assumptions that was made in order to simplify and shorten the process of completing the electronic questionnaire is:

- If there is more than one trailing vehicle in the zone monitored by an assistant, issuance of information, a warning or a control-intervention is only based on the closest (i.e. the most dangerous) trailing vehicle. A similar assumption was made for the original design of the configurator. The results from the reflection sessions did not alter this;
- The threshold condition for determination of the lane change maneuver probability by monitoring the time-to-line crossing cannot be specified by the user. Within the original configurator, it was assumed that a lane change maneuver is soon to be made when the time-

- to-line crossing dropped below 1s. This value is based on findings by Van Winsum et al. (1999). The results from the reflection sessions did not alter this;
- Within the original configurator, characteristics related to the support system's availability were not taken into account in the circumstances under which support is provided. It was assumed that the support system is a permanently functioning system (i.e. the support system's functionality is permanently available). The results from the reflection sessions did not alter this;
 - In the original technology database, status control was part of the *circumstances under which support is provided*. Theoretically, in the new technology database, the status of every assistant could also be controlled independently. However, based on insights acquired during the reflection sessions, a user wants the system to be *completely active* or *completely inactive* during driving. Moreover, the possibility to control the status of every assistant independently would make the operation of the lane change support system more complex for a user. This increase of complexity is considered to outweigh the added value of the possibility to control the status of every assistant independently. Therefore, this option will not be incorporated into the configurator;
 - The circumstances under which the driver can adapt the support system status as well as the circumstances under which the computer agent adapts the support system status may depend on the status of the subject vehicle. Indicators for the vehicle's status could be the engine status, the handbrake status, the vehicle's velocity, its acceleration or its heading. It is expected that the engine status and the vehicle's velocity will be the best indicators for the vehicle's status. Therefore, these are the only options that will be incorporated into the configurator.

The initial lane change support system configurator did not allow a user to choose the mirrors or the HUD as interfaces for rendering visual support. Also, in the case of tactile support, users could not adjust the amplitude or frequency of vibrations. These restraints resulted from incompatibilities between the two software packages that control the simulations, and the limited availability of time and money to solve those. It appeared that all these limitations played a role during the reflection sessions in the sense that users proposed adaptations regarding the mirrors, the HUD and the vibrations. It is technically possible to solve these incompatibilities, but not within the timeframe and money allotted for this project.

Intermezzo

Written from the viewpoint of the researcher

During the process of updating the design environment, it appeared that insufficient means were available to implement adaptations EDB.10, EDB.11 EDB.12 EDB.16, TDB.3, TDB.4 and TDB.8. Especially simulation of dark lighting conditions (EDB.10), support in the mirrors (TDB.3), and support in a HUD (TDB.4) are considered relevant for the design of a lane change support system. Therefore, the question rises whether the design process should be stopped. The answer to this question is "no". The decision to not perform activities that have the potential to increase the quality of the end result because of limited time and money is very characteristic of design processes. In fact, during designing, such considerations and trade-offs are made all the time. Moreover, the design process is not performed to develop the most promising lane change support system, but to evaluate the new product design method. This aim is by no means obstructed by not implementing the adaptations in question.

5.1.7 Reflecting on the updated design environment (activity 1.6)

Participants

All users that were invited for the reflection sessions were invited again for verification sessions. The objective of the verification sessions was to test whether the required adaptations were correctly implemented. Similar to a reflection session, a verification session involved one user at a time, so twelve sessions were performed in total.

Instruction

At the beginning of a verification session, the user received a written instruction. The instruction explained that some changes had been made to the design environment compared to the last time that the user was invited. It stated that the verification session was aimed at obtaining opinions about the implemented adaptations.

The practicing phase

After the user read the instruction, he was offered the opportunity to re-familiarize himself with the design environment. Like the reflection sessions, the user first practiced with the driving simulator, then practiced with the lane change support system configurator, and finally with the support system in a traffic scenario.

Generating and testing designs

After the "practicing phase", the user was asked to configure a lane change support system design with which he expected to be satisfied. When the design was finished, the user was asked to use it within a simulated traffic scenario. At the end of the assessment, the user was asked an opinion about the design. This opinion was not used in the analysis, but it was asked so that the user does not have the feeling that configuration of the design was pointless. Next, the user was asked to configure a new design considerably different from the first design. This series of activities was performed twice. This was considered sufficient for a user to get a good image of the implemented adaptations to the design environment. Scenarios SC.1 and SC.2 (see Table 5.11) were offered. Together, these two scenarios contained all situations (i.e. SI.1 to SI.9; see Table 5.9).

Interview

At the end of the verification session, the user was interviewed. This interview had multiple stages:

- First, questions 4 to 9 from the original interview (see Appendix B) were re-asked to see whether the user answered more positively and had fewer remarks than the first time around;
- Secondly, about every implemented adaptation, the user was asked whether he noticed it or not;
- Thirdly, about every implemented adaptation, the user was asked whether he agreed with the change or not. The user could also have no opinion. In any case, the user was asked to provide a motivation for his answer. If the user had not noticed the specific adaptation, he was later confronted with that adaptation in the design environment so that he could still give an opinion;
- If the user answered that he didn't agree with a specific adaptation, he was asked whether the adaptation should not have been implemented or whether the adaptation had been implemented incorrectly;

- Finally, the user was confronted with all personally proposed adaptations and asked whether they had been implemented according to how he intended.

5.1.8 Registering the behavior and opinions of users (activity 1.7)

The behavior of the users while interacting with the updated design environment, and their opinions on these updates were registered by audio/video recordings and by notes. In addition, the interactions with the updated lane change support system configurator were automatically stored in data files.

5.1.9 Verifying the updates (activity 1.8)

Verifying the adaptations to the environment database

Table 5.13 presents the adaptations that were implemented into the environment database.

<i>Adaptation</i>	<i>Description</i>
EDB.1	The enter lanes are longer
EDB.2	Some vehicles overtake on the right side
EDB.3	The exit lanes are longer
EDB.4	The number of "hesitating vehicles" (continuously changing lanes) is diminished
EDB.5	There are now also overtaking vehicles that do not offer the opportunity to change lanes whenever the subject vehicle's turn signal is activated
EDB.6	The traffic scenarios are longer
EDB.7	Some vehicles merge onto the highway with a high velocity
EDB.8	Navigation information is provided earlier
EDB.9	The number of "weird behaving" vehicles (suddenly braking, continuously changing lanes, large velocity fluctuations) is diminished
EDB.13	The number of vehicles that offer the opportunity to merge onto the highway by moving to the left lane is increased
EDB.14	A traffic jam that is present in both lanes of the highway is present
EDB.15	There are now also vehicles that travel with extremely large speed differences
EDB.17	The benches next to the highway have been removed

Table 5.13: The adaptations that were implemented into the environment database

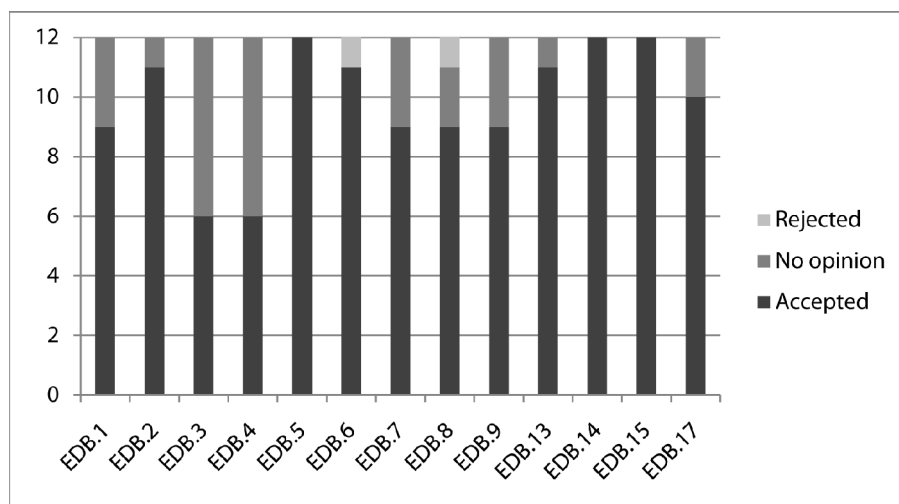


Figure 5.20: Number of users that accepted the adaptations to the environment database (per adaptation)

Figure 5.20 presents the users' opinions on the adaptations to the environment database. Generally, users accepted the adaptations or had no opinion about them. Only twice did a user reject an adaptation: P12 rejected EDB.6. He would rather have shorter scenarios with the possibility to test one or two additional lane change support system designs than longer scenarios that provide more insight into the functionality of a specific design. P2 rejected EDB.8. She remarked that the navigation information was provided so early that she tended to forget to take an exit. Remarkably enough, P2 was one of the people that proposed this adaptation. When asked whether this adaptation was implemented as intended, she confirmed. She concluded by saying that the timing of the navigation information was acceptable, but that it should possibly be repeated shortly before the exit.

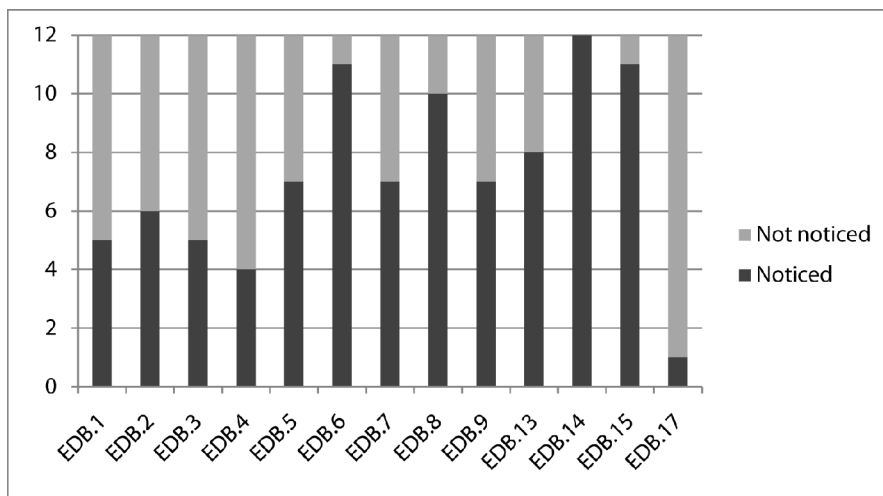


Figure 5.21: Number of users that noticed the adaptations to the environment database (per adaptation)

Per adaptation, Figure 5.21 presents the number of users that noticed the adaptations to the environment database. In comparison with Figure 5.20 it seems that, in general, the adaptations were more often accepted than noticed. Apparently, sometimes, a user does not notice an adaptation but still accepts it. When asked for the reason for accepting an adaptation (whether noticed or not), users generally said that the traffic simulation was more realistic: the environment database had become a better representation of the world relevant to a lane change support system.

Finally, all users confirmed the correct implementation of their own proposed adaptations to the environment database. The only exception is P8 who had no opinion about one of her proposed adaptations: EDB.4. The reason she gave was that she did not notice that the number of "hesitating vehicles" had diminished.

During the interview at the end of the verification session, questions 7, 8 and 9 from the original interview (see Appendix B) were re-asked to illicit new proposals for adapting the environment database. Table 5.14 displays the adaptations that remained after applying the guideline from section 3.2.5 to the proposals.

<i>Adaptation</i>	<i>Description</i>	<i>Proposed by</i>
EDB.23	Vehicles that merge onto the highway with a low velocity should be introduced	P1
EDB.24	A three-lane highway that has faint lane markers under dark lighting conditions should be introduced, because it is difficult to estimate whether an overtaking vehicle is driving in the middle lane or in the left lane	P5
EDB.24	Snow, night and rain should be introduced to the traffic scenarios	P11

Table 5.14: Required adaptations to the environment database (proposed during the verification sessions)

When comparing Table 5.14 with Table 5.4, it is clear that users have fewer remarks than during the reflection sessions. This indicates that the environment database is likely to converge to a “saturated state”. It is also worth noting that users repeated original remarks that were not implemented (EDB.24 = EDB.10). This indicates that the opinions expressed by users are consistent over time.

Intermezzo

Written from the viewpoint of the researcher

In order to get more evidence for the fact that the quality of the environment database is increased by asking users for feedback on its level of realism, two obviously unrealistic elements were introduced into the set of traffic scenarios: vehicles that drive through the crash barrier at the lane drop, and vehicles that crash into the traffic jam. During the interview, when asked for unrealistic elements in the environment database, four different users (P1, P2, P3, P12) mentioned the vehicles that drive through the crash barrier at the lane drop; three different users (P1, P6, P7) mentioned the vehicles that crash into the traffic jam. Their remarks indicated that the quality of the environment database is indeed increased by asking users for feedback on its level of realism.

Verifying the adaptations to the technology database

Table 5.15 presents the adaptations that were implemented into the technology database.

<i>Adaptation</i>	<i>Description</i>
TDB.1	It is now possible to define conditions for support for vehicles in the left adjacent lane that are different from those for the vehicles in the right adjacent lane
TDB.2	It is now possible to configure hybrid systems (i.e. combinations of informing, warning and/or control-intervention systems)
TDB.5	It is now possible to only receive information when the system detects that the driver has the intention to change lanes
TDB.6	The digit in the “digital number display” is enlarged for better readability
TDB.7	The “high volume option” now yields a softer signal

Table 5.15: The adaptations that were implemented into the technology database

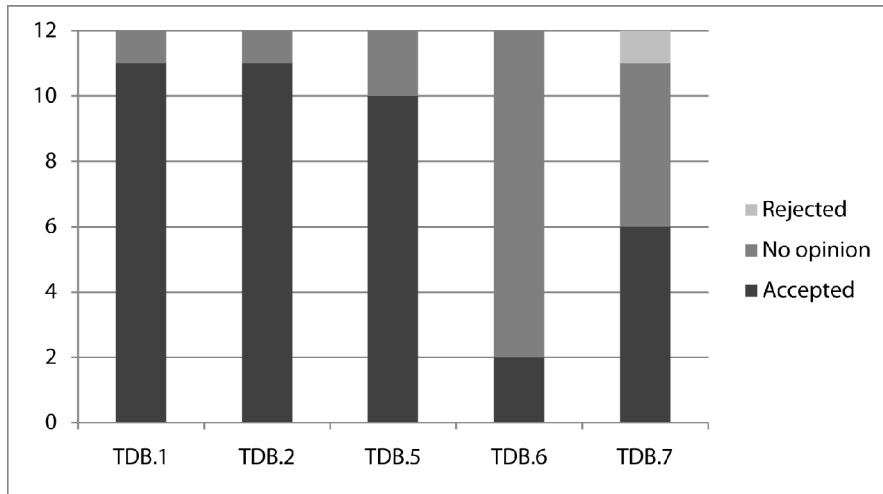


Figure 5.22: Number of users that accepted the adaptations to the technology database (per adaptation)

Figure 5.22 presents the opinions of users about the adaptations to the technology database. Except for P11, no user rejected an adaptation. P11 rejected TDB.7: he said that the original volume was better, because it should never be possible that sounds from the environment (radio, conversation, wind noise, etc.) drown out the auditory support signals.

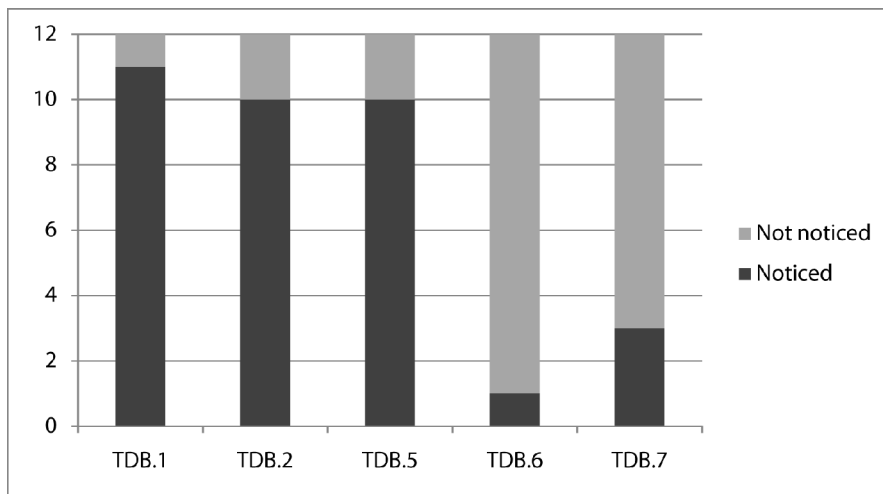


Figure 5.23: Number of users that noticed the adaptations to the technology database (per adaptation)

Per adaptation, Figure 5.23 presents the number of users that noticed the adaptations to the technology database. There is a strong correlation between noticing an adaptation and accepting the adaptation: when a user notices a specific adaptation he tends to accept it. Similarly, there is a strong correlation between not noticing an adaptation and having no opinion about the adaptation: when a user does not notice a specific adaptation, he tends to have no opinion about it.

TDB.1, TDB.2 and TDB.5 are significantly more often noticed and accepted than adaptations TDB.6 and TDB.7. This is probably due to the fact that the latter are related to very detailed attributes of the form of

the provided support, whereas TDB.1, TDB.2 and TDB.5 are related to the fundamental structure of the technology database. When asked for the reason for accepting TDB.1, TDB.2 and TDB.5, users generally said that the possibilities and the flexibility had increased: every imaginable support system can now be configured.

Finally, all users confirmed the correct implementation of all personally proposed adaptations.

During the interview at the end of the verification session, questions 4, 5 and 6 from the original interview (see Appendix B) were re-asked to illicit new proposals for adapting the technology database. Table 5.16 displays the adaptations that remain after applying the guideline from section 3.2.5 to the proposals.

<i>Adaptation</i>	<i>Description</i>	<i>Proposed by</i>
TDB.17	The time to line crossing threshold for assuming that the vehicle is about to leave the lane should be smaller than 1 s	P1
TDB.18	The possibility to have a beep that sounds only once per passing vehicle should be introduced to the technology database	P1

Table 5.16: Required adaptations to the technology database (proposed during the verification sessions)

When comparing Table 5.16 with Table 5.6, it is clear that users had fewer remarks than during the reflection sessions. This indicates that the technology database is likely to converge to a “saturated state”

Intermezzo

Written from the viewpoint of the researcher

In order to get more evidence for the fact that the quality of the technology database is increased by asking users for feedback on its level of completeness, P5 and P8 received an e-mail two days in advance of the verification session that informed them of existence of the LaneFX system. During the verification session, when asked for new elements to be added to the technology database, P8 proposed a side mirror that moves outward to sweep and expose the blind spot (similar to the LaneFX system). Her remark indicated that the quality of the technology database is indeed increased by asking users for feedback on its level of completeness.

Verifying the adaptations to the lane change support system configurator

Table 5.17 presents the adaptations that were implemented into the lane change support system configurator.

<i>Adaptation</i>	<i>Description</i>
CON.1	There is less text on the configuration panel
CON.2	The formulation of questions on the configuration panel is more concise
CON.3	It is now possible to have a short summary of the choices made when the configuration is finished
CON.4	The text-size on the configuration panel is larger
CON.5	The radio-buttons on the configuration panel are larger

Table 5.17: The adaptations that were implemented into the lane change support system configurator

All users accepted all adaptations. They said that it was easier to interact with the configuration panel. CON.3 was especially appreciated: users said that it was convenient that they were reminded of their design choices before the test drive. Two users (P1, P4) proposed a new adaptation: it should be possible to skip the configuration of less important attributes (such as brightness and size of a visual actuator) by simply loading default settings.

5.1.10 Performing another iteration (activity 1.9)

The verifications session showed that the design environment improved significantly. However, the adaptations that were proposed during the verification sessions indicate that it can be improved even further. This implies that another iteration should be performed, which would start with implementing the newly proposed adaptations and inviting a new group of users to reflect on the design environment.

Intermezzo

Written from the viewpoint of the researcher

Performing another iteration would undoubtedly result in an even better representation of the problem-solution space of a lane change support system. However, the design process is not performed to develop the most promising lane change support system, but to evaluate the new product design method. The available resources (i.e. time and money) can be better spent on performing the second phase of the design process than on another iteration of the first phase. Therefore, the first phase of the design process is now concluded, and the second phase is started.

5.2 Performing the second phase of the design process

5.2.1 Introduction

This section describes the second phase of the design process that emerged as a result of applying the new product design method to the design of a lane change support system. According to the descriptions in section 3.1.4, this phase consists of performing activities 2.1 to 2.7. However, the first simplification in section 4.2.8 made that activity 2.2 was not performed. Consequently, the descriptions in this section only concern activities 2.1, 2.3, 2.4, 2.5, 2.6 and 2.7.

5.2.2 Generating and testing candidate designs (activities 2.1 and 2.3)

Participants

48 users were invited for a design session in which they generated lane change support system designs by adapting technology parameters (activity 2.1). Every generated design was immediately tested in a traffic scenario, after which the user was asked to reflect on the degree to which the design fulfilled his needs (activity 2.3). As a result of the first simplification (see section 3.1.4), users were not offered the opportunity to generate their own traffic scenarios (activity 2.2). Instead, during the design sessions, they were confronted with the traffic scenarios that emerged from the first phase of the design process.

A design session involved one user at a time, for a total of 48 design sessions. All users had at least two years of driving experience and drove at least 5.000 km per year. Literature findings suggested that a user's preferences with regard to a lane change support system (and driver support systems in general) may be correlated with age and driving style (e.g. Ward et al., 1996; Hoedemaeker & Brookhuis, 1998; De Waard et al., 1999; Donmez et al., 2006). Therefore, the total group of users was divided according to these two scales. This resulted in a group of 24 "young users" versus a group of 24 "old users", and a group of 24 "aggressive users" versus a group of 24 "non-aggressive users". In this division, "young users" are younger than 35, whereas "old users" are 35 or older. "Aggressive users" have a high score on the needs and driving style questionnaire (NDS) that was developed by Hoedemaeker (1999), whereas "non-aggressive users" have a low score on the NDS. Both the "young group" and the "old group" consisted of 18 male users and 6 female users. The "aggressive group" consisted of 19 male users and 5 female users, whereas the "non-aggressive group" consisted of 17 male users and 7 female users. While dividing the users over the groups, a correlation between age and driving style was found: the group of "aggressive users" consisted of 16 "young users" and 8 "old users"; the group of "non-aggressive users" consisted of 16 "old users" and 8 "young users".

Instruction

At the beginning of a design session, the user received a written instruction that explained that the goal of the session was to specify the design that would best comply with personal preferences.

The practicing phase

Subsequently, the user was offered the opportunity to become familiar with the design environment. This "practicing procedure" was identical to the practicing procedure during the first phase of the design process (see section 5.1.3).

Generating and testing designs

After the practicing phase, the user was asked to configure a lane change support system, experience this design in a specific traffic scenario, and finally assess the design. Assessing a design took place by asking the user for positive and negative system characteristics (in the form of open questions). A user was free to choose the number of design-experience-assessment cycles, with a minimum of 4 and a maximum of 6 cycles. Based on the insights acquired during the first phase of the design process, 4 cycles were considered the minimum required for a user to obtain a good idea of the technical possibilities and of his preferences. At the same time, it was observed that after 5 cycles almost all users said they knew what they prefer. Occasionally, a user would indicate that he would have needed a 6th iteration to come to a final conclusion.

Interview

At the end of the design session, the user was interviewed. This interview was aimed at getting a final opinion about the designs that were created. During the interview, the user was also asked to specify the "most attractive system". The questions that were asked during the interview are depicted in Appendix C.

5.2.3 Registering the behavior and opinions of users (activity 2.4)

The behavior of users while generating and testing candidate designs, and the opinions of users while reflecting on them, was registered by audio/video recordings and by notes. In addition, the interactions

with the lane change support system configurator (i.e. the design choices of users) were also automatically stored in data files.

5.2.4 Specifying attractive lane change support system designs for each user (activity 2.5)

Creating personal reports

For every user, the raw data collected during the design sessions were converted into a “personal report”. Each personal report contained four sections:

1. Personal information of the user (age, driving style, gender);
2. A complete specification of the lane change support system design that was marked “most attractive” by the user;
3. An explanation for why the specified system was so attractive for the user. This explanation also detailed system features that were not present in the “most attractive system”, such as reasons for why certain system features are considered undesirable;
4. A brief description of the user’s behavior during the design sessions with a special attention to striking incidents, actions and behaviors.

These four sections were divided over two pages. The first page of each personal report was filled with objective information (i.e. personal information and a specification of the most attractive system). The second page contained subjective information (i.e. an explanation to the specification and an overview of striking incidents, actions and behaviors). The information stored in the personal reports was factually correct and verifiable. In other words, an independent observer would be able to trace back all information that was presented in the personal reports to the original raw data sources. By means of example, the personal report of P1 is depicted in Appendix D.

Checking the consistency of the personal reports

For every user, the specification of the system design that was considered “most attractive” (section 2 of the personal report) was compared with the explanations given and the behaviors observed (sections 3 and 4 of the personal report, respectively). The personal reports of 30 users did not contain any inconsistencies. This means that, for those 30 users, there is no reason to assume that the specified “most attractive system” will not function satisfactorily in all scenarios for this user.

The other 18 personal reports contained a total of 24 inconsistencies. These could be attributed to three different causes: “limited possibilities of the technology database and the lane change support system configurator”, “different preferences in different scenarios”, and “slips during the design sessions”. Table 5.18, Table 5.19 and Table 5.20 specify the inconsistencies that were found in the personal reports for the respective causes. Every table comes with a description of how the inconsistencies were managed so that an attractive lane change support system design could be specified for each user.

<i>ID</i>	<i>Objective information</i>	<i>Subjective information</i>
INC.1	P2's "most attractive system" automatically activates and deactivates at 80 km/h.	P2 wants different conditions at which the six different assistants that are present in his "most attractive system" should automatically activate/deactivate.
INC.2	P5's "most attractive system" has discrete thresholds for auditory signals: when a certain threshold is crossed, the pitch of the signal is suddenly increased.	P5 wants the thresholds for auditory signals to be "continuous" instead of "discrete": volume, pitch and repetition frequency of an auditory signal should be increased seamlessly as hazards become more serious. Even if there is no danger at all, P5 desires to hear a very faint beep in the background when his turn signal is activated or when he crosses the line markers.
INC.3	P9's "most attractive system" automatically activates at engine start.	P9 distinguishes "safety assistants" from "comfort assistants". Safety assistants save the driver from an accident and should always be active. Comfort assistants increase driving comfort, but it should be possible to manually switch them off.
INC.4	P18's "most attractive system" automatically activates at engine start.	P18 wants hybrid status control: the system should be activated every time the engine starts, but there should also be the possibility to manually activate and deactivate it.
INC.5	P20's "most attractive system" automatically activates and de-activates at 50 km/h.	P20 wants the system to have automatic recognition of the road type (via GPS) so that it functions on highways and in cities, but it can be switched off in traffic jams on the highway.
INC.6	P21's "most attractive system" has manual status control.	P21 wants hybrid status control: the system should be activated every time the engine starts, but there should also be the possibility to manually activate and deactivate it.
INC.7	P21's "most attractive system" only monitors one adjacent lane on every side of the vehicle (so 2 lanes in total).	P21 wants the system to monitor two adjacent lanes on every side of the vehicle (so 4 lanes in total).
INC.8	P30's "most attractive system" automatically activates at engine start.	P30 wants hybrid status control: the system should be activated every time the engine starts, but there should also be the possibility to manually activate and deactivate it.
INC.9	P33's "most attractive system" has visual signals rendered on the dashboard panel.	P33 wants visual signals to be rendered in the mirrors.
INC.10	P33's "most attractive system" has manual status control.	P33 wants the system to be coupled to GPS so that it can be automatically switched on on roads with more than one lane in the same direction and switched off otherwise. Additionally, there should be the possibility to manually activate and deactivate the system.
INC.11	P35's "most attractive system" only renders an "unsafe tone" when it is unsafe.	P35 also wants to receive a "safe tone" when an intended lane change maneuver would be safe.
INC.12	P35's "most attractive system" consists of assistants that function mutually independent.	P35 wants a state estimation algorithm that combines the functionality of multiple – partly overlapping – assistants into one signal.
INC.13	The monitored zones in P42's "most favorite system" end at the front bumper.	P42 wants the monitored zones to be slightly prolonged so that they also cover parts of the adjacent lanes that are located in front of the front bumper. P42 wants vehicles that drive slightly in front of the vehicle to be noticed by the system.
INC.14	P43's "most attractive system" automatically activates and deactivates at 50 km/h.	P43 wants hybrid status control: the system should be automatically activated and deactivated at 50 km/h, but there should also be the possibility to manually activate and deactivate it.
INC.15	P44's "most attractive system" automatically activates and deactivates at 60 km/h	P44 wants hybrid status control: the system should be automatically activated and deactivated at 60 km/h, but there should also be the possibility to manually activate and deactivate it

Table 5.18: Inconsistencies attributed to limited possibilities of the technology database and the lane change support system configurator

The inconsistencies in Table 5.18 were analyzed for recurring themes. According to the guideline in section 3.2.13, every inconsistency that is not part of a recurring theme must be managed by removing the subjective information from the personal report of the user in question. However, when a recurring theme is discovered (i.e. when two or more inconsistencies relate to the same system aspect), the personal reports of the users in question must be extended with a note. The original specifications of these users' "most attractive systems" remain intact. However, the notes reflect the probable choice of the users in case the desired system functionality would have been available in the technology database during the design sessions.

Nine inconsistencies in Table 5.18 are related to the status control module. From these inconsistencies, the following desired status control module functionalities were derived:

- Hybrid status control: a combination of two or more different status control algorithms that work together;
- Independent activation and deactivation of the different assistants in the support system;
- Automatic activation and deactivation based on the road type.

The personal reports of the users in question were made consistent by extending them with a note about the probable choice of the users in case these functionalities would have actually been available during the design sessions.

The six inconsistencies in Table 5.18 that are not related to the status control module are about various different system elements. For the six users in question, the desired system functionality was not converted into a note in the objective part of their personal reports. For consistency, the subjective information was removed from their personal reports.

<i>ID</i>	<i>Objective information</i>	<i>Subjective information</i>
INC.16	The monitored zones in P4's "most attractive system" have a fixed length.	P4 wants the length of the monitored zones to be dependent upon the engine power of the car. The reason for this is that the more powerful the car, the more easily speed differences are bridged and – as a consequence - the more easily she can merge into small inter-vehicle gaps.
INC.17	P24's "most favorite system" contains an assistant that warns him when a vehicle overtakes him on the left with more than 10 km/h velocity difference and – at the same time – he has the intention to change lanes.	Whether or not P24 desires a similar assistant for the right side of the vehicle depends on the country in which he is driving. When driving in Europe, he wouldn't need a similar assistant for the right side of the vehicle, because he is very rarely passed on the right side. However, because it is much more common to be overtaken on the right side on US interstates, his preferences would be different in the USA.
INC.18	The auditory warning sounds in P25's "most attractive system" have a fixed volume.	P25's wants the volume of the auditory warning sounds to be dependent on the volume of the radio.
INC.19	The monitored zones in P34's "most attractive system" have a fixed length.	P34 wants the monitored zone on the left side of the vehicle to be longer on German highways than on Dutch highways. He considers a monitored zone that covers 50 m of the left adjacent lane behind the front bumper to be sufficient for Dutch highways. However, due to the higher speed differences on German highways, the risk of the system reacting too late is unacceptably high with such a zone length.

<i>ID</i>	<i>Objective information</i>	<i>Subjective information</i>
INC.20	The parameters of P42's "most attractive system" have a fixed value.	P42 wants the system to have different parameters on German highways compared to Dutch highways. In Germany, the monitored zone should be longer than 50 m (which is a suitable value for Dutch highways). Also, in Germany, the time-to-collision threshold before receiving a signal should be higher than 3 s (which is a suitable value for Dutch highways). The reasoning is that, on German highways, absolute speeds are higher and, therefore, "safe inter-vehicle gaps" are larger.
INC.21	The parameters of P42's "most attractive system" have a fixed value.	P42 wants the system to have different parameters in urban traffic: the monitored zone should be shorter than 50 m and the time-to-collision threshold before receiving a signal should be lower than 3 s (which are suitable values for Dutch highways). The reasoning is that, in cities, absolute speeds are lower and, therefore, "safe inter-vehicle gaps" are smaller.

Table 5.19: Inconsistencies attributed to different preferences in different scenarios

From the inconsistencies in Table 5.19 follows that the following "scenario characteristics" may correlate with the preferred "lane change support system characteristics":

- Road type;
- Engine power of the vehicle;
- Frequency of being overtaken on the right side of the vehicle in a specific country;
- Frequency of being overtaken with exceptionally high speed differences in a specific country;
- Radio volume.

The personal reports of the users in question were made consistent by extending the specification of the "most attractive system" with a specification of the scenarios in which this system is attractive to the user. Furthermore, in each personal report, one or more alternative systems were specified that, together with the "most attractive system", are expected to function satisfactorily in all scenarios for the user. Each alternative system also comes with a specification of the scenarios in which it is expected to be attractive for the user.

<i>ID</i>	<i>Objective information</i>	<i>Subjective information</i>
INC.22	P3's "most attractive system" gives support when vehicles overtake him on the right with more than 30 km/h speed difference.	P3 wants support for all vehicles that overtake him on the right side (i.e. independent of the speed difference).
INC.23	P18's "most attractive system" has a monitored zone of 20 m on the left side of the vehicle.	P18 wants a monitored zone on the left side of the vehicle that is shorter than 20 m.
INC.24	P27's "most favorite system" has beeps that do not contain additional time-to-collision information.	P27 wants beeps that contain additional time-to-collision information.

Table 5.20: Inconsistencies attributed to slips during the design sessions

Three inconsistencies were attributed to slips during the design sessions (see Table 5.20). A slip is defined as "a discrepancy between the user's behavior and an verbally-expressed preference that was not noticed or not resolved during the design session". The personal reports of the users in question

were made consistent by assuming that the objective specification of the “most attractive system” was true and that the subjective verbally-expressed preference was false. Accordingly, the subjective information that was assumed to be false was removed from the personal reports. Since there are only a few personal reports that contain such inconsistencies, and since these are only about single aspects of the system, this omission was not expected to have a large impact on the results of the design process.

Result

Updated versions of the personal reports were created. As before, each personal report reflects the user’s preferences for a lane change support system. But in contrast to earlier, the subjective information within each personal report is now guaranteed to be fully consistent with the objective information. There are 43 personal reports that specify one lane change support system design that is attractive to the user in question and that is expected to function satisfactorily in all scenarios for that user. There are 5 personal reports that specify a limited amount of lane change support system designs that are attractive to the user in question and that together are expected to function satisfactorily in all scenarios for that user. For every design, these 5 personal reports also contain a specification of the scenarios in which the user expects the specific design to be attractive.

The specifications of the “most attractive system” in all personal reports were compared with each other. It appeared that none of the specifications were identical. In other words, 48 different users have created 48 different “most attractive systems”. Sometimes, differences between users’ specifications can be characterized as “detailed differences”. However, within the total set of 48 personal reports, there are many “fundamental differences”: system features that are considered “fantastic” by the one user are considered “horrible” by the other user (and vice versa). This is, for example, the case for tactile support, kinesthetic support and the continuous issuance of beeps to indicate the presence of other vehicles. It is therefore impossible to specify one single lane change support system design that is attractive to all users. Accordingly, activity 2.6 (organizing the generated information into a hierarchy that is meaningful from a user’s perspective) and activity 2.7 (finding a compromise between the preferences of all stakeholders) should be performed.

5.2.5 Organizing the information into a hierarchy (activity 2.6)

Creating a coding system

A random sample of three personal reports was used to make a first assumption about the set of codes from which the coding system should be made up. For every statement in these personal reports, one or more codes were defined. The defined codes were combined into a list. A trained rater was asked to assign one or more codes from the list to every statement in the sample of personal reports. The average inter-rater reliability per statement (the percentage of the assigned keywords per statement that matches between the designer and the rater) appeared to be 61%. This was considered too low to accept the coding system as a definition of relevant themes.

Therefore, a new coding system was created. This was done from a discussion about the rating results. Coding a new sample of three personal reports yielded an average inter-rater reliability of 73% per statement. After implementing some minor adaptations to the coding system, a sample of ten personal reports was coded. This resulted in an average inter-rater reliability of 75% per statement, which is sufficient to accept the coding system as a definition of relevant themes.

The coding system consists of three main categories:

1. Desirable/undesirable system features;
2. Reasons for considering a system feature to be desirable/undesirable;
3. Circumstances under which a system feature is considered desirable/undesirable.

The complete coding system is depicted in appendix E.

The hierarchy of information

The coding system was used to code the subjective information in all 48 personal reports. This was done by making use of AtlasTI (www.atlasti.com), a software package for qualitative data analysis. The coding system was also used to re-organize the objective information into categories that are meaningful from a user's perspective.

Figure 5.24 depicts the relative frequency at which codes from each of the three main categories of the coding system were assigned during the coding process.

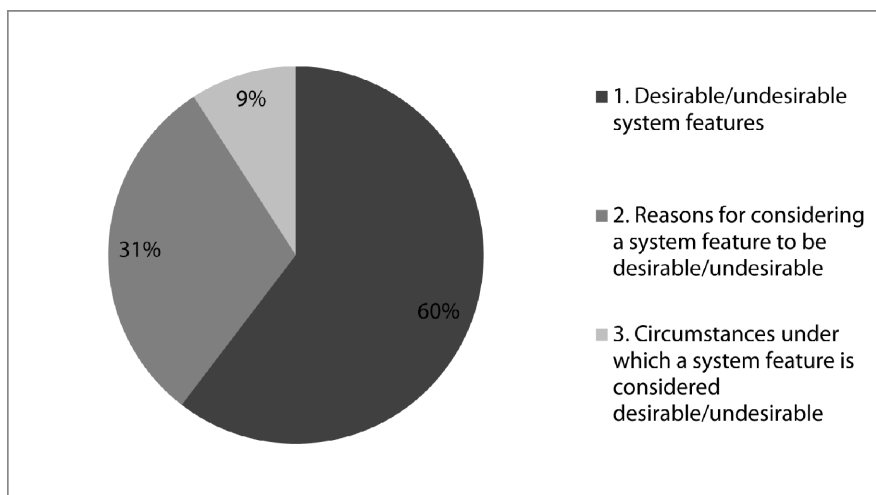


Figure 5.24: Relative frequency at which codes from each of the three main categories were assigned during the coding process

Figure 5.24 implies that users mostly focused on system features that they considered desirable or undesirable (60%). Often (but not always), users also gave reasons for considering a specific system feature to be desirable/undesirable (31%). Finally, users only incidentally specified circumstances under which a system feature is considered desirable/undesirable (9%).

For every subcategory of the coding system, Table 5.21 depicts the frequencies with which statements that are assigned a code from a specific subcategory are also assigned a code from another specific subcategory. These frequencies are relative to the total times the code is assigned. They indicate the relationships between the themes from a user's perspective. For example, 31% of the statements that are assigned the code "1.1 overall system functionality" are also assigned the code "1.3 support signal modality"; 38% of the statements that are assigned "1.3 support signal modality" are also assigned "1.1

overall system functionality". The different shades of grey in Table 5.21 are used to increase readability. They indicate the "strength" of the relationships. They run from light grey for weak relationships to dark grey for strong relationships.

Statements about:	... are also about (%):												
	1.1 Overall system functionality	1.2 Criteria for issuance of support	1.3 Support signal modality	1.4 Additional information content of signals	1.5 Actual support signal attributes	1.6 Perceived support signal attributes	1.7 Status control module functionality	1.8 Perceived support system attributes	2.1 Pleasant feelings and emotions	2.2 Unpleasant feelings and emotions	2.3 Desirable behavioral changes	2.4 Undesirable behavioral changes	3.1 Actual scenario attributes
1.1 Overall system functionality	25	31	5	19	1	2	4	32	22	5	2	8	13
1.2 Criteria for issuance of support	60	29	4	20	1	2	7	35	25	3	2	12	17
1.3 Support signal modality	38	15	7	45	1	1	8	41	44	4	4	10	13
1.4 Additional information content of signals	42	14	49	51	0	0	2	49	35	9	5	7	14
1.5 Actual support signal attributes	47	21	90	15	2	1	8	54	46	6	4	14	14
1.6 Perceived support signal attributes	83	33	50	0	50	0	17	50	33	17	0	0	50
1.7 Status control module functionality	11	5	7	0	4	0	7	47	18	0	0	42	4
1.8 Perceived support system attributes	30	20	46	2	22	2	8	54	34	2	4	14	14
2.1 Pleasant feelings and emotions	43	19	44	8	29	1	10	10	23	7	2	13	13
2.2 Unpleasant feelings and emotions	33	16	55	6	29	1	4	7	27	2	4	13	10
2.3 Desirable behavioral changes	61	18	46	14	32	4	0	4	68	18	4	7	7
2.4 Undesirable behavioral changes	30	13	52	9	26	0	0	9	22	39	4	9	17
3.1 Actual scenario attributes	31	21	34	3	23	0	28	8	39	33	2	2	6
3.2 Perceived scenario attributes	57	32	48	8	25	4	3	9	43	30	3	5	6

Table 5.21: Relative frequencies with which statements that are assigned a code from a specific subcategory are also assigned a code from another specific subcategory

From Table 5.21 follows that:

- All system features are more often associated with "pleasant feelings and emotions" than with "unpleasant feelings and emotions", except for the system feature "support signal modality". This suggests that, of all system features, the "support system modality" is the most important potential source of "unpleasant feelings and emotions";
- Similarly, all system features are more often associated with "desirable behavioral changes" than with "undesirable behavioral changes", except for the "support signal modality". Another exception is "perceived support system attributes". This suggests that, of all system features, the "support system modality" and the "perceived support system attributes" are the most important potential sources of "undesirable behavioral changes";

- All system features have rather strong relationships with “overall system functionality”, “criteria for issuance of support”, “support signal modality” and “actual support signal attributes”, except for the system feature “status control module functionality”. This suggests that users consider the “status control module functionality” to be relatively independent from other system features;
- Generally, users do not focus on circumstances under which a system feature is considered desirable/undesirable. However, two exceptions to this are “perceived support signal attributes” and the “status control module functionality”. This suggests that – from a user’s perspective – preferences for these two system features are more strongly related to the circumstances than are the preferences for other system features;
- Finally, and unsurprisingly, when users consider “desirable behavioral changes”, they also often mention “pleasant feelings and emotions”, and when users consider “undesirable behavioral changes”, they also often mention “unpleasant feelings and emotions”.

5.2.6 Specifying a compromise between the preferences of all stakeholders (activity 2.7)

A compromise between the preferences of all users

For every system feature present in the coding system, an analysis was made of how often users desire it (i.e. how often the system feature appears in the set of “most attractive systems”). Furthermore, there was an analysis made of correlations between desired system features (in the form of “IF the user prefers value A for design parameter p THEN he is likely to prefer value B for design parameter q”). It was also analyzed how personal characteristics of a user (i.e. a user’s age and driving style) correlate with his preferences. Finally, there was an analysis made of users’ reasons for considering system features to be desirable/undesirable, and how this relates to the circumstances under which a lane change support system is used.

These analyses showed that there are large individual differences between users’ preferences for a lane change support system. These differences were not only about design parameters that users generally considered as “details” (such as the “color of a visual signal”), but they were often about design parameters that were generally considered to have an “essential influence” on the overall behavior of the system (such as the “criteria under which support is issued”, or the “modality of the issued support”). Quite often, these differences were insurmountable in the sense that what one user finds “fantastic” another user finds “horrible” (and vice versa).

For example, some users said something along the lines of:

“The control-interventions on the steering wheel are fantastic: they feel very intuitive.”

But there were also quite a few users who said:

“The control-interventions on the steering wheel are horrible: they scare me and they make me want to counter-steer.”

Furthermore, it appeared that users have very different reasons for considering certain system features desirable or undesirable. This makes it so that they solve the trade-offs between arguments *for* and arguments *against* certain system features in very different, and individual, ways.

For example, there were users who said something along the lines of:

“A warning sound is very conspicuous: I always hear it. A warning light on the dashboard would be useless, because I’m already busy with looking at the traffic around me.”

But there were also users who said:

“A warning light on the dashboard is very conspicuous: I see it clearly in my peripheral field of vision. A warning sound would be useless, because it would drown in the background of driving sounds, music, and conversations.”

For two pairs of system features, correlations between desired system features were found (see Figure 5.25 and Figure 5.26).

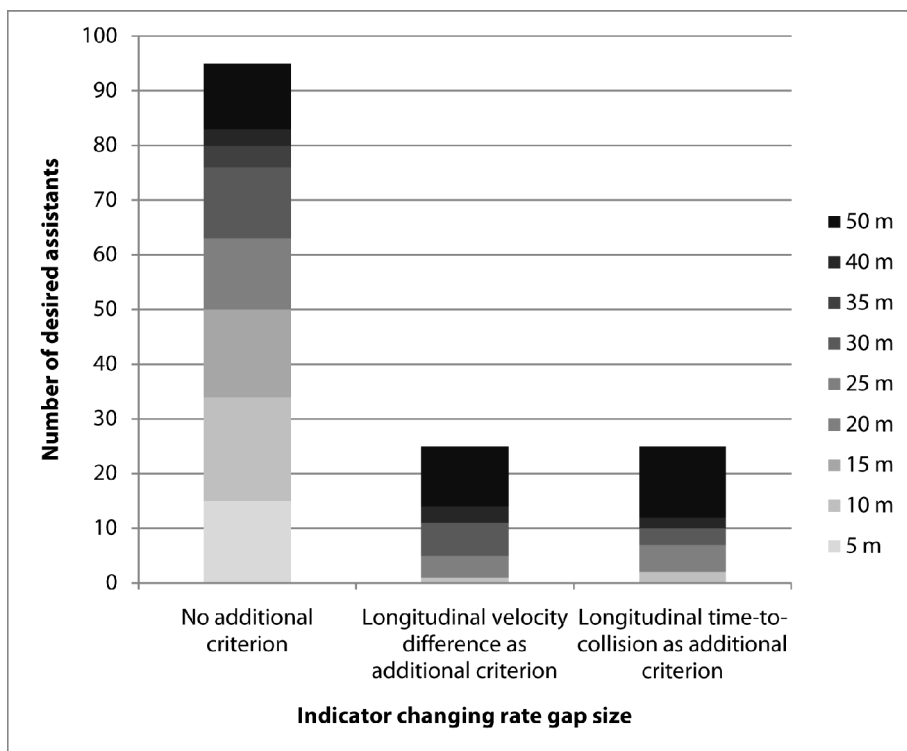


Figure 5.25: Relationship between the indicator for the changing rate of the gap size and the zone length in desired assistants

The three bars in Figure 5.25 show the number of desired assistants (i.e. assistants that are present in the “most attractive systems”) that respectively have *no* additional criterion, the *longitudinal velocity difference* as additional criterion, and the *longitudinal time-to-collision* as additional criterion for the changing rate of the gap size. The different shades of grey indicate how many assistants have a specific zone length. It can be seen that 11 of the 25 (=44%) desired assistants that have the *longitudinal velocity difference* as additional criterion have a zone length of 50m, and that 13 of the 25 (=52%) desired assistants that have the *longitudinal time-to-collision* as additional criterion have a zone length of 50m. However, only 12 of the 95 (=13%) desired assistants that have *no* additional criterion for the changing rate of the gap size have a zone length of 50m. Similarly, it can be seen that 1 of the 25 (=4%) desired

assistants that have the *longitudinal velocity difference* as additional criterion has a zone length of 15 m or shorter, and that 2 of the 25 (=8%) desired assistants that have the *longitudinal time-to-collision* as additional criterion have a zone length of 15 m or shorter. However, 50 of the 95 (=53%) desired assistants that have *no* additional criterion for the changing rate of the gap size have a zone length of 15 m or shorter. These results indicate that the shorter the zone length, the less an additional criterion for the issuance of support is desired, and the longer the zone length, the more an additional criterion for the issuance of support is desired.

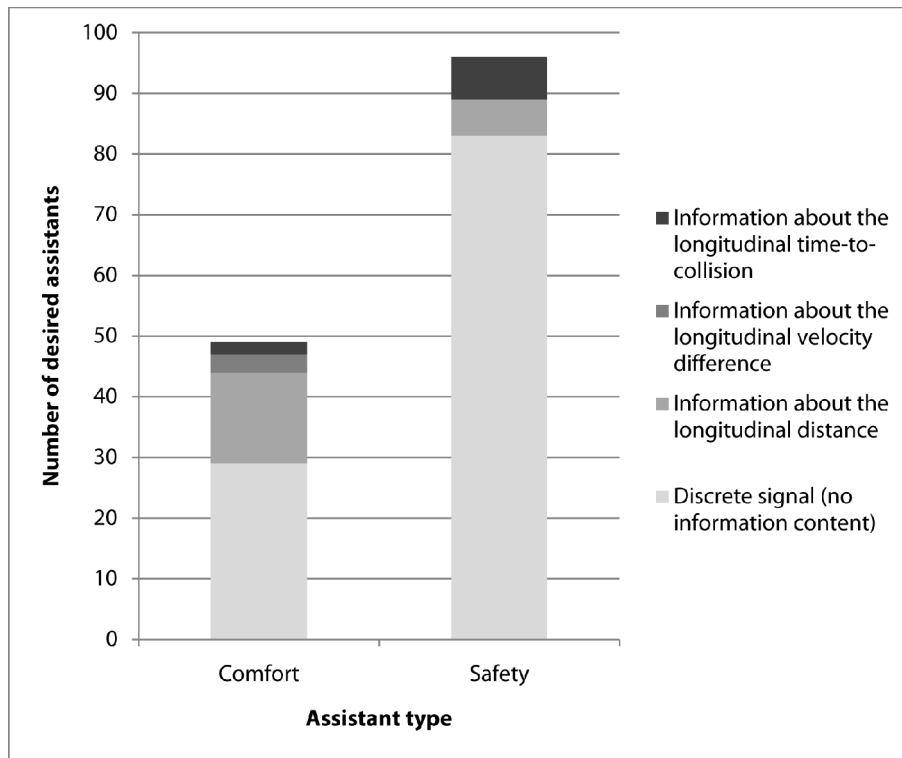


Figure 5.26: Relationship between the assistant type and the information content in desired assistants

The two bars in Figure 5.26 show the number of desired assistants that are “comfort assistants” and the number of desired assistants that are “safety assistants”, respectively. “Comfort assistants” are assistants that give feedback about the traffic environment, independent of the intention to change lanes. “Safety assistants” are assistants that issue a warning or an intervention when the user makes a mistake (i.e. when the user has the intention to change lanes whereas another vehicle is present in an adjacent zone). The different shades of grey indicate how many assistants issue a specific information content. It can be seen that 20 of the 49 (=41%) desired “comfort assistants” issue information content, whereas only 13 of the 96 (=14%) desired “safety assistants” issue information content. This indicates that information content is more appreciated in comfort assistants than in safety assistants.

For three system features, correlations between users’ personal characteristics (i.e. age and driving style) and their preferences were found (see Figure 5.27 to Figure 5.32).

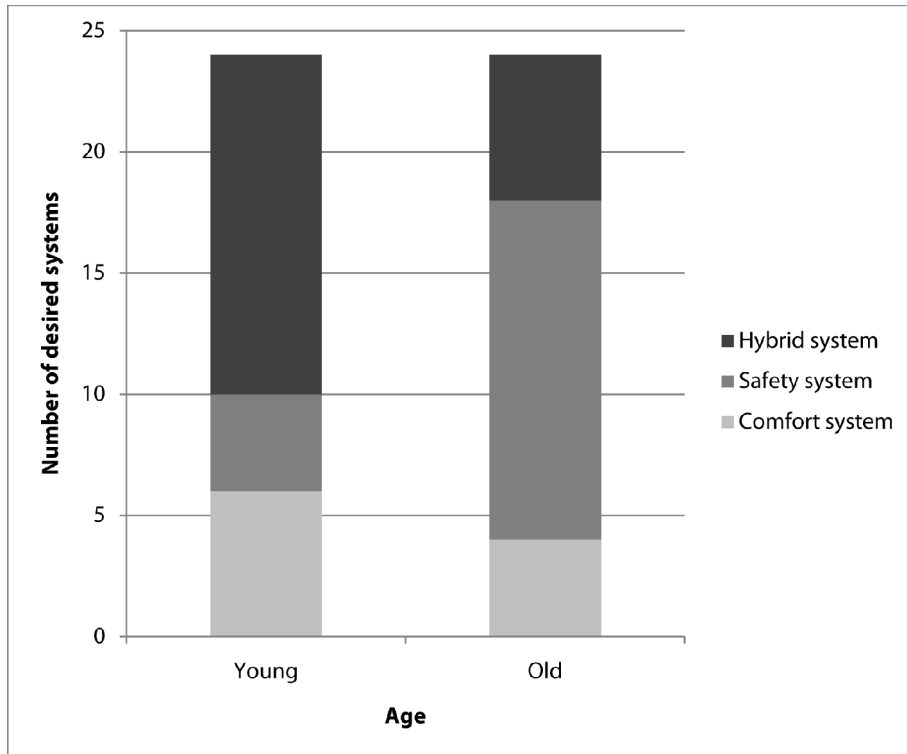


Figure 5.27: Relationship between the user’s age and the desired system type

Per age group, Figure 5.27 shows the number of users that want a “comfort system” (i.e. a system only consisting of comfort assistants), the number of users that want a “safety system” (i.e. a system only consisting of safety assistants), and the number of users that want a “hybrid system” (i.e. a system consisting of both comfort and safety assistants). Only 4 of the 24 (=17%) young users desire a “safety system”, whereas 14 of the 24 (=58%) old users desire such a system. Similarly, it can be seen that 14 of the 24 (=58%) young users desire a “hybrid system”, whereas only 6 of the 24 (25%) old users desire such a system. These results indicate that young users are particularly fond of hybrid systems, and that old users are particularly fond of safety systems.

Figure 5.28 shows that a similar – but less pronounced - correlation exists for aggressive users versus non-aggressive users.

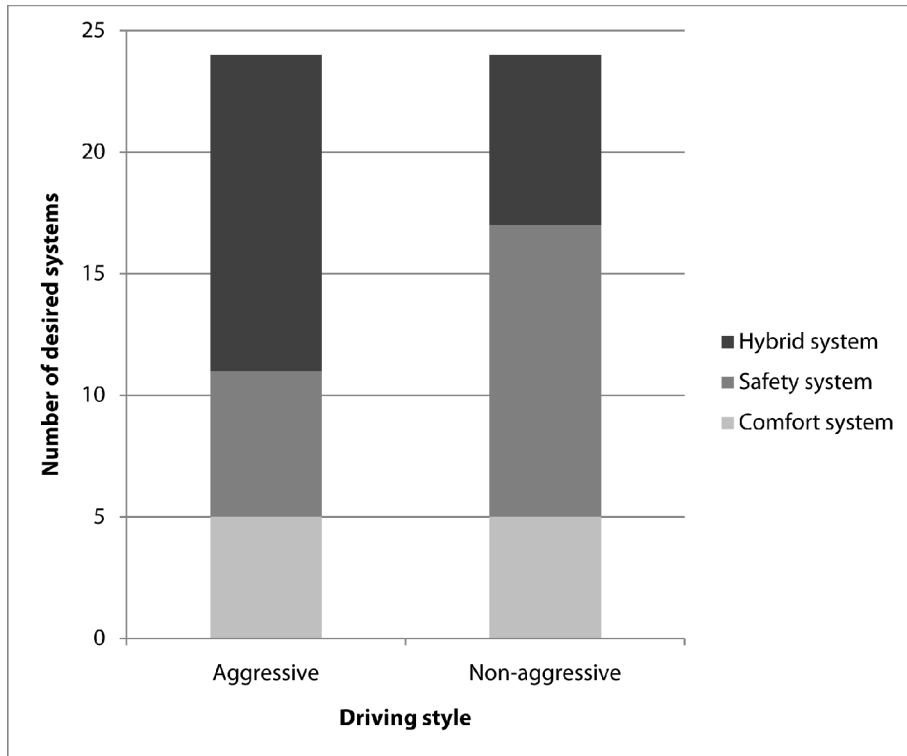


Figure 5.28: Relationship between the user's driving style and the desired system type

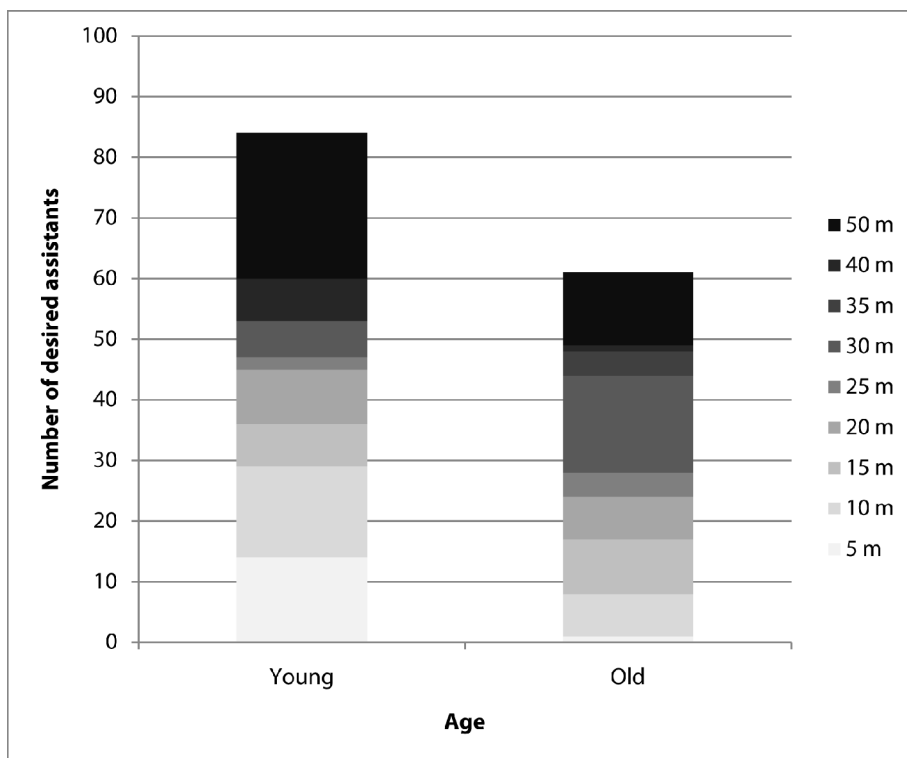


Figure 5.29: Relationship between the user's age and the zone length in desired assistants

Figure 5.29 shows the total number of desired assistants per age group. The different shades of grey indicate how many assistants have a specific zone length. It can be seen that 29 of the 84 (=35%) assistants desired by young users have a zone length of 10m or shorter, whereas only 8 of the 61 (=13%) assistants desired by old users have zone lengths in this range. Similarly, only 24 of the 84 (=29%) assistants desired by young users have a zone length between 15m and 35m, whereas 40 of the 61 (=66%) assistants desired by old users have zone lengths in this range. Finally, 31 of the 84 (=37%) assistants desired by young users have a zone length of 40m or longer, whereas only 13 of the 61 (=21%) assistants desired by old users have zone lengths in this range. These results indicate that young users are particularly fond of support about vehicles that are either close to (0-10m) or far away from the subject vehicle (40-50m). Old users, on the other hand, are particularly fond of support about vehicles that are 15-35m away from the subject vehicle.

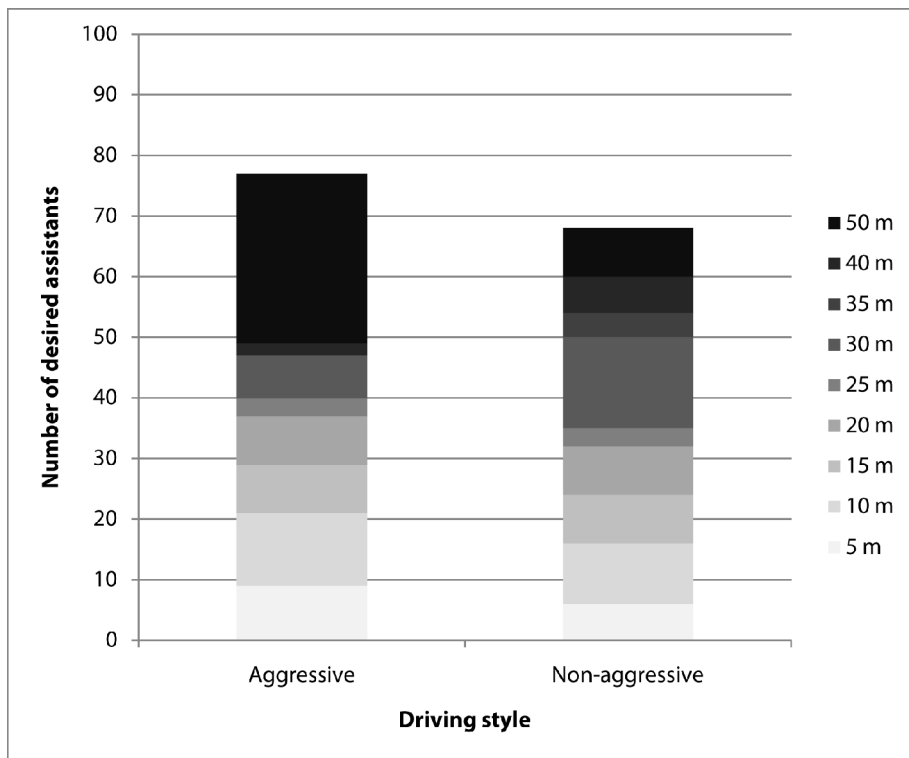


Figure 5.30: Relationship between the user's driving style and the zone length in desired assistants

A similar correlation exists for aggressive users versus non-aggressive users. Figure 5.30 shows the total number of desired assistants per driving style group. The different shades of grey indicate how many assistants have a specific zone length. It can be seen that 28 of the 77 (=36%) assistants desired by aggressive users have a zone length of 50m, whereas only 8 of the 68 (=12%) assistants desired by non-aggressive users have such a zone length. Similarly, only 49 of the 77 (=64%) assistants desired by aggressive users have a zone length shorter than 50m, whereas 60 of the 68 (=88%) assistants desired by non-aggressive users have a zone length in this range. These results indicate that aggressive users are particularly fond of support about vehicles that are far away from the subject vehicle (50m). Non-

aggressive users, on the other hand, are particularly fond of support about vehicles that are closer (0-40m) to the subject vehicle.

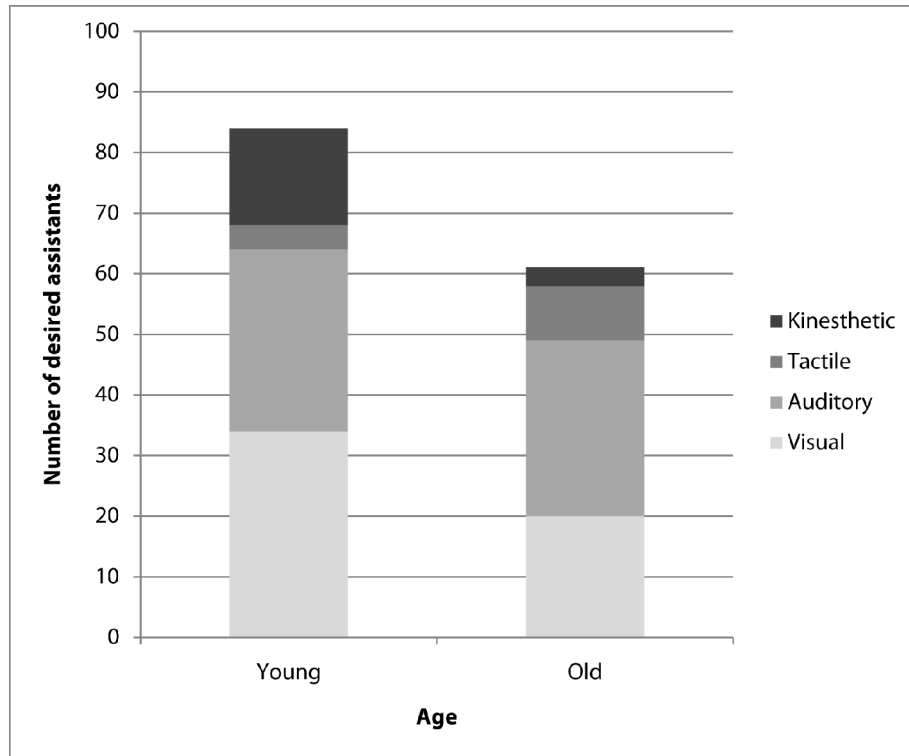


Figure 5.31: Relationship between the user's age and the modality in desired assistants

Figure 5.31 shows the total number of desired assistants per age group. The different shades of grey indicate how many assistants have a specific modality. It can be seen that 16 of the 84 (=19%) assistants desired by young users issue kinesthetic support, whereas only 3 of the 61 (=5%) assistants desired by old users have this modality. This indicates that young users are fonder of kinesthetic support than old users.

A similar correlation was not found between the user's driving style and the modality in desired assistants. Since age and driving style were correlated (see section 5.2.2), this indicated a correlation between the *combination of age and driving style* and the preference for a specific modality: it appeared that the preferences of an aggressive user strongly depend on his age.

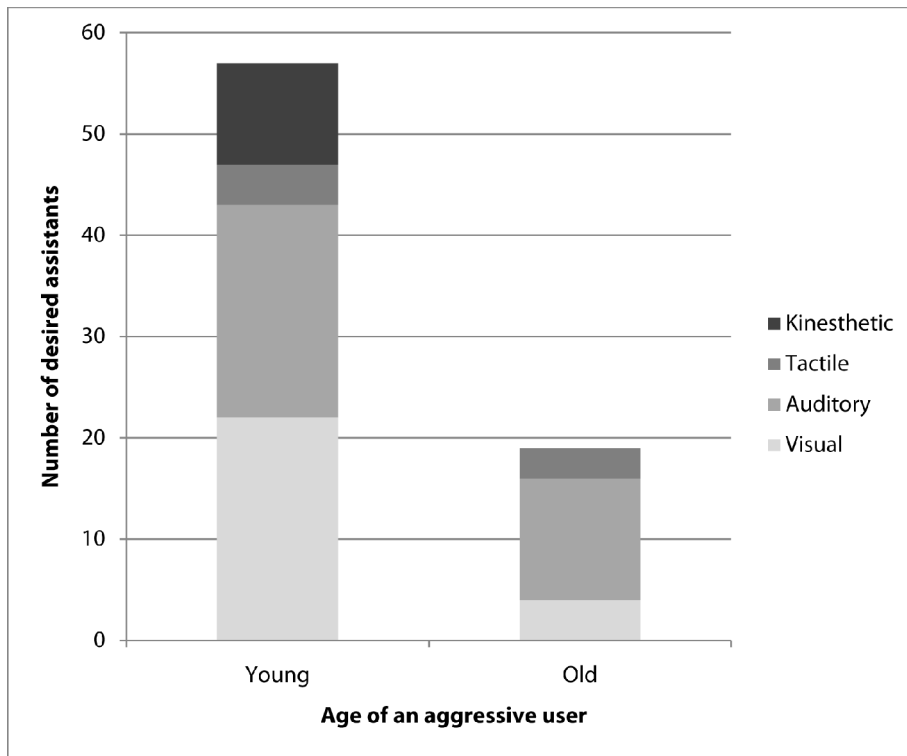


Figure 5.32: Relationship between the combination of age and driving style and the modality in desired assistants

Figure 5.32 shows the total number of desired assistants for the 16 young aggressive users and the 8 old aggressive users, respectively. The different shades of grey indicate how many assistants have a specific modality. It can be seen that 10 of the 57 (=18%) of the assistants desired by young aggressive users issue kinesthetic support, whereas 0 of the 19 (=0%) of the assistants desired by old aggressive users have this modality. Similarly, 22 of the 57 (=39%) of the assistants desired by young aggressive users issue visual support signals, whereas only 4 of the 19 (=21%) of the assistants desired by old aggressive users do this. Finally, 21 of the 57 (=37%) of the assistants desired by young aggressive users issue auditory support signals, whereas 12 of the 19 (=63%) of the assistants desired by old aggressive users do this. These results indicate that young aggressive users are fonder of visual and kinesthetic support than old aggressive users, but that old aggressive users are fonder of auditory support than young aggressive users.

However, despite the correlations that were found between the desired system features, and despite the correlations that were found between the user's age and driving style and his preferences, the preferred layout of a lane change support system is a highly personal matter. There are large (and partly insurmountable) individual differences between users' preferences for a lane change support system. Users have very different reasons for considering certain system features desirable or undesirable, and users solve the trade-offs between arguments *for* and arguments *against* certain system features in very different, and individual, ways. Therefore, the compromise between the preferences of all users is a lane change support system that is *fully adjustable* to the user's individual preferences. Since the results of the first phase of the design process suggest that a lane change support system should be thought of

as an assembly of independently functioning assistants (i.e. modules), the conclusion of the design case is that *fully adjustable modular lane change support systems* should be brought to the market.

In literature, a number of references were found that comply with this conclusion. For example, Lerner et al. (1993; in: Campbell et al., 1996) state that “in a lane change support system, detector sensitivity adjustment may be provided to allow the driver to adjust the range of the sensor to reduce sensitivity and false alarm rates.” They also suggest that “a single master control should be provided to simultaneously adjust the intensity of all displays within a specific mode (i.e. auditory, visual, tactile)”. Campbell et al. (1996) present many factors to take into consideration when designing a driver support system. One of those is the amount of driver control. They write that “options for system parameters for the driver to control include for example turning the system on and off, switching between alert modalities, modifying the intensity of the alert, and adjusting the sensitivity of the system and timing of alerts”. They also suggest that, “in order to better reflect their own driving styles and prevailing driving conditions, drivers may want to adjust the distance setting or time-to-collision parameter. Such a control function might increase user acceptance of the system and reduce the number of nuisance alarms”. Van Driel & Van Arem (2005) conclude from an online survey of user needs for a driver assistance that “the HMI should be easily adjustable, because respondents would like to have the possibility to choose the type of assistance and feedback”.

Although the conclusion of the design case complies with findings of other researchers, the design process revealed the relationships between user characteristics, driving circumstances and preferred system characteristics in greater detail than as they are described in literature.

Intermezzo

Written from the viewpoint of the researcher

So should a fully adjustable modular lane change support system be brought to the market? After having spent all this time and effort on creating a design environment, on making sure that all the represented design information is consistent, and on performing sessions with participants, is the conclusion really that a lane change support system should be fully adjustable and modular? Yes and no. Yes, because this conclusion irrefutably follows from the information that was generated during the design process. No, because this information is one-sided. During the second phase of the design process, only representatives of the stakeholder group “users” were invited to give opinions. Representatives of other stakeholder groups were not offered a chance to express their preferences. This was due to the second simplification that made that the design environment only represented the *use aspects* of a lane change support system (see section 4.2.8).

However, in order to successfully bring a lane change support system to the market, not only the needs and desires of users should be considered, but also those of stakeholders such as marketing managers, production engineers and government representatives. Ideally, the design environment would have facilitated the perspectives of those other stakeholders. Then they could have directly expressed their preferences and could have directly provided input to the process of finding the best compromise. On the other hand, the design information that was now generated (and that completely stems from users) is represented such that it can be easily put into the perspective of other stakeholders’ preferences. The hierarchy of information that was created most certainly allows for finding a compromise between the preferences of users and those of other stakeholders. One that surpasses the “one-sided” compromise of a fully adjustable modular lane change support system. To illustrate this, an (imaginary) lane change support system manufacturer was asked to impose a (hypothetical) constraint:

“Modularity makes the production process more efficient. The lane change support system should therefore be modular. Every assistant (i.e. every module) should function independently of the other assistants (i.e. the other modules) in the system. Users may or may not order specific assistants to be installed in their vehicle. To ensure an effective marketing campaign, a total of six assistants should be offered:

- *Two “comfort assistants” (one for every side of the vehicle) that give feedback about the traffic environment, independent of the intention to change lanes;*
- *Two “safety assistants” (one for every side of the vehicle) that issue a warning when the user makes a mistake (i.e. when the user has the intention to change lanes whereas another vehicle is present in an adjacent zone);*
- *Two “safety assistants” (one for every side of the vehicle) that impose an intervention when the user makes a mistake.”*

The designer was asked to specify a new compromise by combining this constraint with the preferences of users (as reflected by the hierarchy of information). Moreover, the designer was asked to specify why users would be attracted to this compromise, what they might not like about it, and how this is related to the circumstances under which they use the lane change support system.

A compromise between the preferences of all users within the constraint

The specifications of the 48 lane change support systems that were marked “most attractive” by users were considered. For every design parameter of every assistant, it was noted which value was most often preferred. Integrating these findings with the constraint imposed by the manufacturer resulted in a specification of the six assistants that should be brought to the market (see Table 5.22). The first column shows the name of the assistant, the second column specifies the circumstances under which the assistant gives support, the third column specifies the contents of the support provided by the assistant, and the fourth column specifies the form of the provided support.

<i>Name</i>	<i>Circumstances (WHEN)</i>	<i>Contents (THEN)</i>	<i>Form (BY)</i>
Comfort assistant (left)	WHEN a trailing vehicle in the left adjacent lane is closer than 50 m	THEN information about the longitudinal distance to this vehicle	BY a bright, medium sized, static light that is rendered on the left dashboard panel and that changes color as the longitudinal distance becomes shorter
Comfort assistant (right)	WHEN a trailing vehicle in the right adjacent lane is closer than 30 m	THEN a discrete signal	BY a bright, red, medium sized, static light that is rendered on the right dashboard panel
Safety assistant “warning” (left)	WHEN a trailing vehicle in the left adjacent lane is closer than 50 m AND the left turn signal is used OR the time to line crossing with the left lane marker drops below 1 s	THEN a discrete signal	BY a high pitched beep that has a medium volume and a high repetition frequency, and that is rendered in the left rear speaker
Safety assistant “warning” (right)	WHEN a trailing vehicle in the right adjacent lane is closer than 10 m AND the right turn signal is used OR the time to line crossing with the right lane marker drops below 1 s	THEN a discrete signal	BY a high pitched beep that has a medium volume and a high repetition frequency, and that is rendered in the right rear speaker
Safety assistant “intervention” (left)	WHEN a trailing vehicle in the left adjacent lane is closer than 10 m AND the left turn signal is used OR the time to line crossing with the left lane marker drops below 1 s	THEN a control-intervention	BY a powerful torque that is rendered in the steering wheel
Safety assistant “intervention” (right)	WHEN a trailing vehicle in the right adjacent lane is closer than 5 m AND the right turn signal is used OR the time to line crossing with the right lane marker drops below 1 s	THEN a control-intervention	BY a powerful torque that is rendered in the steering wheel

Table 5.22: Specification of the six assistants that should be brought to the market

As shown in Table 5.22, the assistants for the left side of the vehicle differ from the equivalent assistants for the right side of the vehicle. Many users indicated that their needs for lane change support on the left side of the vehicle were different from their needs for on the right side of the vehicle. Vehicles on the left are generally moving faster than the subject vehicle, whereas vehicles on the right are generally moving slower. Lane changes to the left are generally meant to enter traffic or to start a passing

maneuver, whereas lane changes to the right are generally meant to exit traffic or to go back to the right lane after a passing maneuver. Most users considered lane changes to the left as more difficult and more stressful than lane changes to the right. Therefore, most users wanted an asymmetric lane change support system. The few users who preferred a symmetric system argued that asymmetry increases the perceived complexity and perceived inconsistency of the system. In turn, this makes the meaning of a signal less intuitive and, therefore, the system may even cause confusion.

The first two assistants in Table 5.22 are “comfort assistants”. Reasons for users to desire a comfort assistant are that it makes users feel comfortable, relaxed and confident. Users also reported feeling more aware of (and in control of) the traffic situation around the vehicle. Users reported that a comfort assistant improved estimation/decision making. Some users also reported that they glanced less in the mirrors, and, therefore could pay closer attention to the traffic in front of the vehicle. Comfort assistants were considered useful on highways, but also on other roads with multiple lanes going into the same direction. Furthermore, some users felt that comfort assistants were especially useful on German highways. Because of the higher speed differences on German highways, making decisions about changing lanes is considered more difficult than in The Netherlands. Reasons for users not to desire a comfort assistant are that it makes users feel annoyed, irritated, disturbed and overloaded with signals. Users reported that comfort assistants interfered with driving and with in-car activities and that they give irrelevant/redundant signals. The reported undesirable behavioral change of a comfort assistant included: getting lazy (glancing less in mirrors and therefore paying less attention to the traffic situation behind the vehicle), and spending too much time and effort acquiring/interpreting signals (also at the expense of paying less attention to the traffic situation).

The last four assistants in Table 5.22 are “safety assistants”. Reasons for users to desire a safety assistant are that it makes users feel safe and secure. Users reported that it is pleasant and comfortable to know that the system prevents from making mistakes and causing accidents. Users especially appreciated safety assistants when being tired, being less concentrated, or not being used to the circumstances. Reported desirable behavioral changes under influence of a safety assistant were that other vehicles are less often cut-off. One user mentioned that a safety assistant helps reminding to switch off the turn-signal after having changed lanes. Reasons for users not to desire a safety assistant are that it makes users feel annoyed, disturbed, and distracted. When a safety assistant gave support by means of tactile or kinesthetic signals, some users also reported to feel scared, panicked, and alienated. A frequently reported undesirable behavioral change of a safety assistant was getting lazy (glancing less in mirrors and therefore paying less attention to the traffic situation behind the vehicle).

The constraint imposed by the lane change support system manufacturer leaves room for offering “hybrid systems” (i.e. systems consisting of both comfort assistants and safety assistants). A reason for users to desire such a hybrid system is that they not only want to feel comfortable and relaxed, but also safe and secure. A possible drawback of a hybrid system is that the perceived complexity of the system is increased. This means that the meaning of a signal might not be intuitively understood and that the user might get confused (i.e. the user might mix up comfort signals with safety signals).

The second column in Table 5.22 specifies the circumstances under which every assistant gives support. The “length of the monitored zone” has a very large influence on how an assistant behaves. This length determines which trailing adjacent vehicles are noticed by the assistant and which vehicles are not.

From a user's perspective, this length determines for which inter-vehicle gaps the assistant is able to give support. When the zone length is too short, trailing adjacent vehicles were noticed "too late". Users associated a too short zone length with feeling unsafe (feeling that hazardous situations might occur for which the system won't provide adequate support). However, when the zone length is too long, trailing adjacent vehicles were picked up "too early". A too long zone length was associated with feeling annoyed, disturbed and distracted by irrelevant/redundant signals. Large individual differences existed between users in what is considered "too late" and "too early". However, as can be seen in Table 5.22, the most popular zone lengths were:

- 50 m for left comfort assistants;
- 30 m for right comfort assistants;
- 50 m for left safety assistants that give a warning;
- 10 m for right safety assistants that give a warning;
- 10 m for left safety assistants that impose an intervention;
- 5 m for right comfort assistants that impose an intervention.

None of the assistants in Table 5.22 has the changing rate of the inter-vehicle gap (i.e. the speed difference with a trailing adjacent vehicle or the longitudinal time-to-collision with a trailing adjacent vehicle) as an additional criterion for issuance of support. This is because, generally, users were not very fond of this. The choice whether or not to integrate such an additional criterion was a typical trade-off between feeling overloaded with irrelevant signals and feeling unsafe because the system might not issue support in specific hazardous situations. Another argument that was often used against the integration of such an additional criterion was that the assistant seems to behave inconsistently: many users got confused when an assistant did not issue support about *every* vehicle in an adjacent zone but only about *specific* vehicles.

The four safety assistants in Table 5.22 all have both turn signal activation and time-to-line-crossing as indicators for the intention to change lanes. Some users considered the turn signal activation as a better indicator for the intention to change lanes, whereas others considered the time-to-line-crossing as a better indicator. When intending to change lanes, most users first activated the turn signal and only then started the actual steering maneuver that made the time-to-line crossing drop below the threshold of 1 s. This means that users who only desired the time-to-line-crossing as criterion would generally be warned – or prevented – later than users who desired the turn signal activation as criterion. However, most users desired a combination of both indicators. The reason for this is that it is pleasant to have a "backup" in case the turn signal is forgotten.

Most assistants in Table 5.22 issue discrete signals. A discrete signal is either *on* or *off*. When it is on, it tells the user that certain conditions apply; when it is off, it tells the user that those conditions do not apply. The only exception is the comfort assistant for the left side of the vehicle. This assistant gives the user additional information about the longitudinal distance to a vehicle in the monitored zone by means of a light that changes color with the distance. Many users benefited from this additional information. There were quite a few users who liked to receive this information by a digital number. However, an often heard argument against digital numbers is that they were difficult to interpret. Color variations, on the other hand, were considered to be easily interpretable – at least easier than variations in brightness, size, and blinking frequency. Only color-blind users indicated that color variations would not offer any added value for them. Additional information worked into the signal of safety assistants

(and the signal of comfort assistants on the right side of the vehicle) gave users the feeling that the system became too complex, and that the meaning of the signals could not be intuitively understood. They didn't have the time or the ability to interpret the additional information, let alone to do something useful with it.

Both comfort assistants in Table 5.22 render the support by bright, medium sized, static (i.e. not blinking) lights. For the left assistant, this light is rendered on the left dashboard panel. For the right assistant, this light is rendered on the right dashboard panel. Reported pleasant aspects of visual support signals were that they were discrete and not intrusive. An often reported unpleasant aspect was that visual signals were not conspicuous enough, which resulted in not noticing or ignoring the signal. Opinions about the level of disturbance/distraction that a visual support signal induces varied: some users thought that visual signals do not disturb/distract, because they do not have to look at them if they don't want to. However, others thought that visual support signals distract from driving because their attention is drawn to the dashboard panel every time a visual signal is issued. The time and effort that is spent acquiring and interpreting this signal is at the expense of paying attention to the traffic situation. Most users didn't care about whether a visual signal was a light or a visual icon. As long as something popped up on the dashboard panel that could be immediately recognized and understood. The color of a light was considered to be rather unimportant, but most users still preferred this to be red. The side of the visual signal should coincide with the side of the hazard because this makes that the meaning of the signal can be intuitively understood. The brightness, size and blinking frequency of a visual signal together determine whether it is sufficiently conspicuous and sufficiently discrete and whether it is not too dominant and too distracting. Especially with regard to size and blinking frequency, users' preferences varied widely. However, most users wanted lights to be medium-sized and static.

As can be seen in Table 5.22, the safety assistants that give warnings both render the support by a high pitched beep that has a medium volume and a high repetition frequency. For the left assistant, this beep is rendered in the left rear speaker. For the right assistant, this beep is rendered in the right rear speaker. Reported pleasant aspects of auditory support signals were that they are more conspicuous than visual signals, so that they cannot stay unnoticed or be ignored. Another benefit is that they do not distract from looking at the traffic situation, and that they let the user "intuitively" know what is going on next to and behind the vehicle. On the other hand, many users pointed out that the conspicuity of an auditory signal depends on the circumstances. Auditory signals may still stay unnoticed when for example listening to music, talking with passengers, using a cell phone, using the navigation system, or even using other support systems. The various mentioned in-car activities are also strongly related to other unpleasant aspect of auditory signals: its level of disturbance, its level of discretion, and its intrusiveness. Beeps were mostly desired because they offered the best balance between conspicuousness and intrusiveness. Reasons not to desire beeps were that they might "disappear" in other sounds (e.g. music, conversations), or that they might be confused with other beeps inside the vehicle (e.g. navigation system, cell phone). All users who desired auditory icons preferred to have the "horn sound icon". Some users indicated to intuitively understand the meaning of the signal because it coincides with a "natural" signal from the traffic environment that indicates a hazard (i.e. another vehicle using its horn). However, other users indicated that they might confuse the horn sound with a real horn, and that they found this to be unpleasant. Furthermore, an often heard argument against the horn sound is that it induces panic. Spoken texts are generally considered

conspicuous and easy to understand, however most users considered a human voice that warns them to be too dominant and therefore annoying. The volume and the repetition frequency of an auditory signal together determine whether it is sufficiently conspicuous and sufficiently discrete and whether it is not too dominant and too distracting. However, most users seemed to agree on what is the most appropriate volume (medium) and repetition frequency (high). Many users intuitively associated the pitch of a beep with the hazard level of a situation: the higher the pitch, the more dangerous the situation. Furthermore, many users found the pitch to be a decisive factor in whether or not they get annoyed by a beep, in whether or not a beep is conspicuous enough, and in whether or not a beep is considered subtle/discrete. The side of the auditory signal should coincide with the side of the hazard because this makes that the meaning of the signal can be intuitively understood.

The last two safety assistants in Table 5.22 render a powerful torque on the steering wheel when the user makes a mistake. Reported pleasant aspects of kinesthetic support were that it is conspicuous and that its meaning can be intuitively understood. It makes users feel safe and secure because it actively supports in preventing an accident. On the other hand, many users thought that a pro-active system that works on the vehicle's steering system "just goes too far". Although all users realized that the driver is at all times able to overrule an intervention, many users still had the feeling that interventions make them lose control of the vehicle. Feeling scared, panicked and alienated were also frequently heard arguments against kinesthetic support. Some users even reported to be inclined to perform a counter-steering action (i.e. steering towards the hazard instead of away from the hazard) because they intuitively thought that something was wrong with the steering system. The preferred magnitude of the torque is typically a trade-off between conspicuity and the feeling of losing control of the vehicle.

No assistant in Table 5.22 issues tactile support signals. Many users pointed out that they just not liked the "feeling" of a vibration in the seat. They experienced it as too dominant and too physically intrusive. Some even indicated that it made them feel scared. The few users that liked tactile support signals used as arguments that these signals do not distract from looking at the traffic situation, and that they let the user "intuitively" know what is going on next to and behind the vehicle. Moreover, they are conspicuous under all circumstances and yet discrete. In other words: tactile signals cannot stay unnoticed and yet they don't interfere with other in-car activities.

Intermezzo

Written from the viewpoint of the researcher

By combining the constraint imposed by the lane change support system manufacturer with the preferences of users (as reflected by the hierarchy of information), the designer was able to specify a new compromise. Moreover, the designer was able to use the hierarchy of information to specify why users would be attracted to this compromise, what they might not like about it, and how this is related to the circumstances under which they use the lane change support system. This indicates that applying the new product design method is useful, even when the design environment facilitates the perspective of only one stakeholder group and/or when the sessions involve only one stakeholder group.

ASSESSING THE NEW PRODUCT DESIGN METHOD

6

In this chapter, the new product design method is assessed. This is done by performing two experiments. Each experiment coincides with one of the two phases of the design process that emerged from applying the method to the design case.

6.1 Introduction

Figure 6.1 shows the higher-level processes that were performed during the design process that was described in chapter 5. Compared to Figure 3.1, activity 1.b (creating an interface for generating test environments) is missing. Due to the first simplification (see section 4.2.8), this activity was not performed during the design process. Accordingly, activity 2.2 (generating test environments) was also not performed. Instead, the designer generated the scenarios that were offered to users to evaluate their self-configured designs.

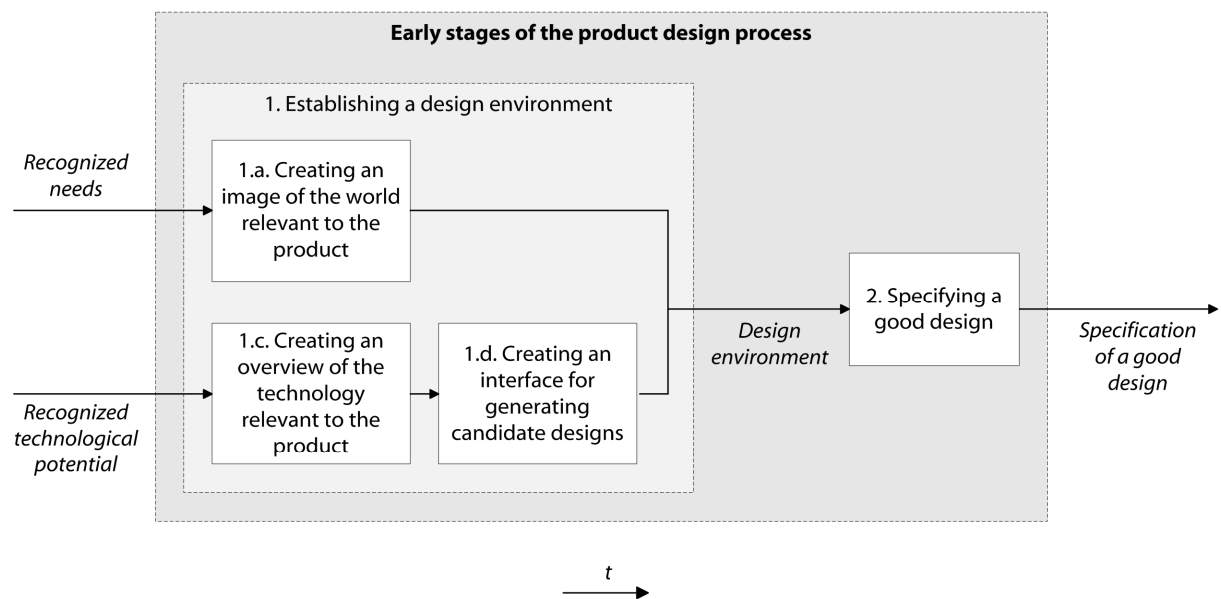


Figure 6.1: The higher-level processes that were performed during the design process

This chapter describes the process of collecting data about the design process, analyzing the collected data, and using the results to test the hypotheses (as they were specified in Table 4.3 and Table 4.4). The descriptions have an "analytical character". The hypotheses are tested, but there will not be reflected on the outcomes. Also, the additional findings (identification of trade-offs, difficulties, strong points, weak points, opportunities) are described in an analytic way. Reflecting on both the results of testing the hypotheses and the additional findings is saved for chapter 7.

6.2 First experiment: assessing the first phase of the design process

6.2.1 Specification

Table 6.1 shows the hypotheses that were tested during the experiment. Table 6.2 shows the criteria for acceptance of every hypothesis. The tables are copies of Table 4.3 and Table 4.7, respectively. The variables "V" in Table 6.2 refer back to Table 4.5.

<i>Hypothesis</i>	<i>Description</i>
HY.1.a	Human actors are able to perform activity 1 (as it was specified in section 3.1.4).
HY.2.a	Activity 1 yields actual results.
HY.3.a	The guideline for the selection of participants for activity 1 (as it was formulated in section 3.2.3) is correct.
HY.4.a	Functions RF.1, RF.2 and RF.3 (see Table 4.2) are fulfilled.

Table 6.1: The hypotheses that were tested during the first experiment

<i>Hypothesis</i>	<i>Criteria for acceptance</i>
HY.1.a	For every activity, V.1 and V.2 should be high for at least 80% of the stakeholders. For every activity, V.3 and V.4 should be positive for at least 80% of the stakeholders. For every activity, V.5 should be positive.
HY.2.a	For every activity, V.6 should be in line with one of the possible outcomes that is specified by the guidelines.
HY.3.a	V.7 and/or V.8 should differ between stakeholder groups. V.9 should correlate with V.10
HY.4.a	For every function, V.14 and V.15 should be positive for at least 80% of the stakeholders. For every function, V.16 and V.17 should be positive.

Table 6.2: The criteria for acceptance of the hypotheses that were tested during the first experiment

The experiment involved 13 participants: 12 users and 1 designer. The data collection process did not interfere with the design process, except for that participants were required to fill out additional questionnaires. Table 6.3 gives an overview of the questionnaires that had to be completed. Every questionnaire is associated with a letter as well as with a number. The letter indicates whether the designer (D) or the users (U) needed to complete the specific questionnaire. For every questionnaire, the first two columns in Table 6.3 specify after which activity it needed to be completed. The total set of questionnaires is depicted in Appendix F.

<i>Activity</i>	<i>Description</i>	<i>Questionnaires designer</i>	<i>Questionnaires users</i>
1.1	Based on an initial assumption about the needs of stakeholders that should be fulfilled by the product and the technological potential that could be exploited by the product, the designer creates a design environment that is easily accessible for all stakeholders.	D1	U1
1.2	All stakeholders interact with the design environment and reflect on it.	D2	U2
1.3	The designer registers the behavior of stakeholders while interacting with the design environment, and registers the opinions of stakeholders while reflecting on it.	D3	-
1.4	The designer uses the registered information to verify the initial assumption about the world and the technology relevant to the product and to reveal desired changes and additions to the design environment.	D4, D5	-
1.5	The designer updates the design environment based on new insights, such that it is kept consistent and that new insights are easily accessible for all stakeholders.	D6, D7	-

<i>Activity</i>	<i>Description</i>	<i>Questionnaires designer</i>	<i>Questionnaires users</i>
1.6	All stakeholders interact with the updated design environment and reflect on the updates.	D8, D9	U3, U4
1.7	The designer registers the behavior of stakeholders while interacting with the updated design environment, and registers the opinions of stakeholders while reflecting on the updates.	D10, D11	-
1.8	The designer uses the registered information to verify the updates and to reveal new desired changes and additions to the design environment.	D12, D13	-
1.9	The designer and all stakeholders repeat activities 1.5 to 1.8 until no more desired changes and additions are revealed.	D14, D15, D16, D17	-

Table 6.3: The questionnaires that needed to be completed during the first experiment

6.2.2 Testing hypothesis HY.1.a

Introduction

Hypothesis HY.1.a is that human actors (i.e. designer and stakeholders) are able to perform activity 1 (i.e. are able to establish a design environment). Table 6.4 depicts the variables that were used to test this hypothesis. Table 6.5 specifies the measurement instruments as well as for which variables these were used.

<i>Variable</i>	<i>Description</i>
V.1	The extent to which stakeholders act according to the instructions given by the designer
V.2	The extent to which stakeholders answer the questions of the designer
V.3	The opinion of stakeholders about their own abilities
V.4	The opinion of the designer about the abilities of stakeholders
V.5	The opinion of the designer about his own abilities

Table 6.4: The dependent variables for testing hypothesis HY.1.a

<i>Instrument</i>	<i>Description</i>	<i>Variables</i>
I.1	Questionnaires	V.3, V.4, V.5
I.2	Direct observations	V.1, V.2
I.3	Indirect observations (i.e. audio/video recordings)	V.1, V.2

Table 6.5: The measurement instruments and the variables for which they were used

According to Table 4.7, the criteria for acceptance of hypothesis HY.1.a were:

- For activities 1.2 and 1.6, the extent to which stakeholders act according to the instructions given by the designer (variable V.1) and the extent to which stakeholders answer the questions of the designer (variable V.2) should be high for at least 80% of the stakeholders;
- For activities 1.2 and 1.6, the opinion of stakeholders about their own abilities (variable V.3) and the opinion of the designer about the abilities of stakeholders (variable V.4) should be positive for at least 80% of the stakeholders;
- For activities 1.1, 1.3, 1.4, 1.5, 1.7, 1.8 and 1.9, the opinion of the designer about his own abilities (variable V.5) should be positive.

Activity 1.1

From the answer given in questionnaire D1 followed that the designer was able to create an image of the world relevant to the product, an overview of the technology relevant to the product, and an interface for generating candidate designs. Results from observing the world, reading literature, and talking to stakeholders made the designer gain sufficient knowledge to design the image and the overview. Thanks to support from computer programmers (from Loosegoose software and ST software), a driving simulation developer (from TNO), an industrial designer, and a production engineer, the designer was also able to actually implement the image and the overview. The image consisted of a set of traffic scenarios and the overview consisted of a set of lane change support system technology. By means of driving simulation functionality, users could realistically interact with both the image and the overview. By simultaneously experiencing a traffic scenario and a selection of lane change support system technology (i.e. a lane change support system), users would be able to form a mental model of a lane change support system's behavior in an effective and efficient way.

The interface for generating candidate designs (i.e. the lane change support system configurator) was an electronic questionnaire in which the set of lane change support system technology was represented by descriptions in natural language, images, and previews of the behavior of the technology. The technology was organized into categories that are meaningful from a user's perspective. By operating the configurator (i.e. reading the questions, looking at the images, experiencing the previews, and giving answers to the questions), users would be able to form a mental model of a lane change support system's functional architecture in an effective and efficient way.

The designer identified two trade-offs that exist during creation of the set of scenarios. The first trade-off is between the level of realism of the scenarios and the number non-recurrent situations that users are confronted with. This trade-off is a logical consequence of the two functions of a scenario. A scenario should provoke users to display natural behavior. A scenario should therefore be a representation of the "common use situations" that are relevant to the product. But a scenario should also confront users with a number of non-recurrent situations (i.e. situations that only occur every once in a while). Just like in reality, sometimes, users should be surprised by unexpected events. However, if the non-recurrent situations would be offered at a "realistic frequency" within the scenarios, users would have to wait endlessly for these events to happen. The second trade-off is between the length of scenarios and the number of iterations that can be performed during a session. Since the attention span and the motivation of users are limited, a session should not take longer than two hours. To enable as many as possible iterations within those two hours, scenarios should be as short as possible. On the other hand, scenarios that are too short do not allow users to properly evaluate the generated candidate designs.

The designer also identified two trade-offs that exist during creation of the configurator. The first trade-off is between the number of design parameters that are adaptable for users and the time required for generating a candidate design. To avoid "contaminating" the design process with the designer's own view on the product, he should not make a distinction between "more important" and "less important" design parameters. Therefore, all design parameters that are present in the technology database should be adaptable for users. However, the more design parameters are adaptable, the longer it takes for users to generate a candidate design. This not only takes precious time, but also yields frustration - especially when users repeatedly have to specify values for parameters that they consider as "less

important". The second trade-off is between the time required for generating a candidate design and the complexity of the configurator. The time decreases with the implementation of shortcut functionalities so that users can skip "personally irrelevant questions". On the other hand, integration of such functionalities into the configurator increases its complexity. The benefit of a straightforward implementation (i.e. without shortcut functionalities) is that users more easily form a mental model of the technology database. Another benefit is that it is impossible for users to "forget" to define crucial values, and that it is guaranteed that the generated candidate designs actually work.

Activity 1.2

From direct and indirect observations appeared that all users were able to interact with the design environment and reflect on it. All users interacted with the lane change support system configurator, thereby forming a mental model of a lane change support system's functional architecture. All users also interacted with the driving simulator functionality of the design environment, thereby realistically experiencing the designs and the traffic scenarios, and forming a mental model of a lane change support system's behavior. Moreover, all users gave answers to the specific questions asked by the designer, thereby providing the designer with feedback about the set of traffic scenarios and the set of lane change support system technology.

From the answers given in questionnaire U2 followed that all 12 users felt that:

- The written instruction was sufficient to understand what was expected from them during the reflection session;
- They became sufficiently familiar with the lane change support system configurator during the "practicing phase" to be able to function well during the reflection session;
- They were able to usefully interact with the driving simulator functionality;
- They were able to understand and operate the lane change support system configurator;
- They were able to assess the behavior of the lane change support systems in the traffic scenarios;
- They were able to understand and answer the questions about the set of traffic scenarios during the interview;
- They were able to understand and answer the questions about the set of lane change support system technology during the interview.

Moreover, 11 of the 12 users felt that, during the "practicing phase", they became sufficiently familiar with the driving simulator functionality to be able to function well during the reflection session. Only 1 user was in doubt: he indicated that, at the moment he finished the practicing phase, he felt too unprepared to start the reflection session. However, afterwards, he said that this feeling did not obstruct him to function well during the reflection session. From remarks made by the other 11 users appeared that some of them also felt that the practicing phase was a little too short.

From the answers given in questionnaire D2 followed that the designer felt that:

- For all 12 users, the written instruction was sufficient to understand what was expected from the user during the reflection session;
- All 12 users became sufficiently familiar with the driving simulator functionality during the "practicing phase" to be able to function well during the reflection session;
- All 12 users became sufficiently familiar with the lane change support system configurator during the "practicing phase" to be able to function well during the reflection session;

- All 12 users were able to usefully interact with the driving simulator functionality;
- All 12 users were able to understand and operate the lane change support system configurator;
- All 12 users were able to assess the behavior of the lane change support systems in the traffic scenarios;
- All 12 users were able to understand and answer the questions about the set of traffic scenarios during the interview;
- All 12 users were able to understand and answer the questions about the set of lane change support system technology during the interview.

Activity 1.3

The behavior of users while interacting with the design environment, and the opinions of users while reflecting on it, were registered by audio/video recordings and by notes. The interactions with the lane change support system configurator (i.e. the design choices of users) were also automatically stored in data files. From the answers given in questionnaire D3 followed that the designer felt that - for all 12 users – the registrations contained opinions about the design environment. All 12 users communicated opinions during the concluding interview, and 5 users (P1, P8, P10, P11 and P12) even made “spontaneous remarks” during interacting with the lane change support system configurator.

Activity 1.4

From the answers given in questionnaires D4 and D5 followed that the designer was able to convert the opinions of users into a list of required adaptations to the set of traffic scenarios, a list of required adaptations to the set of lane change support system technology, and a list of required adaptations to the lane change support system configurator. These lists thereby verified the initial assumption about the world and the technology relevant to the product as well as it revealed new desired changes and additions to the design environment.

Activity 1.5

From the answers given in questionnaires D6 and D7 followed that the designer was able to implement the required adaptations, such that the design environment was kept consistent and that new insights would be easily accessible for all users. During the updating process, the designer received some help from a driving simulation developer from TNO, and from computer programmers from ST software and Loosegoose software

Activity 1.6

From direct and indirect observations, as well as from the answers given in questionnaire U3, U4, D8 and D9, appeared that all users were able to interact with the updated design environment and to reflect on the updates. All users interacted with the lane change support system configurator as well as with the driving simulator functionality of the updated design environment. Moreover, all users gave answers to the specific questions of the designer, thereby providing him with feedback about the updated set of traffic scenarios and the updated set of lane change support system technology.

Activity 1.7

The behavior of users while interacting with the updated design environment, and the opinions of users while reflecting on the updates, were registered by audio/video recordings and by notes. The interactions with the lane change support system configurator (i.e. the design choices of users) were

also automatically stored in data files. From the answers given in questionnaire D10 and D11 followed that the designer felt that – for all 12 users – the registrations contained opinions about the updated design environment. For every user, the designer was able to register his opinion about every implemented adaptation.

Activity 1.8

From the answer given in questionnaire D12 and D13 followed that the designer was able to use the registered opinions to verify the updates, and to reveal new desired changes and additions to the design environment.

Activity 1.9

This activity consists of repeating activities 1.5 to 1.8 until no more desired changes and additions to the design environment are revealed. Since it was not performed during the design process (see section 5.1.10), strictly spoken, it is unknown whether the designer and the users would be able to perform it. However, since they were able to perform activities 1.5 to 1.8, it is assumed that they would also be able to perform activity 1.9.

Conclusion

All criteria for acceptance of hypothesis HY.1.a were fulfilled.

For activities 1.2 and 1.6, the extent to which users acted according to the instructions given by the designer (variable V.1) and the extent to which users answered the questions of the designer (variable V.2) were high for all users (see Figure 6.2).

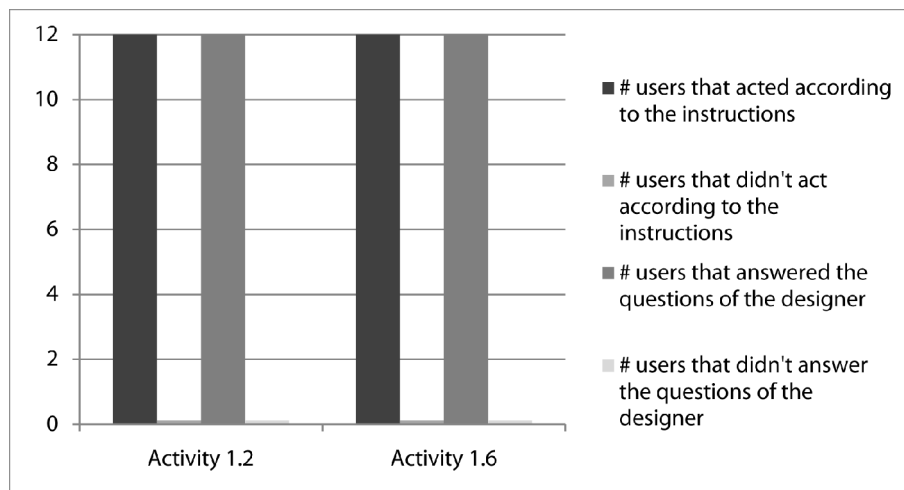


Figure 6.2: The users acted according to the instructions and answered the questions of the designer during activities 1.2 and 1.6

For activities 1.2 and 1.6, the opinion of users about their own abilities (variable V.3) and the opinion of the designer about the abilities of users (variable V.4) were positive for all users (see Figure 6.3).

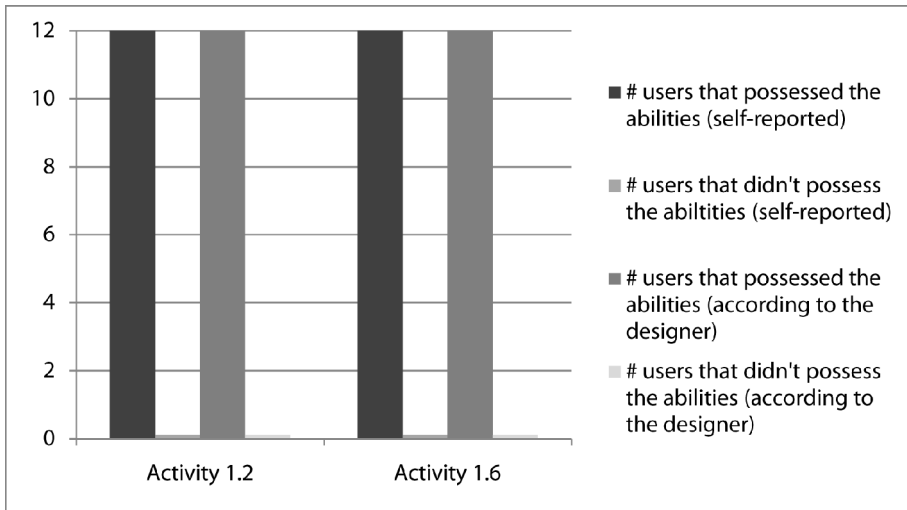


Figure 6.3: The users possessed the abilities to perform activities 1.2 and 1.6

For activities 1.1, 1.3, 1.4, 1.5, 1.7, 1.8 and 1.9, the opinion of the designer about his own abilities (variable V.5) was positive (see Figure 6.4).

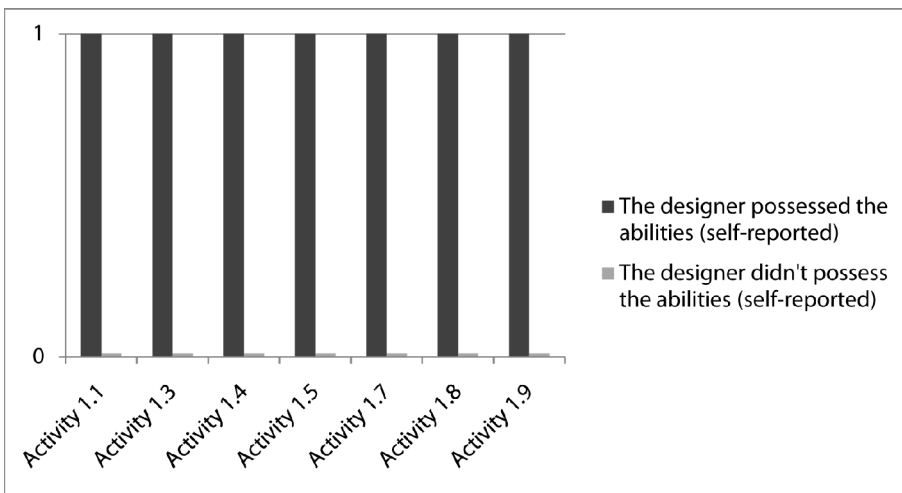


Figure 6.4: The designer possessed the abilities to perform activities 1.1, 1.3, 1.4, 1.5, 1.7, 1.8 and 1.9

Due to the first simplification (see section 4.2.8), activity 1.b (creating an interface for generating test environments) was not performed during the design process. Therefore, strictly spoken, it is unknown whether human actors would be able to perform it. However, since the designer and the users were able to create an interface for generating candidate designs (activity 1.d), it is assumed that they would also be able to create one for generating test environments. Therefore, hypothesis HY.1.a is accepted.

Furthermore, testing hypothesis HY.1.a yielded the following additional findings:

- The identification of two trade-offs that exist during creation of an image of the world relevant to the product (activity 1.1): the level of realism of the scenarios versus the number non-

- recurrent situations that users are confronted with, and the length of scenarios versus the number of iterations that can be performed during a session;
- The identification of two trade-offs that exist during creation of an interface for generating candidate designs (activity 1.1): the number of design parameters that are adaptable for users versus the time required for generating a candidate design, and the time required for generating a candidate designs versus the complexity of the configurator;
 - The identification of a difficulty during creation of the initial design environment and during updating it according to new insights (activities 1.1 and 1.5): the designer needed support from others in accomplishing those activities.

6.2.3 Testing hypothesis HY.2.a

Introduction

Hypothesis HY.2.a is that performing activity 1 (i.e. establishing a design environment) yields actual results. Table 6.6 depicts the variable that was used to test this hypothesis. Table 6.7 specifies the measurement instrument that was used.

<i>Variable</i>	<i>Description</i>
V.6	The design information that is generated

Table 6.6: The dependent variable for testing hypothesis HY.2.a

<i>Instrument</i>	<i>Description</i>	<i>Variable</i>
I.4	Design information (e.g. notes, documents, the design environment, etc.)	V.6

Table 6.7: The measurement instrument and the variable for which it was used

According to Table 4.7, the criterion for acceptance of hypothesis HY.2.a was:

- For every activity, the design information that is generated (variable V.6) should be in line with one of the possible outcomes that is specified by the guidelines.

Activity 1.1

The main results of this activity were:

- A set of traffic scenarios with which can be realistically interacted by means of driving simulator functionality;
- A set of lane change support system technology with which a user could interact in two different ways: by means of the lane change support system configurator and by means of the driving simulation functionality.

However, due to incompatibilities between the two software packages, and insufficient time and money to solve those, a few possibly relevant elements were not implemented.

Secondary results of this activity included:

- A report on supporting spatial-temporal cognition and control during lane change tasks (Tideman & Spenkelink, 2005);
- A document containing requirements to the design environment;
- A document that describes the conceptual design of the design environment;

- Documents containing detailed specifications of the design environment;
- A document that describes the implementation process of the software;
- Sketches, 3D models and prototypes of the hardware;
- Pictures and movies of the physical creation process of the hardware.

Activities 1.2 and 1.3

The results of these activities were notes and audio/video recordings of the behavior of users while interacting with the design environment, as well as notes and audio/video recordings of the opinions of users while reflecting on it.

Activity 1.4

This activity resulted in a list of required adaptations to the design environment.

Activity 1.5

The main results of this activity were:

- An updated set of traffic scenarios;
- An updated set of lane change support system technology;
- An updated lane change support system configurator.

However, due to technical constraints and the limited availability of time and money to solve those, adaptations EDB.10, EDB.11, EDB.12 and EDB.16 (see Table 5.4) and adaptations TDB.3, TDB.4, and TDB.8 (see Table 5.6) were not implemented.

Secondary results of this activity included:

- A document containing requirements to the updated design environment;
- A document that describes the conceptual design of the updated design environment;
- Documents containing detailed specifications of the updated design environment;
- A document that describes the process of updating the software.

Activities 1.6 and 1.7

The results of these activities were notes and audio/video recordings of the behavior of users while interacting with the updated design environment, as well as notes and audio/video recordings of the opinions of users while reflecting on the updates.

Activity 1.8

This activity resulted in a verification of every update and a list of new desired changes and additions to the design environment.

Activity 1.9

This activity consists of repeating activities 1.5 to 1.8 until no more desired changes and additions to the design environment are revealed. Since it was not performed during the design process (see section 5.1.10), strictly spoken, it is unknown whether it would yield actual results. However, since activities 1.5 to 1.8 yielded actual results, it is assumed that activity 1.9 would also yield actual results.

Conclusion

The criterion for acceptance of hypothesis HY.2.a was fulfilled. For every activity, the design information that is generated (variable V.6) was in line with one of the possible outcomes that is specified by the guidelines (see Figure 6.5).

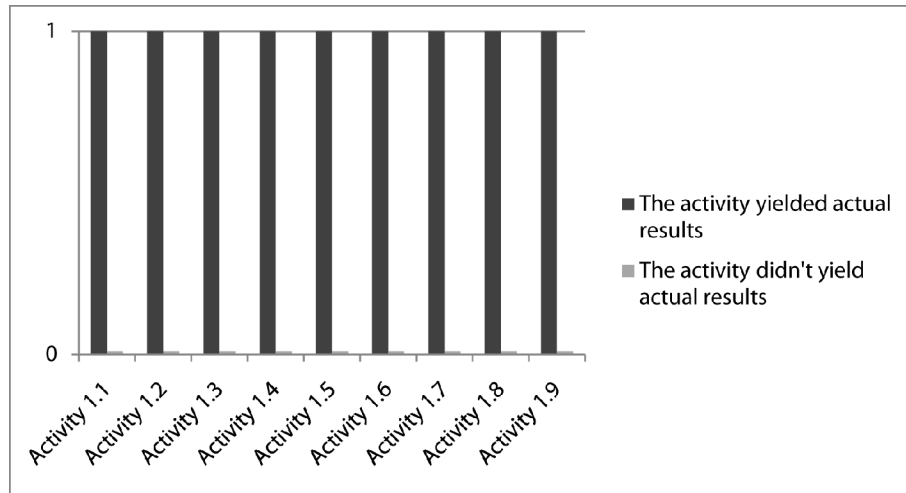


Figure 6.5: Every activity yielded actual results

Due to the first simplification (see section 4.2.8), activity 1.b (creating an interface for generating test environments) was not performed during the design process. Therefore, strictly spoken, it is unknown whether this activity would yield actual results. However, since creating an interface for generating candidate designs (activity 1.d) yielded actual results, it is assumed that creating one for generating test environments would also yield actual results. Therefore, hypothesis HY.2.a is accepted.

Furthermore, testing hypothesis HY.2.a yielded the following additional findings:

- The identification of a difficulty during updating the image of the world relevant to the product (activity 1.5): due to technical constraints and the limited availability of time and money to solve those, some required adaptations were not implemented;
- The identification of a difficulty during creating and updating the overview of the technology relevant to the product (activity 1.1 and 1.5): due to technical constraints and the limited availability of time and money to solve those, some possibly relevant elements and required adaptations were not implemented.

6.2.4 Testing hypothesis HY.3.a

Introduction

Hypothesis HY.3.a is that the guideline for the selection of participants for activity 1 (i.e. establishing a design environment) is correct. This guideline can be found in section 3.2.3. Table 6.8 depicts the variables that were used to test this hypothesis. Table 6.9 specifies the measurement instruments as well as for which variables these were used.

<i>Variable</i>	<i>Description</i>
V.7	The behavior of stakeholders during the reflection sessions
V.8	The type of design information that is generated by stakeholders during the reflection sessions
V.9	The amount of design information that is generated by stakeholders during the reflection sessions
V.10	The ease of stakeholders in getting familiar with new computer interfaces

Table 6.8: The dependent variables for testing hypothesis HY.3.a

<i>Instruments</i>	<i>Description</i>	<i>Variables</i>
I.1	Questionnaires	V.10
I.2	Direct observations	V.7
I.3	Indirect observations (i.e. audio/video recordings)	V.7
I.4	Design information (e.g. notes, documents, the design environment, etc.)	V.8, V.9

Table 6.9: The measurement instruments and the variables for which they were used

According to Table 4.7, the criteria for acceptance of hypothesis HY.3.a were:

- The behavior of stakeholders during the reflection sessions (variable V.7) and/or the type of design information that is generated by stakeholders during the reflection sessions (variable V.8) should differ between stakeholder groups;
- The amount of design information that is generated by stakeholders during the reflection sessions (variable V.9) should correlate with the ease of stakeholders in getting familiar with new computer interfaces (variable V.10).

Testing the first criterion

To test the first criterion, the group of users was divided into 4 “driver support system developers” and 8 “driver support system consumers”. The “developers” all have a professional career in the field of driver support systems, whereas the “consumers” have not. Therefore, the “developers” and the “consumers” have different views on a lane change support system and they may be regarded as different stakeholder groups.

During the reflection and verification sessions, the designer treated the “developers” and the “consumers” in exactly the same way. Since the design environment solely represented the use aspects of a lane change support system, the perspectives of the “developers” were not necessarily completely facilitated. Consequently, they were forced to consider a lane change support system from a “consumer-point-of-view”. However, since all “developers” were also car drivers – and therefore used to this “consumer-point-of-view” - this was no problem for them.

From direct and indirect observations appeared that “driver support system developers” and “consumers” behaved differently during the reflection sessions. “Consumers” exclusively reasoned from their own perspectives in the sense that they only talked about their own preferences. In contrast, “developers” often also took other perspectives into account in the sense that they also thought about in which situations others might need lane change support and about what system features would be desirable/undesirable for others. It also appeared that the reflection sessions triggered “developers” to transfer knowledge that they gained from their own research, from their professional experience, and from literature. In contrast, “consumers” didn’t transfer such knowledge.

Testing the second criterion

To test the second criterion, the group of users was divided into 4 “users that have much difficulty in getting familiar with new computer interfaces” and 8 “users that have little difficulty in getting familiar with new computer interfaces”. The division was made based on questionnaire U1. While dividing the users over the groups, a correlation between “ease of getting familiar with new computer interfaces” and “view on driver support systems” was found: the group of “driver support system developers” exclusively consists of “users that have little difficulty in getting familiar with new computer interfaces”; the group of “users that have much difficulty in getting familiar with new computer interfaces” exclusively consists of “consumers”. Furthermore, it appeared that “users that have much difficulty in getting familiar with new computer interfaces” were averagely older and lower educated than “users that have little difficulty in getting familiar with new computer interfaces”.

Figure 6.6 depicts the number of adaptations to the design environment that were proposed by every user group. It is also shown how many of these adaptations concerned the environment database, the technology database and the lane change support system configurator. Please note that, in Figure 6.6, the two scales along which users were divided are combined so that:

- The first bar shows the number of adaptations proposed by the 4 *consumers* that have *much difficulty* in getting familiar with new computer interfaces;
- The second bar shows the number of adaptations proposed by the 4 *consumers* that have *little difficulty* in getting familiar with new computer interfaces;
- The third bar shows the number of adaptations proposed by the 4 *developers* that have *little difficulty* in getting familiar with new computer interfaces.

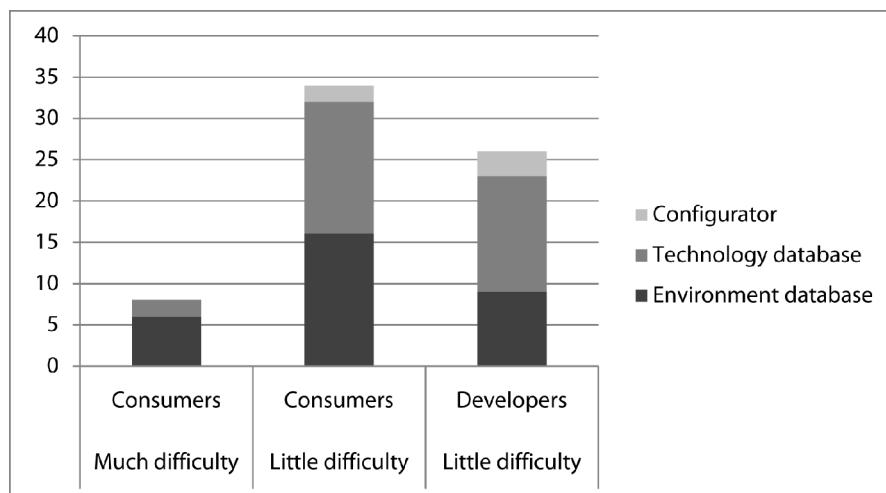


Figure 6.6: The number of proposed adaptations per user group

Figure 6.6 shows that there were large differences in the amount of generated design information between “users that have much difficulty in getting familiar with new computer interfaces” and “users that have little difficulty in getting familiar with new computer interfaces”. The 4 “consumers that have much difficulty with getting familiar with new computer interfaces” proposed - by far - the lowest number of adaptations (8). They also scored lowest for every separate category. The 4 “consumers that

have little difficulty with getting familiar with new computer interfaces” proposed the most adaptations (34). For two of the four adaptation types, they also scored higher than anybody else. Only for adaptations that regard the lane change support system configurator, “developers” proposed more adaptations (3 versus 2).

Conclusion

Both criteria for acceptance of hypothesis HY.3.a were fulfilled:

- The behavior of stakeholders during the reflection sessions (variable V.7) and the type of design information that is generated by stakeholders during the reflection sessions (variable V.8) differed between stakeholder groups;
- The amount of design information that is generated by stakeholders during the reflection sessions (variable V.9) correlated with the ease of stakeholders in getting familiar with new computer interfaces (variable V.10).

Therefore, hypothesis HY.3.a is accepted.

6.2.5 Testing hypothesis HY.4.a

Introduction

Hypothesis HY.4.a is that the new product design method stimulates and enables human actors (i.e. designer and stakeholders) to generate design information (fulfillment of function RF.1), to represent the generated design information such that it is easily accessible for all stakeholders (fulfillment of function RF.2), and to make sure that the represented design information is consistent (fulfillment of function RF.3). Table 6.10 depicts the variables that were used to test this hypothesis. Table 6.11 specifies the measurement instrument as well as for which variables it was used.

<i>Variable</i>	<i>Description</i>
V.14	The opinion of the designer about the extent to which stakeholders seemed stimulated to perform activities
V.15	The opinion of the designer about the extent to which stakeholders seemed enabled to perform activities
V.16	The opinion of the designer about the extent to which he felt stimulated to perform activities
V.17	The opinion of the designer about the extent to which he felt enabled to perform activities

Table 6.10: The dependent variables for testing hypothesis HY.4.a

<i>Instrument</i>	<i>Description</i>	<i>Variables</i>
I.1	Questionnaires	V.14, V.15, V.16, V.17

Table 6.11: The measurement instrument and the variables for which it was used

According to Table 4.7, the criteria for acceptance of hypothesis HY.4.a were:

- For function RF.1, the opinion of the designer about the extent to which stakeholders seemed *stimulated* to perform activities (variable V.14), and the opinion of the designer about the extent to which stakeholders seemed *enabled* to perform activities (variable V.15) should be positive for at least 80% of the stakeholders;
- For every function, the opinion of the designer about the extent to which he felt *stimulated* to perform activities (variable V.16) and the opinion of the designer about the extent to which he felt *enabled* to perform activities (variable V.17) should be positive.

Function RF.1

From the answers given in questionnaire D14 followed that the designer felt *stimulated* to create an environment that gives a detailed description of the “problem-solution space” of a lane change support system. The designer also felt stimulated to generate design information in the form of documents about the creation process of this environment. He realized that establishing such an environment is a “design and production process” of its own, and that a detailed and accurate documentation increases the effectiveness and efficiency of such a creation process. From the answers given in questionnaire D14 also followed that the designer felt *enabled* to actually establish the environment. However, he remarked that this was not due to the new product design method per se, but due to the facilities (e.g. time, money, help from others) that happened to be available.

From the answers given in questionnaire D15 followed that the designer felt that all users were *stimulated* to generate design information. During the reflection and verification sessions, they were triggered continuously - and in multiple different ways - to do so. For example, they were triggered by events in the scenarios, by the possibilities that the lane change support system configurator offered, by the behavior of the self-configured designs in the scenarios, and by the designer who asked them all kinds of questions. From the answers given in questionnaire D15 also followed that the designer felt that all users were *enabled* to generate design information. During the reflection and verification sessions, there was sufficient time available to let them say everything that they wanted to say, and to let them do everything they wanted to do.

Function RF.2

From the answers given in questionnaire D17 followed that the designer felt *stimulated* to represent the generated design information such that it is easily accessible for all users. During creating and updating the design environment, the designer continuously realized that representing all design information such that it is understandable for all users is essential for the success of the design process. If users would not be able to understand and interact with the design information, the design process would immediately stop without having a result. From the answers given in questionnaire D17 also followed that the designer felt *enabled* to represent the generated design information such that it is easily accessible for all users. The designer remarked that this task may require performing a preliminary test on the complexity level that users can handle. But on the other hand, if the initial design environment would have appeared too complex, the designer would have had the chance to correct this during the updating process.

Function RF.3

From the answers given in questionnaire D16 followed that the designer felt *stimulated* to make sure that the represented design information is consistent. The generated design information, which originated from many different sources, had to be combined into one single simulation model. This implied that the information had to be made consistent. From the answers given in questionnaire D16 also followed that the designer felt *enabled* to make sure that the represented design information is consistent. However, the designer remarked that, due to technical constraints and the limited availability of time and money to solve those, some possibly relevant elements and required adaptations were not implemented into the simulation model. The absence of the elements and adaptations in question can be considered as inconsistencies in the represented design information.

Conclusion

Both criteria for acceptance of hypothesis HY.4.a were fulfilled.

For function RF.1, the opinion of the designer about the extent to which users seemed *stimulated* to perform activities (variable V.14), and the opinion of the designer about the extent to which users seemed *enabled* to perform activities (variable V.15) were positive for all users (see Figure 6.7).

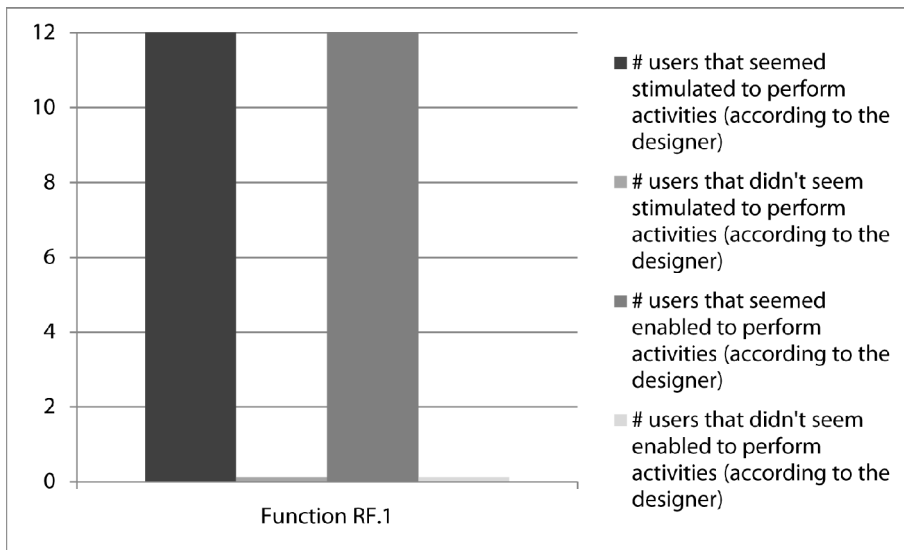


Figure 6.7: Function RF.1 is fulfilled (as far as the users are concerned)

For every function, the opinion of the designer about the extent to which he felt *stimulated* to perform activities (variable V.16) and the opinion of the designer about the extent to which he felt *enabled* to perform activities (variable V.17) were positive (see Figure 6.8).

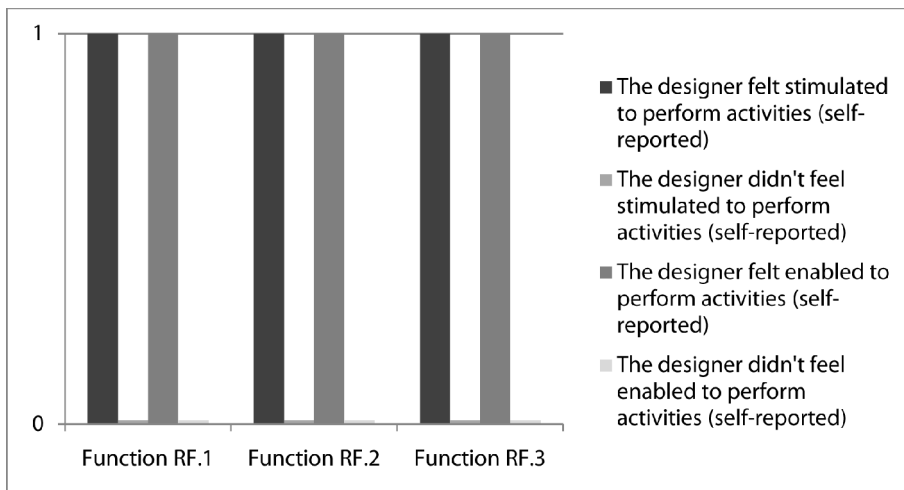


Figure 6.8: Functions RF.1, RF.2 and RF.3 are fulfilled (as far as the designer is concerned)

Therefore, hypothesis HY.4.a is accepted.

Furthermore, testing hypothesis HY.4.a yielded the following additional finding:

- The identification of a difficulty during making sure that the represented design information is correct (function RF.3): due to technical constraints and the limited availability of time and money to solve those, some possibly relevant elements and required adaptations were not implemented. The absence of the elements and adaptations in question can be considered as inconsistencies in the represented design information.

6.3 Second experiment: assessing the second phase of the design process

6.3.1 Specification

Table 6.12 shows the hypotheses that were tested during the experiment. Table 6.13 shows the criteria for acceptance of every hypothesis. The tables are copies of Table 4.4 and Table 4.8, respectively. The variables "V" in Table 6.13 refer back to Table 4.5.

<i>Hypothesis</i>	<i>Description</i>
HY.1.b	Human actors are able to perform activity 2 (as it was specified in section 3.1.4).
HY.2.b	Activity 2 yields actual results.
HY.3.b	The guideline for the selection of participants for activity 2 (as it was formulated in section 3.2.11) is correct.
HY.4.b	Functions RF.4, RF.5, RF.6 and RF.7 (see Table 4.2) are fulfilled.

Table 6.12: The hypotheses that were tested during the second experiment

<i>Hypothesis</i>	<i>Criteria for acceptance</i>
HY.1.b	For every activity, V.1 and V.2 should be high for at least 80% of the stakeholders. For every activity, V.3 and V.4 should be positive for at least 80% of the stakeholders. For every activity, V.5 should be positive.
HY.2.b	For every activity, V.6 should be in line with one of the possible outcomes that is specified by the guidelines.
HY.3.b	V.11 should differ between stakeholder groups.
HY.4.b	For every function, V.12, V.13, V.14 and V.15 should be positive for at least 80% of the stakeholders. For every function, V.16 and V.17 should be positive.

Table 6.13: The criteria for acceptance of the hypotheses that were tested during the second experiment

The experiment involved 49 participants: 48 users and 1 designer. None of the participating users was also involved in the first experiment. However, the designer was the same person as during the first experiment. The data collection process did not interfere with the design process, except for that participants were required to fill out additional questionnaires. Table 6.14 gives an overview of the questionnaires that had to be completed. The total set of questionnaires is depicted in Appendix G.

<i>Activity</i>	<i>Description</i>	<i>Questionnaires designer</i>	<i>Questionnaires users</i>
2.1	All stakeholders adapt technology parameters, thus generating candidate designs.	D18	U5, U6
2.3	All stakeholders test the candidate designs in the test environments, and reflect on the degree to which they fulfill their needs.	D19	U7
2.4	The designer registers the behavior of stakeholders while generating candidate designs, generating test environments, and testing the candidate designs in the test environments. The designer also registers the opinions of stakeholders while reflecting on the degree to which the candidate designs fulfill their needs.	D20, D21, D22, D23	U8, U9, U10
2.5	The designer uses the registered information to specify attractive designs for each stakeholder.	D24	-
2.6	If not all "attractive designs" are identical, the designer organizes the registered information into a hierarchy that is meaningful from a stakeholder's perspective.	D25	-
2.7	The designer uses the hierarchy to specify a compromise between the preferences of all stakeholders.	D26, D27	-

Table 6.14: The questionnaires that needed to be completed during the second experiment

6.3.2 Testing hypothesis HY.1.b

Introduction

Hypothesis HY.1.b is that human actors (i.e. designer and stakeholders) are able to perform activity 2 (i.e. are able to specify a good design). Table 6.15 depicts the variables that were used to test this hypothesis. Table 6.16 specifies the measurement instruments as well as for which variables these were used.

<i>Variable</i>	<i>Description</i>
V.1	The extent to which stakeholders act according to the instructions given by the designer
V.2	The extent to which stakeholders answer the questions of the designer
V.3	The opinion of stakeholders about their own abilities
V.4	The opinion of the designer about the abilities of stakeholders
V.5	The opinion of the designer about his own abilities

Table 6.15: The dependent variables for testing hypothesis HY.1.b

<i>Instrument</i>	<i>Description</i>	<i>Variables</i>
I.1	Questionnaires	V.3, V.4, V.5
I.2	Direct observations	V.1, V.2
I.3	Indirect observations (i.e. audio/video recordings)	V.1, V.2

Table 6.16: The measurement instruments and the variables for which they were used

According to Table 4.8, The criteria for acceptance of hypothesis HY.1.b were:

- For activities 2.1 and 2.3, the extent to which stakeholders act according to the instructions given by the designer (variable V.1) and the extent to which stakeholders answer the questions of the designer (variable V.2) should be high for at least 80% of the stakeholders;

- For activities 2.1 and 2.3, the opinion of stakeholders about their own abilities (variable V.3) and the opinion of the designer about the abilities of stakeholders (variable V.4) should be positive for at least 80% of the stakeholders;
- For activities 2.4, 2.5, 2.6 and 2.7, the opinion of the designer about his own abilities (variable V.5) should be positive.

Activity 2.1

From direct and indirect observations appeared that all users were able to generate candidate designs by adapting technology parameters. Some users took longer than others; some needed a little help during the practicing phase whereas others understood it right away. But, in the end, everybody was able to do it. It appeared that an electronic questionnaire - in which the set of technology relevant to the product is represented by descriptions in natural language, images, and previews of the behavior of the technology - lets users effectively and efficiently form a mental model of the product's functional architecture. It enables users to make choices. The fact that choices could be made by simply touching the screen appeared to make the operation intuitively understandable: all users were able to operate it right away.

From the answers given in questionnaire U6 followed that all 48 users felt that they were able to generate candidate designs by adapting technology parameters. Seventeen users made an additional remark about the lane change support system configurator. Three users complimented its usability (P13, P32, P33). Four users remarked that it took them some time to oversee all the options that were offered (P5, P6, P11, P31). Seven users made a remark about the conciseness of the formulations, the font size, and the size of the radio buttons (P1, P2, P8, P14, P20, P37, P45). Two users suggested the integration of additional shortcut and memory functions into the lane change support system configurator to speed up the generation of redesigns (P16, P36). Finally, one user stated that the position of the lane change support system configurator made it difficult to operate for left-handed people (P34). These remarks confirm the existence of one of the trade-offs that were identified by the designer (see section 6.2.2): the trade-off between the time required for generating a candidate design and the complexity of the configurator. However, these remarks also imply that an additional trade-off exists during creation of the interface for adapting technology parameters. The 5-dimensional trade-off between the aesthetic design of the interface, the clarity of the explanations, the conciseness of the descriptions, the font size, and the size of the radio buttons.

From the answers given in questionnaire D18 followed that the designer felt that all users were able to generate candidate designs by adapting technology parameters. For nine users, the designer made an additional remark. Seven of those were about the surprisingly high pace with which users operated the lane change support system configurator (P2, P12, P14, P20, P26, P36, P46). P14 even operated it with two hands. On the other hand, two remarks were about the surprisingly low pace with which users operated the lane change support system configurator (P3, P11). However, the designer also remarked that this was certainly not because they didn't understand it. It was more that the users in question were at times a little indecisive. Summarizing, it appeared that there were significant individual differences in the pace with which users generate candidate designs.

Furthermore, users appeared to have two different strategies for generating candidate designs. The first strategy is to start out with generating and testing a candidate design that complies with (expected)

preferences. Subsequent iterations are then used to fine-tune it. The second strategy is to use the first couple of iterations to generate and test “random designs”, just to see what possibilities the technology database offers and to experience the behavior of some different technologies. The last couple of iterations are then used to quickly iterate towards a personal “most attractive system”.

Activity 2.3

From direct and indirect observations appeared that all users were able to test the generated candidate designs in the test environments, and to reflect on the degree to which the designs fulfill their needs. Some users were better “test drivers” than others; some gave more and more detailed information than others; some started talking automatically whereas others needed to be “pushed a little”. But, in the end, everybody was able to do it.

From the answers given in questionnaire U7 followed that 42 of the 48 users felt that they were able to test the generated candidate designs in the test environments, and to reflect on the degree to which the designs fulfill their needs. This means that there were 6 users that had doubts about this. The remarks made by these users exemplified these doubts:

- The traffic scenarios were not critical enough in the sense that more unusual or dangerous situations should occur (P5);
- It took sometimes a long time before the traffic situation that was required to properly test the system occurred in the traffic scenario (P16);
- I would have liked to configure traffic scenarios myself (P18);
- The traffic scenario that was offered was not always tuned to what I wanted to test in a specific iteration (P24, P29);
- The set of traffic scenarios should have contained a weaving lane (P28).

The remarks indicated that not being able to test the generated candidate designs in the test environments was not due to *insufficient abilities* of users, but due to *insufficient facilities* offered by the design environment. The third simplification (i.e. not performing activities 2.2 and 2.4) was experienced as too constraining. The remarks made by users who answered positively to the question whether they felt able to test the generated candidate designs in the test environments also pointed in this direction. No less than twelve users commented on the contents of the traffic scenarios (P9, P10, P11, P17, P19, P20, P26, P31, P37, P42, P47, P48). The tenor of these remarks was that the traffic scenario that was offered was not always tuned to what the user wanted to test in a specific iteration, and that this should be solved by allowing users to generate scenarios themselves. Furthermore, three users remarked that they found it difficult to test the systems and to reflect on them (P4, P12, P35), but these users didn’t elaborate on why they found that difficult. Four users made a compliment about the quality of the set of traffic scenarios (P6, P20, P34, P45). Finally, one user remarked that he liked that it was possible to perform maneuvers that he wouldn’t perform in real traffic (P36).

From the answers given in questionnaire D19 followed that the designer felt that all users were able to test the generated candidate designs in the test environments, and to reflect on the degree to which the designs fulfill their needs. For six users, the designer made an additional remark. P9 kept having doubts about what would be the “most attractive system”. P19 initially drove relatively slowly because he needed some more time to get used to the driving simulator functionality. Four users were complimented on their testing and reflecting behavior (P2, P44, P45, P46).

Furthermore, users appeared to have two different strategies for testing candidate designs. The first strategy is to behave normally, in order to find out how a design would work under normal circumstances. The second strategy is to behave like a “test driver” (i.e. to perform dangerous maneuvers that would never be performed in real traffic). This behavior is typically aimed at finding out where the system borders of the specific lane change support system design lie, and how the system behaves under dangerous circumstances. Most users, however, follow a combination of both strategies. For example, they use the first stretch of the traffic scenario to drive normally, the second stretch to perform a couple of dangerous maneuvers, and the third stretch to drive normally again.

Activity 2.4

From the answer given in questionnaire D20 followed that the designer was able to register the behavior of all users while generating candidate designs, to register the behavior of all users while testing the candidate designs in the test environments, and to register the opinions of all users while reflecting on them. For none of the users, the designer was able to register their behavior while generating test environments, but this was solely due to the first simplification (see section 4.2.8). For three users (P18, P40, P46), the designer made an additional remark. These all regarded the fact that the users in question were thus triggered by the design environment and/or the design process that they even needed to be tempered in their enthusiasm.

Activity 2.5

From the answers given in questionnaire D24 followed that, for every user, the designer was able to identify the design that best fulfills his needs and best exploits the technological potential. This was done by creating personal reports. Each personal report reflected a user’s preferences for a lane change support system, both “objectively” and “subjectively”. For two users (P30, P41), the designer made an additional remark. Both remarks regarded the fact that, initially, the users in question did not desire any lane change support. However, during the design session they both discovered that a lane change support system could be useful and pleasant. Apparently, the design environment not only functioned as a design tool, but also as a tool for making users familiar with new technology and as a tool for letting users experience the potential benefits of new technology.

Activity 2.6

From questionnaire D25 followed that the designer was able to develop a coding system for organizing the generated information into a hierarchy. To improve the coding system’s reliability, the designer received help from a trained rater. With the coding system, the designer was able to code the subjective information in all 48 personal reports, as well as to re-organize the objective information into categories that are meaningful from a user’s perspective. The software tool AtlasTI proved to be useful during these processes.

Activity 2.7

From questionnaire D26 followed that the designer was able to use the hierarchy of information to specify a compromise between the preferences of all stakeholders. To test this, the preferences of all users were combined with a (hypothetical) constraint of an (imaginary) lane change support system manufacturer. The designer was also able to use the hierarchy of information to specify why users would be attracted to this compromise, what they might not like about it, and how this is related to the circumstances under which they use the lane change support system.

Conclusion

All criteria for acceptance of hypothesis HY.1.b were fulfilled.

For activities 2.1 and 2.3, the extent to which users acted according to the instructions given by the designer (variable V.1) and the extent to which users answered the questions of the designer (variable V.2) were high for all users (see Figure 6.9).

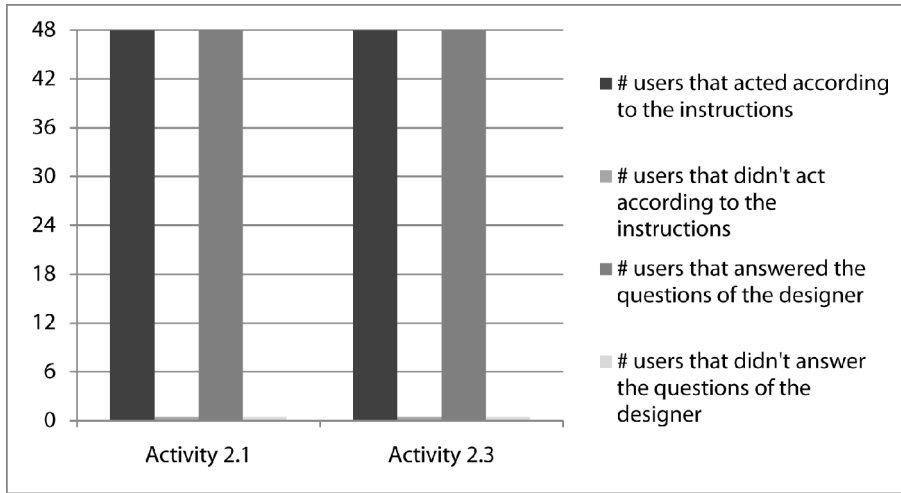


Figure 6.9: The users acted according to the instructions and answered the questions of the designer during activities 2.1 and 2.3

For activity 2.1, the opinion of users about their own abilities (variable V.3) and the opinion of the designer about the abilities of users (variable V.4) were positive for all users. For activity 2.3, the opinion of users about their own abilities (variable V.3) was positive for 87,5% of the users, and the opinion of the designer about the abilities of users (variable V.4) was positive for all users (see Figure 6.10).

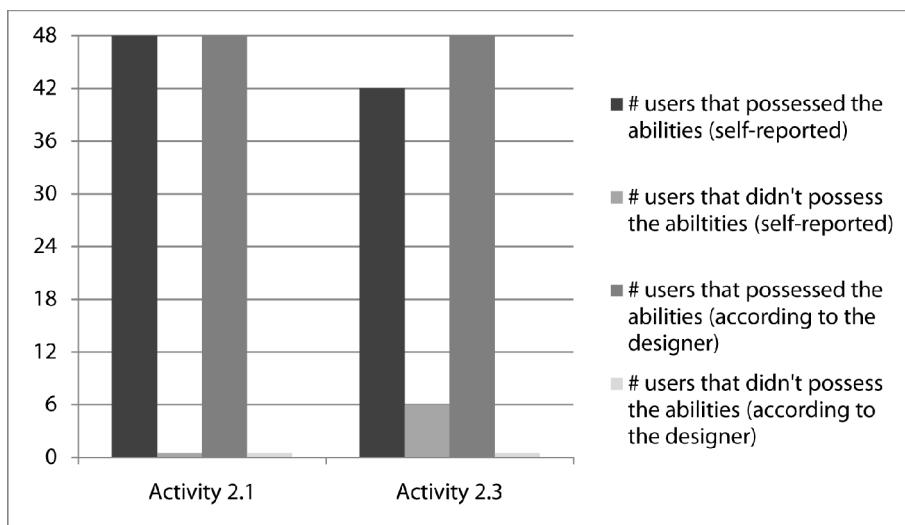


Figure 6.10: The users possessed the abilities to perform activities 2.1 and 2.3

For activities 2.4, 2.5, 2.6 and 2.7, the opinion of the designer about his own abilities (variable V.5) was positive (see Figure 6.11).

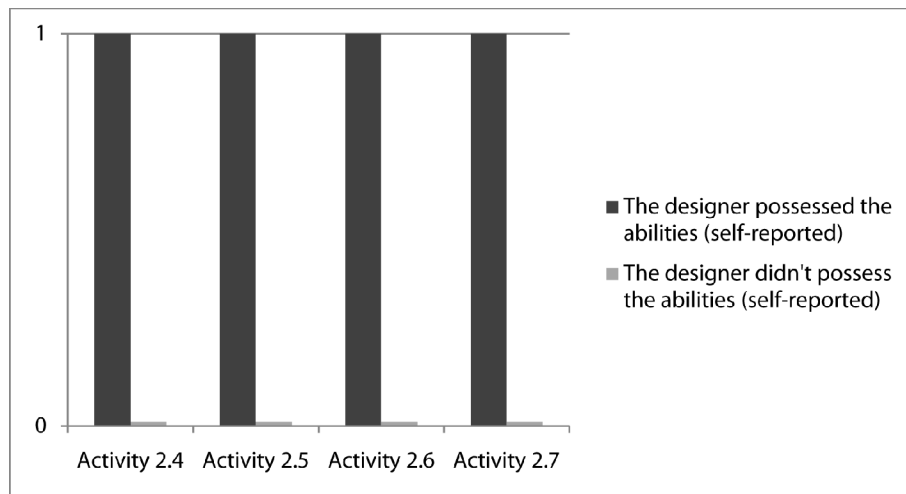


Figure 6.11: The designer possessed the abilities to perform activities 2.4, 2.5, 2.6 and 2.7

Due to the first simplification (see section 4.2.8), activity 2.2 (users adapting environment parameters, thus generating test environments) was not performed during the design process. Therefore, strictly spoken, it is unknown whether users would be able to perform it. However, since the users were able to adapt technology parameters, thus generating candidate designs (activity 2.1), it is assumed that they would also be able to create test environments. Therefore, hypothesis HY.1.b is accepted.

Furthermore, testing hypothesis HY.1.b yielded the following additional findings:

- The confirmation of a trade-off that exists during creation of an overview of the technology relevant to the product, as it was identified during activity 1.1 (activity 2.1): the time required for generating a candidate design versus the complexity of the configurator;
- The identification of a trade-off that exists during creation of an overview of the technology relevant to the product (activity 2.1): the aesthetic design of the interface versus the clarity of the explanations versus the conciseness of the descriptions versus the font size versus the size of the radio buttons.;
- The identification of two different strategies for generating candidate designs (activity 2.1): starting out with generating and testing a candidate design that complies with (expected) preferences and using subsequent iterations to fine-tune it versus using the first couple of iterations to generate and test "random designs" and using subsequent iterations to quickly iterate towards a personal "most attractive system";
- The confirmation that users should be allowed to generate scenarios themselves (activity 2.3): the traffic scenario that was offered was not always tuned to what the user wanted to test in a specific iteration;
- The identification of two different strategies for testing candidate designs (activity 2.3): behaving normally to find out how a design would work under normal circumstances versus behaving like a "test driver" (i.e. to perform dangerous maneuvers that would never be

performed in real traffic) to find out where the system borders of the specific lane change support system design lie, and how the system behaves under dangerous circumstances;

- The identification of an opportunity during specification of attractive designs (activity 2.5): the design environment not only functioned as a design tool, but also as a tool for making users familiar with new technology and as a tool for letting users experience the potential benefits of new technology.

6.3.3 Testing hypothesis HY.2.b

Introduction

Hypothesis HY.2.b is that performing activity 2 (i.e. specifying a good design) yields actual results. Table 6.17 depicts the variable that was used to test this hypothesis. Table 6.18 specifies the measurement instrument that was used.

<i>Variable</i>	<i>Description</i>
V.6	The design information that is generated

Table 6.17: The dependent variable for testing hypothesis HY.2.b

<i>Instrument</i>	<i>Description</i>	<i>Variable</i>
I.4	Design information (e.g. notes, documents, the design environment, etc.)	V.6

Table 6.18: The measurement instrument and the variable for which it was used

According to Table 4.8, the criterion for acceptance of hypothesis HY.2.b was:

- For every activity, the design information that is generated (variable V.6) should be in line with one of the possible outcomes that is specified by the guidelines.

Activity 2.1

This activity resulted in a set of data files that contain the specifications of the candidate designs that were generated by users.

Activities 2.3 and 2.4

These activities resulted in notes and audio/video recordings of the behavior of users while generating and testing candidate designs, as well as notes and audio/video recordings of the opinions of users while reflecting on the candidate designs.

Activities 2.5, 2.6 and 2.7

These activities resulted in:

- 48 personal reports, each reflecting a user's preferences for a lane change support system;
- A reliable coding system for organizing the generated information into a hierarchy;
- A hierarchy of information, containing both objective information and subjective information, and both "technology information" and "environment information";
- A document in which the preferences of users were combined with a (hypothetical) constraint of an (imaginary) lane change support system manufacturer and a compromise was found;

- A specification of why users would be attracted to this compromise, what they might not like about it, and how this is related to the circumstances under which they use the lane change support system.

Conclusion

The criterion for acceptance of hypothesis HY.2.b was fulfilled. For every activity, the design information that is generated (variable V.6) was in line with one of the possible outcomes that is specified by the guidelines (see Figure 6.12).

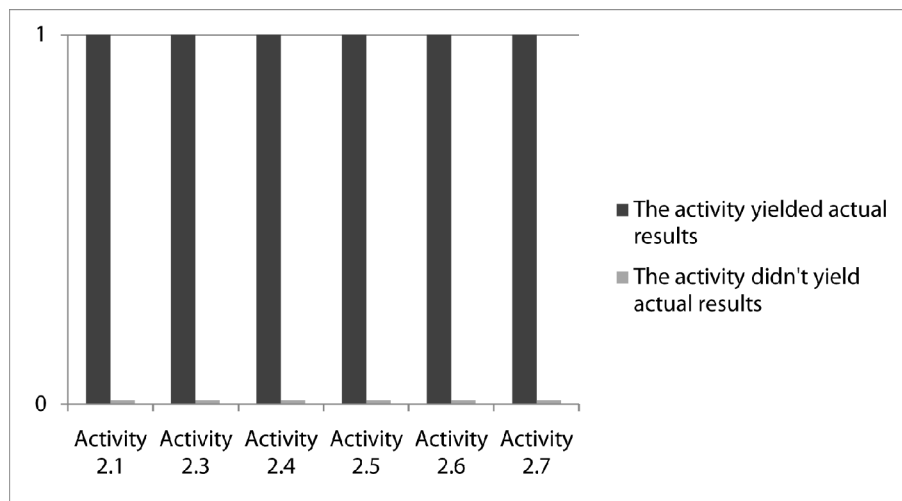


Figure 6.12: Every activity yielded actual results

Due to the first simplification (see section 4.2.8), activity 2.2 (users adapting environment parameters, thus generating test environments) was not performed during the design process. Therefore, strictly spoken, it is unknown whether this activity would yield actual results. However, since generating candidate designs (activity 2.1) yielded actual results, it is assumed that generating test environments would also yield actual results. Therefore, hypothesis HY.2.b is accepted.

6.3.4 Testing hypothesis HY.3.b

Introduction

Hypothesis HY.3.b is that the guideline for the selection of participants for activity 2 (i.e. specifying a good design) is correct. This guideline can be found in section 3.2.11. Table 6.19 depicts the variables that were used to test this hypothesis. Table 6.20 specifies the measurement instrument as well as for which variables it was used.

Variable	Description
V.11	The opinions of stakeholders about how positive and negative consequences of choices should be weighed

Table 6.19: The dependent variables for testing hypothesis HY.3.b

<i>Instrument</i>	<i>Description</i>	<i>Variables</i>
I.4	Design information (e.g. notes, documents, the design environment, etc.)	V.11

Table 6.20: The measurement instrument and the variables for which it was used

According to Table 4.8, the criterion for acceptance of hypothesis HY.3.b was:

- The opinions of stakeholders about how positive and negative consequences of choices should be weighed (variable V.11) should differ between stakeholder groups.

Testing the criterion

To properly test the criterion, representatives from different stakeholder groups should have been invited. Correlations between the “perspective on a lane change support system” and the “stakeholder’s opinions about how positive and negative consequences of choices should be weighed” would have indicated that the guideline is correct. However, since the design environment solely represented the “use aspects” of a lane change support system, and perspectives of other stakeholder groups were not necessarily facilitated, it was impossible to perform such an experiment. Representatives from stakeholder groups whose perspectives were not facilitated would have been forced to consider the product from a user’s perspective. Consequently, opinions from their perspectives would have been unreliable.

Therefore, the criterion was tested differently. The group of users was divided according to the exact same scales that the designer used during the second phase of the design process: “age” and “driving style”. This resulted in a group of 24 “young users” versus a group of 24 “old users”, and a group of 24 “aggressive users” versus a group of 24 “non-aggressive users” (see also section 5.2.2). It was assumed that these were actually four different “stakeholder groups”, instead of subgroups of the stakeholder group “users”. This means that it was assumed that the representatives of each of these groups have a unique view on a lane change support system. Accordingly, differences in the opinions about how positive and negative consequences of choices should be weighed between representatives of these groups would indicate that the criterion is fulfilled.

As described in section 5.2.6, the designer found the following correlations the age of users and their preferences:

- Young users are particularly fond of hybrid systems, whereas old users are particularly fond of safety systems;
- Young users are particularly fond of support about vehicles that are either close to (0-10m) or far away from the subject vehicle (40-50m). Old users, on the other hand, are particularly fond of support about vehicles that are 15-35m away from the subject vehicle;
- Young users are fonder of kinesthetic support than old users.

Furthermore, the designer found the following correlations between the driving style of users and their preferences:

- Aggressive users are particularly fond of hybrid systems, whereas non-aggressive users are particularly fond of safety systems;

- Aggressive users are particularly fond of support about vehicles that are far away from the subject vehicle (50m). Non-aggressive users, on the other hand, are particularly fond of support about vehicles that are closer (0-40m) to the subject vehicle;

Finally, the designer found a correlation between the *combination of age and driving style* and the preferences of users: it appeared that the preferences of an aggressive user for a specific support modality strongly depend on his age. Young aggressive users are fonder of visual and kinesthetic support than old aggressive users, whereas old aggressive users are fonder of auditory support than young aggressive users.

Conclusion

The criterion for acceptance of hypothesis HY.3.b was fulfilled:

- The opinions of stakeholders about how positive and negative consequences of choices should be weighed (variable V.11) differed between stakeholder groups.

Therefore, hypothesis HY.3.b is accepted.

6.3.5 Testing hypothesis HY.4.b

Introduction

Hypothesis HY.4.b is that the new product design method stimulates and enables human actors (i.e. designer and stakeholders) to give opinions about the represented design information (fulfillment of function RF.4), to verify their opinions about the represented design information (fulfillment of function RF.5), to weigh positive and negative consequences of choices (fulfillment of function RF.6), and to find a compromise between the preferences of all stakeholders (fulfillment of function RF.7). Table 6.21 depicts the variables that were used to test this hypothesis. Table 6.22 specifies the measurement instrument as well as for which variables it was used.

Variable	Description
V.12	The opinion of stakeholders about the extent to which they felt stimulated to perform activities
V.13	The opinion of stakeholders about the extent to which they felt enabled to perform activities
V.14	The opinion of the designer about the extent to which stakeholders seemed stimulated to perform activities
V.15	The opinion of the designer about the extent to which stakeholders seemed enabled to perform activities
V.16	The opinion of the designer about the extent to which he felt stimulated to perform activities
V.17	The opinion of the designer about the extent to which he felt enabled to perform activities

Table 6.21: The dependent variables for testing hypothesis HY.4.b

Instrument	Description	Variables
I.1	Questionnaires	V.12, V.13, V.14, V.15, V.16, V.17

Table 6.22: The measurement instrument and the variables for which it was used

According to Table 4.8, the criteria for acceptance of hypothesis HY.4.b were:

- For functions RF.4, RF.5 and RF.6, the opinion of stakeholders about the extent to which they felt *stimulated* to perform activities (variable V.12), and the opinion of stakeholders about the extent to which they felt *enabled* to perform activities (variable V.13) should be positive for at least 80% of the stakeholders;

- For functions RF.4, RF.5 and RF.6, the opinion of the designer about the extent to which stakeholders seemed *stimulated* to perform activities (variable V.14), and the opinion of the designer about the extent to which stakeholders seemed *enabled* to perform activities (variable V.15) should be positive for at least 80% of the stakeholders;
- For function RF.7, the opinion of the designer about the extent to which he felt *stimulated* to perform activities (variable V.16) and the opinion of the designer about the extent to which he felt *enabled* to perform activities (variable V.17) should be positive.

Function RF.4

From questionnaire U8 followed that all 48 users answered positively to the question whether they were *stimulated* to give opinions about the represented design information. Eight users made an additional remark. Seven of those (P8, P11, P24, P29, P30, P32, P37) were complimentary. These users remarked that they had the feeling to have said everything they wanted to say, that they felt stimulated by the conversations with the designer after every design iteration, and that it was nice that the designer kept pushing for answers. One user made a critical remark (P19). He indicated that he would have needed more time to be able to fully empathize with the design problem. Multiple design sessions that each take less time (e.g. design sessions that take place a couple of days in a row, but that each take approximately 45 minutes) would have given him the chance to let his thoughts settle overnight. He expected that this would make his opinions to be more reliable. From questionnaire U8 also followed that all 48 users answered positively to the question whether they were *enabled* to give opinions about the represented design information. Three users made an additional remark (P6, P11, P31). These users said that there was sufficient time and that there were sufficient possibilities to form an opinion and to communicate this opinion.

From questionnaire D21 followed that, for all users, the designer answered positively to the question whether users appeared to be stimulated and enabled to give opinions about the represented design information. For four users, the designer made an additional remark (P9, P37, P39, P42). All four users couldn't stop talking about their experiences and preferences. P37 even explained his considerations about every option that was offered by the lane change support system configurator.

Function RF.5

From questionnaire U9 followed that 46 of the 48 users felt *stimulated* to verify their opinions about the represented design information. This means that there were 2 users who had doubts about this. However, the users in question didn't leave remarks on the questionnaire to exemplify these doubts. Eight other users did leave an additional remark. Half of them were complimentary (P2, P4, P6, P37). These users said that it was fun to verify the opinions, that it was pleasant that there is a "build up" to the "ideal system", that they felt stimulated to make maneuvers just to test the support system's behavior, and that they felt stimulated to configure another system as a result of their opinions about previous systems. The other half of the remarks was critical (P8, P16, P30, P45). These users said that it was sometimes difficult to translate opinions about a previous system to a new configuration, that opinions would probably be different for longer rides, that they sometimes had to provoke a certain traffic situation to test the system, and that they wanted to be more stimulated to be a test-driver during evaluation (instead of just driving according to the traffic rules). From questionnaire U9 also followed that all 48 users felt *enabled* to verify their opinions about the represented design information. Seven users left an additional remark. Three were complimentary (P11, P34, P37). Users said that there

was plenty of time and there were plenty of opportunities available to verify opinions, that the designer provided sufficient help during redesigning, and that there were sufficient simulation possibilities. Four remarks were critical (P1, P16, P21, P24). The tenor of these remarks was that the traffic scenario that was offered was not always tuned to what the user wanted to test in a specific iteration, and that this should be solved by allowing users to generate scenarios themselves.

From questionnaire D22 followed that, for all users, the designer answered positively to the question whether users appeared to be stimulated and enabled to verify their opinions about the represented design information. For no less than twenty-eight users, the designer made additional remarks. These remarks all contained examples of how the designer stimulated (or sometimes even convinced) users to configure and test another system to verify their opinions. The designer always did this by asking questions such as: "Are you sure that feature A is better than feature B?" Or: "You seem to be sure that feature A is better than feature B, but how does that change when you combine feature B with feature C?" Because the designer had such a good knowledge of the possibilities that were present in the technology database, it was never difficult for him to formulate such questions.

Function RF.6

From questionnaire D23 followed that all users were stimulated and enabled to weigh positive and negative consequences of choices. The fact that users were given a proactive role in the design process appeared to contribute to this. Many users appeared to feel "responsible" for the success of the design process. Users felt that they were given the important task to determine which lane change support system should be brought onto the market. Users generally appeared to be able to handle this responsibility in the sense that they carefully weighed arguments pro and arguments against certain system features. Moreover, after every design iteration, the designer explicitly asked the user what he considered to be pleasant properties and what he considered to be unpleasant properties of the generated design. All users always answered these questions.

From questionnaire U10 followed that 45 of the 48 users felt *stimulated* to weigh positive and negative consequences of choices. This means that there were 3 users who had doubts this. The remarks left by these users exemplified these doubts:

- I did not always consciously realize that every choice has positive and negative consequences, and I didn't know I was supposed to say things about this (P11);
- I didn't feel that this was part of the session (P16);
- Short animations in the lane change support system configurator about the behavior of the system would be helpful in weighing positive and negative consequences of choices (P30).

The remarks indicated that these three users considered *feeling stimulated* as something different than *being stimulated* to weigh positive and negative consequences of choices. For the three users in question, not *feeling stimulated* to weigh positive and negative consequences of choices was due to the fact that they were not *explicitly told* to do so during the design sessions. However, from direct and indirect observations (see above) appeared that all users (including the three users in question) *actually weighed* positive and negative consequences of choices during the design sessions. Apparently, somehow, they were *stimulated* to do so, but they were just not conscious about it. Three other users (P20, P34, P43) left complimentary remarks about the level to which they felt stimulated to weigh positive and negative consequences of choices.

From questionnaire U10 also followed that all 48 users felt *enabled* to weigh positive and negative consequences of choices. Seven users left an additional remark. Four were complimentary (P6, P30, P34, P43). These users said that they were offered the possibility to design a new system every iteration, that there were sufficient iterations available, that there was sufficient time available per iteration, and that they received proper help during redesigning. Two remarks were critical (P17, P48). These users said that not all relevant situations were integrated into the scenarios, and that sometimes scenarios were too short to test everything properly. The tenor of these remarks was that the traffic scenario that was offered was not always tuned to what the user wanted to test in a specific iteration, and that this should be solved by allowing users to generate scenarios themselves.

Function RF.7

From questionnaire D27 followed that the designer was *stimulated* to find a compromise between the preferences of all users. The presence of a large body of detailed and reliable information about the preferences of 48 users invited the designer to do so. From questionnaire D27 also followed that the designer was *enabled* to find a compromise between the preferences of all users. Information analysis tools – as well as some help from a trained rater - enabled the designer to do so.

Conclusion

All criteria for acceptance of hypothesis HY.4.b were fulfilled.

For function RF.4, the opinion of users about the extent to which they felt *stimulated* to perform activities (variable V.12) was positive for all users. For functions RF.5 and RF.6, the opinion of users about the extent to which they felt *stimulated* to perform activities (variable V.12) were positive for 96% and for 94% of all users, respectively. For functions RF.4, RF.5 and RF.6, the opinion of users about the extent to which they felt *enabled* to perform activities (variable V.13) were positive for all users (see Figure 6.13).

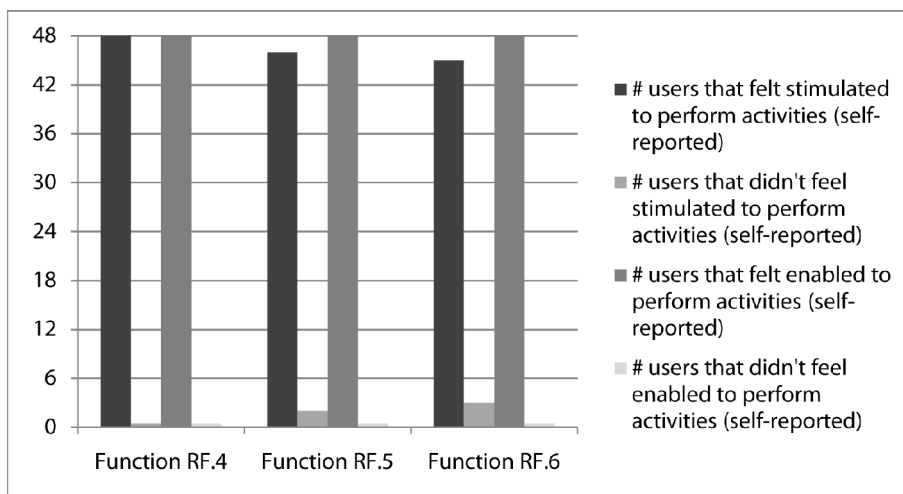


Figure 6.13: Functions RF.4, RF.5 and RF.6 are fulfilled (according to the users)

For functions RF.4, RF.5 and RF.6, the opinion of the designer about the extent to which users seemed *stimulated* to perform activities (variable V.14), and the opinion of the designer about the extent to

which users seemed *enabled* to perform activities (variable V.15) were positive for all users (see Figure 6.14).

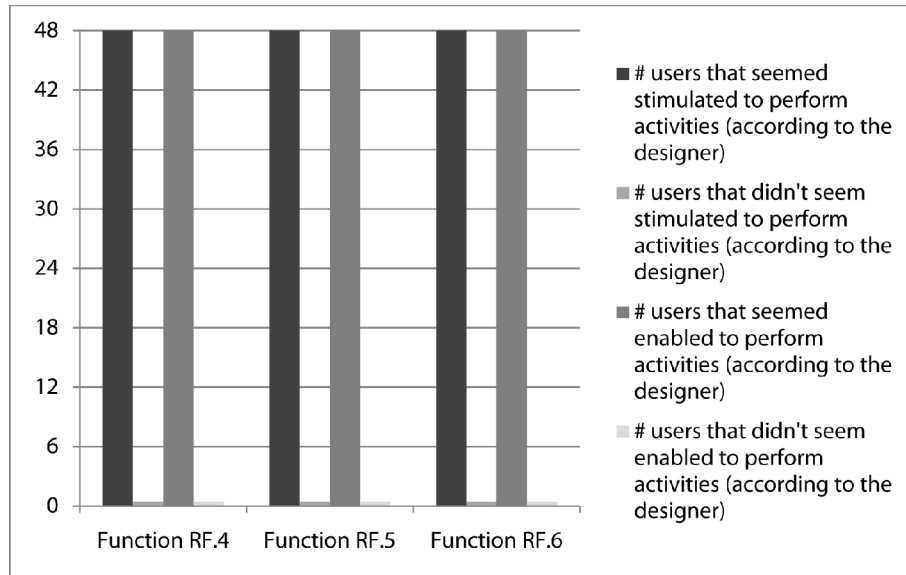


Figure 6.14: Functions RF.4, RF.5 and RF.6 are fulfilled (according to the designer)

For function RF.7, the opinion of the designer about the extent to which he felt *stimulated* to perform activities (variable V.16) and the opinion of the designer about the extent to which he felt *enabled* to perform activities (variable V.17) were positive (see Figure 6.15).

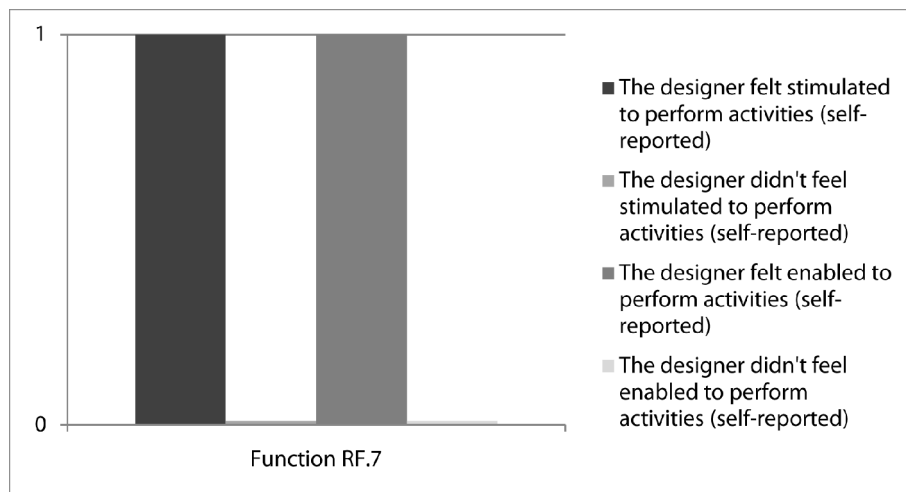


Figure 6.15: Function RF.7 is fulfilled

Therefore, hypothesis HY.4.b is accepted.

Furthermore, testing hypothesis HY.4.b yielded the following additional findings:

- The identification of an opportunity during giving opinions about the represented design information (function RF.4): multiple design sessions that each take less time (e.g. design sessions that take place a couple of days in a row, but that each take approximately 45 minutes) would give users the chance to let their thoughts settle overnight, and would possibly make their opinions to be more reliable;
- The confirmation that users should be allowed to generate scenarios themselves (functions RF.5 and RF.6): the traffic scenario that was offered was not always tuned to what the user wanted to test in a specific iteration;
- The identification of a strong point of the new product design method (function RF.6): the fact that users were given a proactive role in the design process appeared to make many users feel “responsible” for the success of the design process. Users generally appeared to be able to handle this responsibility in the sense that they carefully weighed arguments pro and arguments against certain system features.

6.4 Conclusion

6.4.1 Assessment results

All hypotheses were accepted. This means that:

- Human actors (i.e. designers and stakeholders) are able to perform the activities that are prescribed by the method (hypothesis HY.1);
- These activities yield actual results (hypothesis HY.2);
- The guidelines for the selection of participants are correct (hypothesis HY.3);
- The functions of the new product design method are fulfilled (hypothesis HY.4).

The hypotheses were accepted based on data from four different sources (i.e. questionnaires, direct observations, indirect observations, and design information). Not only were all criteria for acceptance of the hypotheses fulfilled, but the data from each source were generally also consistent with the data from the other sources. This is an indicator for the fact that the assessment results are reliable, and that the conclusion that the hypothesis may be accepted is valid.

6.4.2 Additional findings

Testing the hypotheses also yielded some additional findings (AFs; see Table 6.23). Firstly, five trade-offs that existed during creation of the design environment (AF.1, AF.2, AF.3, AF.4, and AF.5) were identified. Secondly, it was found that there were two difficulties during creating and updating the design environment (AF.6 and AF.7). Thirdly, it appeared that there were two different strategies of users for generating candidate designs (AF.8 and AF.9), two different strategies of users for testing candidate designs (AF.10 and AF.11), and a possible alternative way of scheduling design sessions (AF.12). Fourthly, it was confirmed that users should be allowed to generate scenarios themselves (AF.13). Fifthly, it was found that the design environment had four additional functions (AF.14, AF.15, AF.16 and AF.17). Finally, a strong point of the new product design method (AF.18) was identified.

<i>Add. finding</i>	<i>Description</i>
AF.1	The trade-off between the level of realism of the scenarios and the number non-recurrent situations that users are confronted with.
AF.2	The trade-off between the length of scenarios and the number of iterations that can be performed during a session.
AF.3	The trade-off between the number of design parameters that are adaptable for users and the time required for generating a candidate design.
AF.4	The trade-off between the time required for generating a candidate designs and the complexity of the configurator.
AF.5	The 5-dimensional trade-off between the aesthetic design of the configurator, the clarity of the explanations, the conciseness of the descriptions, the font size, and the size of the radio buttons.
AF.6	The designer needed support from others during creation of the initial design environment and during updating it according to new insights.
AF.7	The designer would have needed more time and money to implement some possibly relevant elements and required adaptations into the design environment.
AF.8	To start out with generating and testing a candidate design that complies with (expected) preferences. Subsequent iterations are then used to fine-tune it.
AF.9	To use the first couple of iterations to generate and test "random designs", just to see what possibilities the technology database offers and to experience the behavior of some different technologies. The last couple of iterations are then used to quickly iterate towards a personal "most attractive system".
AF.10	To behave normally, in order to find out how a design would work under normal circumstances.
AF.11	To behave like a "test driver" (i.e. to perform dangerous maneuvers that would never be performed in real traffic). This behavior is typically aimed at finding out where the system borders of the specific lane change support system design lie, and how the system behaves under dangerous circumstances.
AF.12	To schedule multiple design sessions for each user that each take less time (e.g. design sessions that take place a couple of days in a row, but that each take approximately 45 minutes). This would give users the chance to let their thoughts settle overnight, and would possibly make their opinions to be more reliable.
AF.13	The traffic scenario that was offered was not always tuned to what the user wanted to test in a specific iteration.
AF.14	Making users familiar with new technology.
AF.15	Letting users experience the potential benefits of new technology.
AF.16	Communicating expert-knowledge, as well as the reasoning behind this knowledge.
AF.17	Verifying findings from literature.
AF.18	The fact that users were given a proactive role in the design process made many users feel "responsible" for the success of the design process. Users were generally able to handle this responsibility in the sense that they carefully weighed arguments pro and arguments against certain system features.

Table 6.23: Additional findings

REFLECTING ON THE NEW PRODUCT DESIGN METHOD

7

This chapter reflects on the new product design method. The chapter is divided into two sections. The first section describes to what extent the new product design method meets its objectives. The second section describes to what extent the assessment results are generally applicable.

7.1 Does the new product design method meet its objectives?

7.1.1 Introduction

Section 4.1 outlined that it is impossible to make a reliable comparison between the results of applying a specific product design method and applying *another* product design method (or applying *no* product design method). Therefore, rather than examining the *product* that resulted from applying the new product design method to a design case, the *design process* that emerged was examined. More specifically, hypotheses about the new product design method's viability and the degree to which it fulfills its functions were tested. These tests resulted in the acceptance of all hypotheses (see section 6.4.1).

7.1.2 Is the new product design method viable?

The results of testing hypotheses HY.1, HY.2 and HY.3 show that people are able to perform the activities prescribed by the new product design method. The first phase of the design process was performed with 12 users and 1 designer, and the second phase with 48 users and 1 designer. It appeared that everybody was able to perform all required activities. Also, all activities yielded actual results. The design information that was generated during every activity was always in line with one of the possible outcomes as specified by the guidelines. And, finally, it seems that for both phases of the design process, the guidelines for the selection of participants are correct. These results lead to the conclusion that the new product design method is viable.

Within the specific setup of the assessment process, it was impossible to reliably verify a number of criteria that a product design method should meet in order to be viable (see section 4.2.4). More specifically, it was impossible to reliably verify whether the guidelines are unambiguous, whether they provide guidance under all circumstances, and whether they are generic. Therefore, a definite conclusion can't be drawn yet about the viability of the new product design method under all circumstances. During the assessment process, however, it was illustrated that the basic mechanism of the new product design method works.

7.1.3 Does the new product design method fulfill its functions?

The result of testing hypothesis HY.4 shows that people were sufficiently stimulated and enabled to generate design information, to represent the generated design information such that it is easily accessible, and to make sure that the represented design information is consistent. It also appeared that people were sufficiently stimulated and enabled to give opinions about the represented design information, to verify their opinions about the represented design information, to weigh positive and negative consequences of choices, and to find compromises. All this resulted in a consistent image of

each user's preferences as well as in a compromise between all those preferences. It is, therefore, concluded that the new product design method fulfills its functions.

7.1.4 Conclusion

The new product design method meets its objectives. It is viable in the sense that people are able to perform the specified activities, that these activities yield actual results, and that the guidelines for the selection of participants are correct. It fulfills its functions in the sense that it stimulates and enables the designer to create a consistent image of everybody's preferences and to specify a compromise between all those preferences. It should still be verified whether the guidelines are unambiguous, whether they provide guidance under all circumstances, and whether they are generic. However, the exact formulation of the guidelines is only a detail. The important thing is that the basic mechanism of the new product design method has been proven to work.

7.2 Are the assessment results generally applicable?

7.2.1 Introduction

Within the confines of a specific design case, the new product design method meets its objectives. However, the new product design method was originally developed to support all type 2 product design processes (see section 2.6). In addition, it was expected that it would be possible to apply the new product design method to all design cases (see section 3.3). It must, therefore, be analyzed to what extent the assessment results are generally applicable. This section outlines the impact of the case-specific circumstances on the general applicability of the results. The descriptions will however be limited to the general *feasibility* of applying the new product design method. The general *desirability* of applying it will be addressed in chapter 8.

7.2.2 Are the results applicable to other products?

The new product design method was applied to the design of a lane change support system. More specifically, to a *highway* lane change support system in which the driver is "in the loop". Although it was possible to create designs that would also function in cities and on rural roads, the structure and the contents of the technology database were geared to facilitating the generation of lane change support systems that are used on highways. Accordingly, the environment database only contained *highway* traffic scenarios. This constraint was set to reduce the level of complexity of the simulation model. Excluding fully automatic control systems from the technology database was done because, due to legal constraints, such systems are not likely to enter the market in the near future. However, there is no reason to assume that the new product design method wouldn't be applicable to the design of lane change support systems that also impose non-overridable interventions and/or to systems that also function in cities and on rural roads. The hardware of the design environment wouldn't have to be changed. It would only require some adaptations to the simulation model.

Similarly, it can be assumed that it would be possible to successfully apply the new product design method to the design of *other* driver support systems, such as parking assistants, adaptive cruise controls, lane departure warning systems, and lane keeping systems. To be able to show stakeholders the effects of choices while designing such systems, it might not only be necessary to adapt the design environment's software, but also its hardware. However, implementing such adaptations would definitely be feasible.

Actually, it can be assumed that it would be possible to successfully apply the new product design method to the design of all products that have a certain level of modularity or configurability. However, one prerequisite has to be met: it should be technically possible to create interfaces for stakeholders to generate candidate designs and test environments, and to offer simulations of those designs in those environments such that stakeholders can make a reliable assessment of the designs' properties. As indicated in section 4.3.2, there are currently not a lot of products that comply to this prerequisite. On the other hand, as VR simulation technology and information visualization techniques mature, the number of products to which the new product design method can be successfully applied will increase.

7.2.3 Are the results applicable to other aspects of product design?

As described in section 4.2.8, the design process that was performed while assessing the new product design method only considered the "use aspects" of product design. The design environment was solely aimed at representing those use aspects, whereas other aspects (such as production, marketing, maintenance, etc.) were not represented. This was done to reduce the design environment's level of complexity. However, there is no reason to assume that the new product design method wouldn't allow the representation of other aspects of the product. Of course, as long as the prerequisite is met that it is technically possible to create interfaces for stakeholders to generate candidate designs and test environments, and to offer simulations of those designs in those environments such that stakeholders can make a reliable assessment of the designs' properties.

7.2.4 Are the results applicable to other stakeholder groups?

The fact that the design environment only represented the use aspects of the product resulted in only representatives from the stakeholder group "users" participating in the design process. However, there is no reason to assume that the new product design method would exclude (a) specific stakeholder group(s) from participating during the design process. Users can be considered as "most critical" in the sense that – of all stakeholder groups - the way users communicate differs most from the way designers communicate. Therefore, the finding that the new product design method can be successfully applied for the stakeholder group "users" may be extrapolated to all imaginable stakeholder groups.

7.2.5 Are the results applicable when multi-actor sessions are performed?

Another consequence of the fact that the design environment only represented the use aspects of the product is that no multi-actor sessions were performed during the second phase of the design process. As described in section 3.2.11, these are sessions in which representatives from two or more stakeholder groups are invited at the same time. However, it can be assumed that the new product design method would also allow the performance of such multi-actor sessions. Apart from that the design environment should facilitate the perspectives of at least two stakeholder groups, no additional requirements would have to be met.

7.2.6 Are the results applicable when stakeholders are allowed to generate scenarios?

As described in section 4.2.8, activity 1.b (creating an interface for generating test environments) and activity 2.2 (all stakeholders adapt environment parameters, thus generating test environments for the candidate designs) were not performed while assessing the new product design method. Instead, during the design process, the designer generated the scenarios that were offered to stakeholders to evaluate their self-configured designs. This constraint was set to reduce the complexity of the design environment. However, during the assessment process, creating an interface for generating candidate designs (activity 1.d) has appeared to be possible. It can therefore be assumed that it would also be

possible to create an interface for generating test environments. Similarly, it has appeared that stakeholders are able to generate candidate designs (activity 2.3). It can therefore also be assumed that they would also be able to generate test environments.

7.2.7 Are the results applicable when a design team applies the method?

As described in section 4.2.1, the design process that was performed to assess the new product design method was completed by a single designer. This constraint was set because there were not enough resources available to have a design team perform the design process. The designer was allowed to consult others as well as to delegate tasks to others, but the responsibility of successfully completing the design case was solely his. As a result, communication and collaboration processes between members of the design team were absent during the design process. However, it is unlikely that application of the new product design method would have had negative effects on such communication and collaboration processes. Quite the contrary: one of the trends that were used as a basis for the new method was “considering the design process as a group activity in which communication and collaboration play a central role” (see Table 2.3). Moreover, during the assessment process, it appeared that explicitly showing the consequences of choices to stakeholders supported the communication processes between the designer and the stakeholders. It is therefore likely that the new product design method would also support communication and collaboration between members of the design team.

7.2.8 Conclusion

The results of the assessment process are generally applicable. It was shown that the assessment results are also applicable to aspects of product design other than the “use aspects”, and to stakeholder groups other than the stakeholder group “users”. It was also shown that the assessment results are applicable when multi-actor sessions are performed, when stakeholders are allowed to generate scenarios, and when a design team applies the method. It was finally shown that the assessment results are applicable to all products that have a certain level of modularity or configurability. It should, however, be technically possible to create interfaces for stakeholders to generate candidate designs and test environments, and to offer simulations of those designs in those environments such that stakeholders can make a reliable assessment of the designs’ properties. There are currently not a lot of products that comply to this prerequisite. On the other hand, as VR simulation technology and information visualization techniques mature, the number of products to which the new product design method can be successfully applied will increase.

This chapter concludes the thesis. First, the research results are summarized. Next, it is described to what extent the research objective has been met. Finally, directions for future research are discussed.

8.1 Summary of the research results

Creating good products is not an easy thing to do. There are usually many different people who have an interest in the product. Each of these stakeholders has his own ideas and agenda, which may conflict with the ideas and agendas of others. Designers have an extremely tough job trying to satisfy the differing needs and desires of all stakeholders. Moreover, it is very difficult for designers to determine what those needs and desires are in the first place - especially when dealing with complex products and/or products that don't exist yet. To make matters worse, designers are always confined by time and cost constraints.

Through the years, various methods and tools have been developed that support designers in dealing with these difficulties. But, so far, these methods and tools have only been a band-aid on a wound. Design has essentially remained a process in which designers are forced to make assumptions about what other people want. This is especially true when designing products that are new, that are complex, and that involve many different stakeholders. For such products, there is no method that adequately supports designers in determining stakeholders' preferences and finding the best compromise between those preferences.

Therefore, the goal of the research was the development of a new product design method that adequately supports designers in determining stakeholders' preferences and finding the best compromise between those preferences. A method that gives stakeholders insight into the consequences of their decisions and enables them to express their preferences. A method that provides designers with the information necessary to create a good design. A method that specifically supports the design of products that are new, that are complex, and that involve many different stakeholders.

Basing a new product design method on elements that are already present in current design practice increases the chance that designers are actually going to use it. That is why the research began with an analysis of how designers work and a review of currently available design tools. This resulted in the identification of seven trends in supporting the design of products that are new, that are complex, and that involve many different stakeholders:

1. Performing activities simultaneously;
2. Considering the product design process as a group activity;
3. Involving intended users during the product design process;
4. Using scenarios;
5. Applying tools that stimulate creativity;
6. Using virtual reality simulation;
7. Using gaming principles.

It was expected that the research objective could be achieved by combining the essence of all seven trends into one new product design method. Therefore, the trends were translated into a set of functions that the new product design method should fulfill and a set of prerequisites for how those functions should be fulfilled. Based on these functions and prerequisites, the new product design method was developed.

While applying the new product design method, the design process is split into two separate phases. The first phase is aimed at developing a design environment that is a valid representation of the world relevant to the product, including the technology that may be usefully applied to the product. This design environment enables a stakeholder to generate designs and scenarios, and to realistically experience the behavior of those designs in the scenarios. The second phase of the design process is aimed at specifying a good design. Representatives from all stakeholder groups are invited for design sessions in which they must iteratively work towards a personal "most attractive design". The generated information is used to specify a compromise between the preferences of all stakeholders.

The new product design method was evaluated by applying it to a design case: the design of a lane change support system. This is a product that supports car drivers during lane change maneuvers. The design process that emerged was analyzed by testing hypotheses about the new product design method's viability and the degree to which it fulfills its functions.

It was found that the new product design method is viable in the sense that people are able to perform the specified activities, that these activities yield actual results, and that the guidelines for the selection of participants are correct. It was also found that the new product design method fulfills its functions in the sense that it stimulates and enables the designer to create a consistent image of everybody's preferences and to reach a compromise between all those preferences.

An analysis of the impact of the case-specific circumstances on the assessment process revealed that the findings are generally applicable. The new product design method can be successfully applied to the design of all products that have a certain level of modularity or configurability. It should, however, be technically possible to create interfaces for stakeholders to generate candidate designs and test environments, and to offer simulations of those designs in those environments such that stakeholders can make a reliable assessment of the designs' properties. There are currently not a lot of products that comply to this prerequisite. On the other hand, as VR simulation technology and information visualization techniques mature, the number of products to which the new product design method can be successfully applied will increase.

8.2 Has the research objective been met?

The research objective was to develop a new product design method that adequately supports designers in determining stakeholders' preferences and finding the best compromise between those preferences. Such a method has been developed. Moreover, evaluating the new method led to the conclusion that it is viable and that it fulfills its functions. Even though these conclusions followed from applying the new product design method to a specific design case, it was shown that they are also generally applicable. The conclusions from the evaluation process are therefore clear indicators for the fact that the research objective has been met.

The evaluation process also yielded some additional findings (see Table 6.23). Most findings would be in line with the fact that the research objective has been met - at least, they would not obstruct it. There is, however, one finding that might throw a spanner in the works. This is the finding that the availability of sufficient time and money is essential for the successful application of the new product design method.

Application of the new product design method asks for a considerable investment. It costs a significant amount of time and money to create a design environment, perform reflection sessions, update the design environment, perform verification sessions, perform design sessions, and – last but not least - continuously assure that all information is consistent. A company has to have a certain size or turnover in order to be able to do such an investment. Moreover, the added value of the results of applying the new product design method might not always be worth the investment. In fact, it depends on the design case whether or not the investment would be worth the added value.

It is difficult to exactly specify for which products the added value of applying the new product design method would be worth the investment and for which products this would not be the case. This is typically something that should be learnt in practice. However, the chances of getting a “return on investment” generally increase the less familiar designers are to the product, the more complex the product is, and the more stakeholders are involved in the process. The investment will certainly be returned when the new product design method is used to design products that should be “first time right” in order to not endanger users and to not affect the company’s image.

For example, when designing a lane change support system – or any other driver support system – it can be safely said that the added value of applying the new product design method would be worth the investment. Driver support systems form the “link” between contemporary human controlled car driving and future computer controlled car driving. It is therefore very probable that they will be mass-produced. The technology needed to successfully create driver support systems is maturing, and there are many different possibilities to implement this technology. The question that manufacturers and governments are now struggling with is: what is the “best” implementation?

Answering this question is particularly difficult. There are a couple of reasons for this. Firstly, there are so many design parameters that the number of possible implementations is virtually endless. Secondly, many different people have an interest in driver support systems. Not only manufacturers and governments, but also mainly just car drivers. Moreover, the group of car drivers is not a very homogenous group of people in the sense that they don’t all have the same needs, behaviors, and preferences. Thirdly, driver support systems are so new that nobody really knows what their impacts are going to be – impacts on driving behavior of individual drivers, but also impacts on the performance of the traffic system as-a-whole. Given the intrinsic dangerous nature of the traffic system (more than one million people killed in road crashes each year), these impacts should be known before a specific driver support system is brought to the market.

Despite the many design parameters, despite the many different people that are involved, and despite the uncertainties about the real-world impacts, it has been shown that applying the new product design method can provide a reliable answer to the question what would be the “best” implementation of a driver support system. During the evaluation process, this question has been answered from a

user's (i.e. car driver's) perspective. However, as described in section 7.2, there is no reason to assume that it wouldn't be possible to answer it from the perspectives of other stakeholders.

In the context of the automotive industry, the time and money that were spent on reliably specifying the "best" implementation of a driver support system from a user's perspective would be totally and utterly acceptable. Automotive manufacturers already spend much time and money on driving simulation. However, active user participation during synthesizing design activities is rare. In this respect, adopting the design method that was developed in this research wouldn't cost them additional time and money. It would rather open up a whole new world of possibilities - and maybe even a whole new world of findings. It would offer them a way to work more effectively and efficiently, while not spending more resources. Moreover, it would diminish the risk of putting products on the market that endanger the driver's safety and that affect the company's image because they are not "first time right". For automotive manufacturers, using the new product design method as an alternative to the current ways of working would, therefore, be worth the investment.

On the other hand, there are also products for which it can be safely said that the added value of applying the new product design method would not be worth the investment. Coffee cups, for example. Coffee cups can be described by only a handful of parameters. Also, coffee cups exist long enough for designers to be familiar with the parameters that describe them, with the stakeholders that have an interest in them, with the needs and desires of those stakeholders, and with what would be a good compromise between everybody's preferences.

The range of products that is situated between "coffee cups" and "driver support systems" - in terms of novelty, complexity, and the number of different stakeholders that are involved - is rather large. For some of those products, the added value of applying the new product design method will appear to be worth the investment, and for some others not. However, independent of the question whether it would be worth to apply the new product design method, it can be said that the *result* of applying the new product design method would be *useful* for the design of *any* product. This result is a hierarchy of information that represents the preferences of all stakeholders. A hierarchy of which the structure is meaningful from a stakeholder's perspective, and that consists of both objective information and subjective information. A hierarchy in which, for every stakeholder, the objective information is fully consistent with the subjective information.

In other words, independent of the specific design case, the body of information that results from applying the new product design method is useful. The information is consistent and therefore reliable. The way it is organized allows designers to easily "zoom in" and "zoom out" on the entirety of information. Moreover, it allows designers to perform both quantitative and qualitative analyses in their quest for the best compromise between stakeholders' preferences. In short, the body of information that results from applying the new product design method is all that designers need to draw a reliable conclusion about what would be a good design. It is therefore concluded that the research objective has been met.

8.3 Directions for future research

In addition to providing answers, research also produces new questions. The main question that was produced by this research – and that could not be answered - is whether applying the new product

design method results in more effective and more efficient products and/or in more effective and more efficient product creation processes. Since product development is a historic process that cannot be repeated, this question can only be answered empirically. More specifically, it can only be answered by analyzing the products and product creation processes that result from applying the new product design method over a longer period of time, and by comparing these with results from applying *other* product design methods (or with results from applying *no* product design methods). This implies that a prerequisite for being able to answer this question is that designers are actually going to use the new product design method in practice.

Another issue that should be addressed in future research comes from the fact that all four roles in this research were fulfilled by the same person. To the extent possible, measures have been taken not to let the results be influenced by the fact that the researcher, the design method developer, the analyst and the designer were not four different people. However, there is no guarantee that the results of the evaluation process – and therefore the conclusion of this research – were not influenced by these circumstances. The complete research being performed by one person also made it impossible to reliably verify whether the guidelines are unambiguous. Accordingly, this should be tested as well.

It should also still be verified whether the guidelines provide guidance under all circumstances and whether they are generic. During this research, this was not possible because the new product design method was only applied to one design case. In addition, it should be investigated whether a designer should meet specific requirements in order to be able to successfully apply the new product design method. The designer that applied the new product design method to the design case during this research had experience in VR simulation as well as in usability testing. It should be tested whether designers who have no experience in these fields are also able to successfully apply the new product design method.

Finally, it would be interesting to know what happens when the new product design method is applied by a design team instead of by a single designer. To what extent are the communication and collaboration processes between members of the design team supported? Similarly, it would be valuable to find out what happens when multi-actor sessions are performed. These are sessions in which representatives from two or more stakeholder groups are invited at the same time. It is probable that, during multi-actor sessions, stakeholders are going to “directly” negotiate with each other about what would be the best compromise. It should be investigated whether this actually happens, and, if so, what the benefit of this would be compared to when the designer specifies an “indirect” compromise between stakeholders’ preferences.

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APPENDICES

Appendix A: Technical details design environment

Figure A.1 depicts the design environment's hardware architecture.

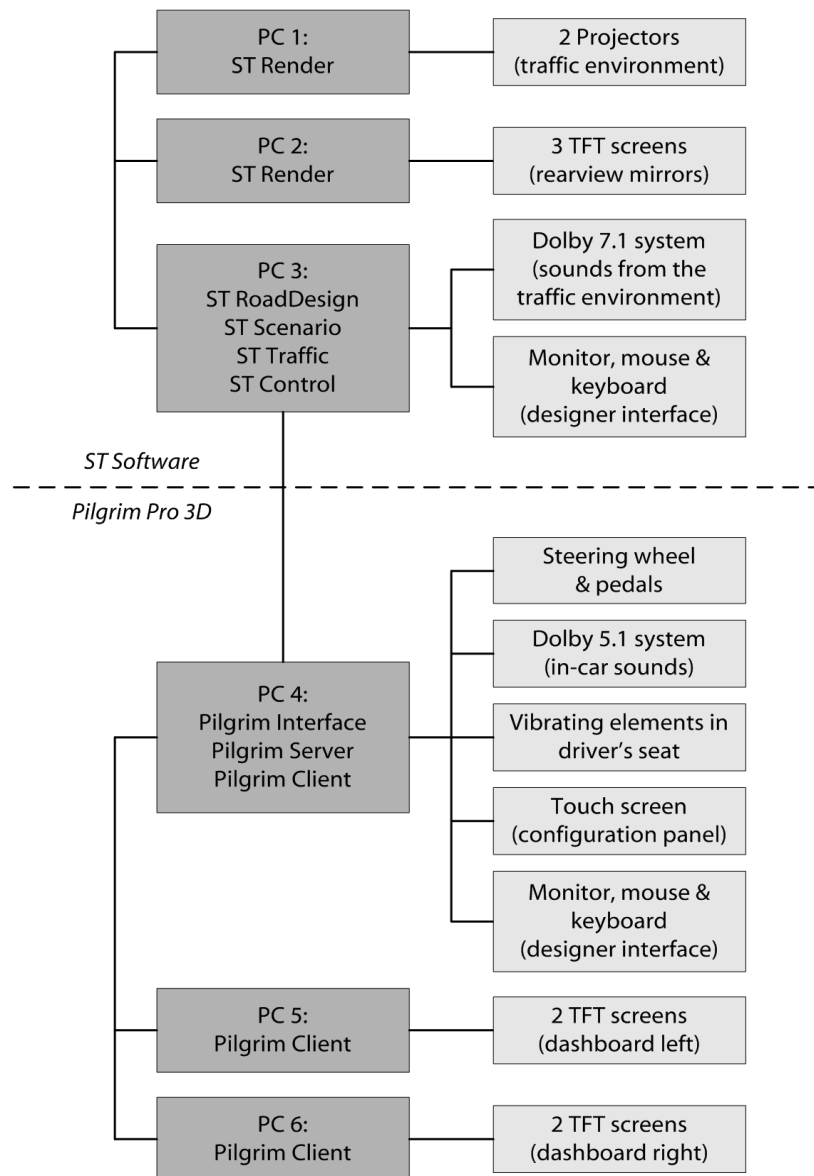


Figure A.1: The design environment's hardware architecture

Figure A.1 shows that the design environment consists of six PCs that are each connected to two or more interfaces:

- PC 1 is connected to two projectors that project the traffic environment onto a large curved screen in front of the mock-up;
- PC 2 is connected to three TFT screens that are installed inside of the mock-up and that offer rearview mirror functionality;
- PC 3 is connected to a Dolby 7.1 system that is installed outside of the mock-up and that displays sounds from the traffic environment. PC 3 is also connected to a monitor, a mouse and a keyboard. These interfaces are used by the designer to adapt the environment database as well as to start and stop traffic scenarios;
- PC 4 is connected to a force feedback steering wheel and pedal set that offer the user the means to control the vehicle within the traffic environment. The steering wheel can also be used to render kinesthetic support signals to the user. Furthermore, PC 4 is connected to a Dolby 5.1 system that is installed inside of the mock-up as well as to vibrating elements that are installed in the driver's seat. These interfaces are used to offer support signals through auditory and tactile channels, respectively. PC 4 is also connected to a touch screen that is installed in the middle console of the mock-up. This is the interface for the lane change support system configurator. Finally, PC 4 is connected to a monitor, a mouse and a keyboard. These interfaces are used by the designer to adapt the technology database;
- PC 5 and PC 6 are each connected to two TFT screens that are installed inside of the mock-up. Together, these four screens form a dashboard. They offer standard dashboard functionality (i.e. speedometer, rev counter, turn signal indicators), but they can also be used to offer visual support signals to the user.

The six PCs are split into two groups of three PCs. Each group forms a local network. The local network formed by PC 1, PC 2 and PC 3 runs ST Software, which is dedicated driving simulator software. The local network formed by PC 4, PC 5 and PC 6 runs Pilgrim Pro 3D, which is a generic 3D engine. The two local networks are connected through an UDP channel that is set up between PC 3 and PC 4. This channel is used to exchange data between the two software packages.

ST Software consists of a number of modules that, together, provide driving simulator functionality:

- The ST RoadDesign module is used to create road networks. It generates both graphical networks for the human driver and logical networks for the traffic participants that are controlled by the ST Traffic module. The graphical networks are built in the OpenSceneGraph (OSG) format, an open source 3D graphics toolkit. Using ST RoadDesign, the designer makes a 2D design of a road network which is then automatically converted into a 3D world. Within the design environment, ST RoadDesign is installed on PC 3;
- The ST Scenario module is a scripting tool that generates scenarios. In this context, a scenario is a predefined list of situations with a start and an end condition. Each scenario activates and terminates automatically when required. Any number of scenarios can be active at the same time. Among other things, scenarios generate traffic participants, define the starting point of the vehicle in the road network, and provide navigation instructions to the driver. ST Scenario uses the third-party text editor TextPad for creating script files and performing syntax checks on the scripts. Within the design environment, ST Scenario is installed on PC 3;

- The ST Traffic module provides real-time simulations based on the ST Scenario scripts and the logical network that was created by ST RoadDesign. Within the design environment, ST Traffic is installed on PC 3;
- The ST Control module is the graphical interface for the designer. Using ST Control, the designer can configure all ST Software modules and control the communication between those modules. ST Control is also used to start and stop traffic scenarios. Within the design environment, ST Control is installed on PC 3;
- The ST Render module is a real-time renderer that enables real-time visualization of the simulated traffic environment. ST Render receives real-time simulated traffic data from ST Traffic and displays it onto one or more connected graphical displays. In ST Render, viewing angles, viewing positions and viewports can be defined. Within the design environment, ST Render is installed on PC 1 and on PC 2.

Just like ST Software, Pilgrim Pro 3D also consists of multiple modules. Together, these modules allow a user to design a lane change support system and experience this design in the traffic environment that is provided by ST software:

- The Pilgrim Interface module is a tool that is used to write Lua script files. When loaded into the Pilgrim Server module, these script files form the lane change support system configurator. Each question in the electronic questionnaire has its own script file. A script file loads a question, lists the possible options, and allows a user to choose one of those options. A script file also communicates the design choice to the Pilgrim Server module. Finally, a script file directs the user to the next question to be answered. This next question may depend on an answer given earlier in the questionnaire. Within the design environment, Pilgrim Interface is installed on PC 4;
- The Pilgrim Server module is the core of the Pilgrim network. This is where the lane change support system design is generated and simulated in real-time. Using the C++ Software Development Kit (SDK), the designer fills the technology database with assistants. Assistants can be visual, auditory, tactile or kinesthetic. Every assistant has a set of attributes. Examples of attributes are "brightness", "size", "pitch", "volume", "repetition frequency", "amplitude" and "interface ID". Every assistant also has a set of conditions under which it will become active. Based on the design choice of the user received from the Pilgrim Interface module, an assistant may be created, values of attributes may be set, or conditions under which the assistant becomes active may be defined. Within the design environment, Pilgrim Server is installed on PC 4;
- The Pilgrim Client module is a real-time renderer. When Pilgrim Server commands that a specific assistant should become active, Pilgrim Client will render it. Depending on the specific modality of the assistant, this rendering might be done on a visual, auditory, tactile or kinesthetic display. Within the design environment, Pilgrim Client is installed on PC 4, PC 5 and PC 6.

More information about ST Software is available at www.stsoftware.nl. More information about Pilgrim Pro 3D is available at www.pilgrim-visuals.com.

Appendix B: Interview reflection session (in Dutch)

Inleiding

U heeft zojuist een aantal verschillende rijstrookwissel-assistenten ontworpen en deze ook getest in een aantal verschillende verkeersscenario's. Ik wil u nu een aantal vragen stellen die erop gericht zijn uw mening over de verschillende systemen in kaart te brengen.

Vraag 1

Wat vond u prettige eigenschappen van de systemen die u geconfigureerd heeft? Waarom vond u dit prettig? Hingen deze nog samen met dingen die in het verkeersscenario gebeurden?

Vraag 2

Wat vond u minder prettige eigenschappen van de systemen die u geconfigureerd heeft? Waarom vond u dit minder prettig? Hingen deze nog samen met dingen die in het verkeersscenario gebeurden?

Vraag 3

Van de vijf systemen die u geconfigureerd en getest heeft, wat vond u het meest prettige systeem? Waarom vond u dat?

Vraag 4

Had u tijdens de sessie het gevoel dat u een bepaald systeem wilde configureren, maar dat dat niet - of niet goed - mogelijk was met het configuratiescherm? Zo ja: welke opties had u dan nog willen kiezen? Onafhankelijk van het antwoord: heeft u toevallig nog ideeën voor extra functionaliteit of voor nog meer opties die eventueel in een rijstrookwissel-assistent zouden kunnen zitten?

Vraag 5

Vond u dat de omschrijvingen van de keuzemogelijkheden op het configuratiescherm overeenkwamen met hoe het systeem uiteindelijk ging werken in de verkeersscenario's? Zo nee: welke omschrijvingen waren dit? Zo ja: dus u werd nooit verrast doordat het systeem zich anders gedroeg dan u verwacht had?

Vraag 6

Bent u nog keuzemogelijkheden op het configuratiescherm tegengekomen die totaal overbodig zijn? Zo ja: welke keuzemogelijkheden waren dit? Zo nee: dus er waren geen keuzemogelijkheden waarvan u zich niet kan voorstellen dat iemand die ooit zou willen kiezen?

Vraag 7

Komt u in het dagelijks leven bij het autorijden situaties tegen die te maken hebben met rijstrookwisselingen, maar die u niet voorbij hebt zien komen in de verkeersscenario's? Zo ja: welke situaties? Zo nee: dus u kunt geen nieuwe verkeerssituaties verzinnen die eventueel nog van belang zijn voor de werking van een rijstrookwissel-assistent?

Vraag 8

Heeft u nog dingen in de verkeersscenario's gezien waarvan u denkt dat die niet erg waarheidsgetrouw zijn? Zo ja: wat dan? Zo nee: dus de weg zag er natuurlijk uit, de omgeving naast de weg zag er natuurlijk uit en ook de andere weggebruikers gedroegen zich op een natuurlijke manier?

Vraag 9

Heeft u nog dingen in de verkeersscenario's gezien waarvan u dacht dat deze overbodig zijn bij het testen van een rijstrookwissel-assistent? Zo ja: wat dan? Zo nee: dus er kwamen geen situaties voor die helemaal niets te maken hadden met de werking van een rijstrookwissel-assistent?

Vraag 10

Bood de rijsimulator zelf voldoende faciliteiten om aan de sessie mee te kunnen doen? Lijkt bijvoorbeeld de bediening van stuur en pedalen of de manier waarop het dashboard en de spiegels zitten genoeg op hoe het in een echte auto zit? Zo nee: waarin zitten de verschillen? Zo ja: dus u vond dat het rijden in de rijsimulator zeer goed lijkt op het rijden in een echte auto?

Appendix C: Interview design session (in Dutch)

Inleiding

U heeft zojuist een aantal verschillende rijstrookwissel-assistenten ontworpen en deze ook getest in een aantal verschillende verkeersscenario's. Ik wil u nu een aantal vragen stellen die erop gericht zijn uw mening over de verschillende systemen in kaart te brengen.

Vraag 1

Wat vond u prettige eigenschappen van de systemen die u geconfigureerd heeft? Waarom vond u dit prettig? Hingen deze nog samen met dingen die in het verkeersscenario gebeurden?

Vraag 2

Wat vond u minder prettige eigenschappen van de systemen die u geconfigureerd heeft? Waarom vond u dit minder prettig? Hingen deze nog samen met dingen die in het verkeersscenario gebeurden?

Vraag 3

Van alle systemen die u geconfigureerd en getest heeft, wat vond u het meest prettige systeem? Waarom vond u dat?

Appendix D: Example of a personal report (P1)

1. Personal information

Age (age category): 28 (young)
NDS score (driving style): 1,08 (non-aggressive)
Gender: M

2. Specification most attractive system

Ass.	Circumstances (WHEN)	Contents (THEN)	Form (BY)
1	WHEN a trailing vehicle in the left adjacent lane is closer than 30 m AND the longitudinal time-to-collision with this vehicle is less than 1 s AND the time to line crossing with the left lane marker drops below 1 s	THEN control-intervention	BY a powerful torque that is rendered in the steering wheel
2	WHEN a trailing vehicle in the left adjacent lane is closer than 50 m AND the longitudinal time-to-collision with this vehicle is less than 3 s AND the left turn signal is used	THEN warning	BY a spoken text ("pas op") that has a medium volume, that is not repeated, and that is rendered in the left rear speaker
3	WHEN a trailing vehicle in the right adjacent lane is closer than 15 m	THEN warning	BY a yellow, medium bright, medium sized, static light that is rendered on the right dashboard panel
<i>Status control module</i>			
Agent that controls the system status:			Human
Circumstances under which human driver can adapt the system status:			Always

3. Explanation to the specification of the most attractive system (in Dutch)

- Het is prettig dat het systeem mij attendeert als het verkeer dreigt te gaan (voor links). Het moet dit in eerste instantie met een geluidje proberen en als het echt gevaarlijk wordt met een rukje aan het stuur.
- Het is prettig dat het systeem extra informatie geeft die mij helpt bij de inschatting (voor rechts). Het moet een lampje op het dashboard zijn. Niet te dicht bij de zijspiegel, want dan doe je de werking weer teniet. Ik gebruik het zo dat op het moment dat het lampje brandt ik weet dat ik niet in de spiegel hoeft te kijken. Als het lampje niet brandt, dan kijk ik wel.
- Het systeem moet niet te complex worden: ik moet niet hoeven nadenken over wat een signaal betekent. Als het systeem te ingewikkeld is kan ik er niet op vertrouwen.
- Ik wil voor rechts gewaarschuwd worden als er iets zit, maar het moet wel subtiel zijn. Anders stoort het mij. Ik moet het alleen zien als ik het ook wil zien.
- Het systeem moet handmatig in- en uitschakelbaar zijn, want ik wil zelf de baas blijven in mijn auto. Er zijn op een gegeven moment situaties waarin je denkt: zet nu maar even uit.
- Wat betreft de lengte van de zone die in de gaten gehouden wordt wil ik een afstand waarbij ik veilig en comfortabel in een gat tussen twee auto's kan.
- Een lampje links op het dashboard dat waarschuwt als er iets in een zone van 30 meter zit is op zich prettig. Echter, ik zou dit niet in mijn auto willen, want het gevaar bestaat dat ik er teveel op ga vertrouwen en niet meer in mijn spiegel ga kijken.
- Een assistent die "pas op" zegt als er iets naast je zit en je richtingaanwijzer aan staat is prettig: want dan sta je namelijk op het punt een fout te maken. Het mag ook een ander auditief signaal zijn.
- Een rukje aan stuur als laatste back-up is fijn, maar ik hoop dat ik hem nooit nodig zal hebben.
- Voor rechts moet de zone die in de gaten gehouden wordt korter zijn dan voor links: 15 m voor rechts versus 30 à 50 m voor links. 30 m voor rechts is veel te lang.
- Voor links wil ik alleen een waarschuwing als het gevaarlijk is. Als het echt gevaarlijk wordt zelfs een ingreep aan het stuur.
- Voor rechts een lampje die aangeeft of het kan of niet. Ik kan dan zelf beslissen of ik ernaar kijk of niet.
- Een trilling in de stoel is vervelend.
- Piepjes zijn ook vervelend, dan moet je gaan nadenken wat dat piepje ook weer betekent. Een stem die "pas op" zegt is veel duidelijker.

4. Striking incidents, actions and behaviors

- P1 does not want to receive continuous (visual) warnings about vehicles in his left blind spot because he noticed that he stops checking his left mirror when changing lanes to the left.
- P1 wants to continuously receive visual warnings about vehicles in his right blind spot: as long as the warning signal is there, he does not check his right mirror. When the warning signal disappears, he checks whether it is safe to go. The warning signal should be located on the dashboard so that he doesn't have to turn his head to see it.

Appendix E: The coding system

1. Desirable/undesirable system features

1.1. Overall system functionality

- 1.1.a Support in making estimations/decisions (comfort system)
- 1.1.b Prevention of making mistakes/causing accidents (safety system)
- 1.1.c Support for the left side of the vehicle
- 1.1.d Support for the right side of the vehicle
- 1.1.e Blind spot support
- 1.1.f Support for fast approaching vehicles
- 1.1.g Support for being passed on the wrong side
- 1.1.h Other overall system functionalities

1.2. Criteria for issuance of support

- 1.2.a Distance to an adjacent trailing vehicle (size of the inter-vehicle gap, length of the monitored zone)
- 1.2.b Changing rate of the inter-vehicle gap (relative velocity, time-to-collision)
- 1.2.c Intention to change lanes (turn signal use, time-to-line-crossing)
- 1.2.d Other criteria for issuance of support

1.3 Support signal modality

- 1.3.a Visual (light, visual icon, written text, digital number, analogue indicator)
- 1.3.b Auditory (beep sound, auditory icon, spoken text, spoken number)
- 1.3.c Tactile (vibration)
- 1.3.d Kinesthetic (torque, control-intervention)
- 1.3.e Other support signal modalities

1.4 Information content of signals

- 1.4.a Information about the distance to an adjacent trailing vehicle
- 1.4.b Information about the velocity difference with an adjacent trailing vehicle
- 1.4.c Information about the time-to-collision with an adjacent trailing vehicle
- 1.4.d Other information contents of signals

1.5 Actual support signal attributes

- 1.5.a Attributes of a visual signal (color, icon, text, brightness, size, blinking frequency, interface, location on interface, way of expressing information content)
- 1.5.b Attributes of an auditory signal (pitch, icon, text, volume, repetition frequency, interface, way of expressing information content)
- 1.5.c Attributes of a tactile signal (frequency, amplitude, pulse frequency, interface, way of expressing information content)
- 1.5.d Attributes of a kinesthetic signal (magnitude, direction, interface)
- 1.5.e Other support signal attributes

1.6 Perceived support signal attributes

- 1.6.a Relevance/redundancy of a signal
- 1.6.b Conspicuity of a signal
- 1.6.c Subtlety/discreteness of a signal
- 1.6.d Dominance/intrusiveness of a signal
- 1.6.e Other perceived support signal attributes

1.7 Status control module functionality

- 1.7.a Manual status control
- 1.7.b Automatic status control (e.g. system activated at engine start, at a certain velocity, on a certain road type)
- 1.7.c Hybrid status control (a combination of two or more different algorithms that work together, e.g. a combination of manual and automatic status control)
- 1.7.d Status information (status icon)
- 1.7.e Other status control module functionalities

1.8 Perceived support system attributes

- 1.8.a Configurability/adaptability of the system
- 1.8.b Symmetry/asymmetry of the system
- 1.8.c Complexity/straightforwardness of the system
- 1.8.d Failure rate of the system
- 1.8.e Price of the system
- 1.8.f Frequency of signals being issued by the system
- 1.8.g Other perceived support system attributes

2. Reasons for considering a system feature to be desirable/undesirable

2.1. Pleasant feelings and emotions under influence of the system

- 2.1.a Feeling satisfied/not annoyed/not scared/not panicked/not alienated
- 2.1.b Feeling comfortable/relaxed/secure (feeling more aware of the traffic situation around the vehicle)
- 2.1.c Feeling safe (trusting the system, feeling able to count on the system, knowing that the system prevents from making mistakes/causing accidents)
- 2.1.d Feeling in control of the system/situation/vehicle
- 2.1.e Feeling that the meaning of a signal can be intuitively understood (feeling that the system works straightforward/consistent)
- 2.1.f Feeling that signals are relevant (feeling that signals offer added value, feeling that signals are useful)
- 2.1.g Feeling that signals are conspicuous (feeling that signals cannot stay unnoticed or be ignored)
- 2.1.h Feeling that signals are subtle/discrete (feeling that signals are not disturbing or distracting)
- 2.1.i Other pleasant feelings and emotions under influence of the system

2.2. Unpleasant feelings and emotions under influence of the system

- 2.2.a Feeling unsatisfied/uncomfortable/not relaxed/insecure
- 2.2.b Feeling annoyed
- 2.2.c Feeling scared/panicked/alienated
- 2.2.d Feeling disturbed/distracted (feeling overloaded with signals, feeling that signals interfere with driving or with in-car activities)
- 2.2.e Feeling unsafe (distrusting the system, not feeling able to count on the system, feeling that hazardous situations might occur for which the system won't provide adequate support)
- 2.2.f Feeling that control of the system/situation/vehicle is lost
- 2.2.g Feeling that the meaning of a signal cannot be intuitively understood (feeling that the system is too complex, feeling that the system works inconsistently, feeling confused)
- 2.2.h Feeling that signals are irrelevant/redundant (feeling that signals do not offer added value, feeling that signals are not useful)
- 2.2.i Feeling that signals are not conspicuous enough (feeling that signals might stay unnoticed or be ignored)
- 2.2.j Feeling that signals are too dominant/intrusive
- 2.2.k Feeling that system activation may be forgotten
- 2.2.l Having bad associations with automation in vehicles (having bad memories of incidents with automation in vehicles)
- 2.2.m Other unpleasant feelings and emotions under influence of the system

2.3. Desirable behavioral changes under influence of the system

- 2.3.a Improved (faster/better) estimation/decision making
- 2.3.b Less unnecessarily glancing in mirrors (paying more attention to the traffic situation in front of the vehicle, spending less effort during driving)
- 2.3.c Less cutting-off others
- 2.3.d More consequently switching off the turn-signal after having changed lanes
- 2.3.e Other desirable behavioral changes under influence of the system

2.4. Undesirable behavioral changes under influence of the system

- 2.4.a Getting lazy/counting on the system (less glancing in mirrors, paying less attention to the traffic situation behind the vehicle)
- 2.4.b Counter steering (steering towards the hazard instead of away from the hazard)
- 2.4.c Spending time/effort acquiring/interpreting signals (paying less attention to the traffic situation)
- 2.4.d Spending time/effort getting used to the system (paying less attention to the traffic situation)
- 2.4.e Other undesirable behavioral changes under influence of the system

3. Circumstances under which a system feature is considered desirable/undesirable

3.1. Actual scenario attributes

- 3.1.a Road type (e.g. urban roads, rural roads, highways)
- 3.1.b Country (e.g. Netherlands, Germany, USA)
- 3.1.c Traffic intensity (e.g. calm, busy, traffic jam)
- 3.1.d Behavior of other road users (e.g. social, antisocial, driving fast, driving slow)
- 3.1.e Vehicle properties (e.g. engine power)
- 3.1.f In-car activities (e.g. listening to music, talking with passengers, using cell phone, using navigation system, using other support systems)
- 3.1.g Personal conditions (e.g. personal driving style, driving experience, being tired, being less concentrated, falling asleep, not being used to the circumstances, being forgetful)
- 3.1.h Advancing time (e.g. now, next week, in two months, next year, in 10 years)
- 3.1.i Other actual scenario attributes

3.2. Perceived scenario attributes

- 3.2.a Hazard level of a situation
- 3.2.b Frequency of occurrence of a certain situation
- 3.2.c Maneuver type (e.g. merging, overtaking, returning to the right lane)
- 3.2.d Differences between the traffic situation on the left side of the vehicle and the traffic situation on the right side of the vehicle
- 3.2.e Other perceived scenario attributes

Appendix F: Questionnaires first experiment (in Dutch)

Questionnaire D1

Vraag 1

Was je in staat om een beeld van de voor het product relevante wereld te creëren die naar verwachting gemakkelijk toegankelijk is voor alle stakeholders? (ja/nee)

Opmerkingen: _____

Vraag 2

Was je in staat om een overzicht van de voor het product relevante technologie te creëren die naar verwachting gemakkelijk toegankelijk is voor alle stakeholders? (ja/nee)

Opmerkingen: _____

Questionnaire D2

Vraag 1

Was de schriftelijke instructie die de gebruiker vooraf ontving voldoende om te begrijpen wat er van hem of haar verwacht werd tijdens de sessie? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Vraag 2

Kreeg de gebruiker vooraf voldoende gelegenheid om aan de rijnsimulator te wennen? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Vraag 3

Begreep de gebruiker het configuratiescherm en was de gebruiker goed in staat het te bedienen? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Vraag 4

Was de gebruiker goed in staat de werking van de ontworpen systemen te beoordelen in de verkeersscenario's? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Vraag 5

Was de gebruiker goed in staat te antwoorden op de vragen tijdens het evaluatiegesprek? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Questionnaire D3

Vraag 1

Bevatten de antwoorden van de gebruiker op de interviewvragen informatie over de kwaliteit van het simulatiemodel en kon deze informatie worden vastgelegd? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Vraag 2

Maakte de gebruiker "spontane opmerkingen" over de kwaliteit van het simulatiemodel en kon deze informatie worden vastgelegd? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Questionnaire D4

Vraag 1

Was je in staat om de van gebruikers afkomstige informatie te combineren in een eenduidige lijst met benodigde aanpassingen aan de technology database? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Questionnaire D5

Vraag 1

Was je in staat om de van gebruikers afkomstige informatie te combineren in een eenduidige lijst met benodigde aanpassingen aan de environment database? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Questionnaire D6

Vraag 1

Was je in staat om alle benodigde aanpassingen te implementeren in de technology database? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Questionnaire D7

Vraag 1

Was je in staat om alle benodigde aanpassingen te implementeren in de environment database? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Questionnaire D8

Vraag 1

Was de gebruiker goed in staat om zijn mening te geven over de aanpassingen die verricht zijn aan de technology database? (ja/nee)

Wat zou er nog verbeterd kunnen worden bij het vragen naar de mening van de gebruiker over de aanpassingen in de technology database? _____

Questionnaire D9

Vraag 1

Was de gebruiker goed in staat om zijn mening te geven over de aanpassingen die verricht zijn aan de environment database? (ja/nee)

Wat zou er nog verbeterd kunnen worden bij het vragen naar de mening van de gebruiker over de aanpassingen in de environment database? _____

Questionnaire D10

Vraag 1

Was je in staat om het gedrag van de gebruiker tijdens het omgaan met het geüpdate configuratiescherm en de technology database te registeren? (ja/nee)

Opmerkingen: _____

Vraag 2

Was je in staat om de meningen van de gebruiker over het geüpdate configuratiescherm en de technology database te registeren? (ja/nee)

Opmerkingen: _____

Questionnaire D11

Vraag 1

Was je in staat om het gedrag van de gebruiker tijdens het omgaan met de geüpdate set scenario's te registeren? (ja/nee)

Opmerkingen: _____

Vraag 2

Was je in staat om de meningen van de gebruiker over de geüpdate set scenario's te registeren? (ja/nee)

Opmerkingen: _____

Questionnaire D12

Vraag 1

Was je in staat om de geïmplementeerde updates aan het configuratiescherm en de technology database te verifiëren? (ja/nee)

Opmerkingen: _____

Vraag 2

Was je in staat om nieuwe gewenste updates aan het configuratiescherm en de technology database te onthullen? (ja/nee)

Opmerkingen: _____

Questionnaire D13

Vraag 1

Was je in staat om de geïmplementeerde updates aan de set scenario's te verifiëren? (ja/nee)

Opmerkingen: _____

Vraag 2

Was je in staat om nieuwe gewenste updates aan de set scenario's te onthullen? (ja/nee)

Opmerkingen: _____

Questionnaire D14

Vraag 1

Werd je voldoende *gestimuleerd* om ontwerp informatie te genereren? (ja/nee)

Opmerkingen: _____

Vraag 2

Ben je voldoende *in de gelegenheid gesteld* om ontwerp informatie te genereren? (ja/nee)

Opmerkingen: _____

Questionnaire D15

Vraag 1

Werden alle gebruikers voldoende *gestimuleerd* om ontwerp informatie te genereren? (ja/nee)

Opmerkingen: _____

Vraag 2

Zijn alle gebruikers voldoende *in de gelegenheid gesteld* om ontwerp informatie te genereren? (ja/nee)

Opmerkingen: _____

Questionnaire D16

Vraag 1

Werd je voldoende *gestimuleerd* om consistente ontwerp informatie te genereren? (ja/nee)

Opmerkingen: _____

Vraag 2

Ben je voldoende *in de gelegenheid gesteld* om consistente ontwerp informatie te genereren? (ja/nee)

Opmerkingen: _____

Questionnaire D17

Vraag 1

Werd je voldoende *gestimuleerd* om ontwerp informatie zondanig te presenteren dat het gemakkelijk toegankelijk is voor alle stakeholders? (ja/nee)

Opmerkingen: _____

Vraag 2

Ben je voldoende *in de gelegenheid gesteld* om ontwerp informatie zondanig te presenteren dat het gemakkelijk toegankelijk is voor alle stakeholders? (ja/nee)

Opmerkingen: _____

Questionnaire U1

Persoonlijke gegevens

Naam: _____

Geslacht: _____

Geboortejaar: _____

Hoogst afgeronde middelbare schoolopleiding: _____

Aantal jaar in bezit van rijbewijs: _____

Gemiddeld aantal kilometer per jaar: _____

Vraag 1

Heeft u wel eens gehoord van "bestuurdersondersteunende systemen" in auto's? (ja/nee)

Zo ja: kunt u een korte omschrijving geven van wat ermee bedoeld wordt? _____

Zo nee: wat denkt u dat ermee bedoeld wordt? _____

Vraag 2

Stel u heeft een nieuw programma op uw computer, hoeveel moeite kost het u om daarmee om te leren gaan?

(zeer veel moeite / veel moeite / gemiddeld / weinig moeite / zeer weinig moeite)

Questionnaire U2

Vraag 1

Was de schriftelijke instructie die u vooraf ontving voldoende om te begrijpen wat er van u verwacht werd tijdens de sessie? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Vraag 2

Kreeg u vooraf voldoende gelegenheid om aan de rijnsimulator te wennen? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Vraag 3

Begreep u het configuratiescherm en was u goed in staat het te bedienen? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Vraag 4

Was u goed in staat de werking van de ontworpen systemen te beoordelen in de verkeersscenario's? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Vraag 5

Was u goed in staat te antwoorden op de vragen tijdens het evaluatiegesprek? (ja/nee)

Wat zou er nog verbeterd kunnen worden? _____

Questionnaire U3

Vraag 1

Was u goed in staat om uw mening te geven over de aanpassingen die verricht zijn aan het configuratiescherm? (ja/nee)

Wat zou er nog verbeterd kunnen worden bij het vragen naar uw mening over de aanpassingen aan het configuratiescherm? _____

Questionnaire U4

Vraag 1

Was u goed in staat om uw mening te geven over de aanpassingen die verricht zijn aan de verkeersscenario's? (ja/nee)

Wat zou er nog verbeterd kunnen worden bij het vragen naar uw mening over de aanpassingen aan de verkeersscenario's? _____

Appendix G: Questionnaires second experiment (in Dutch)

Questionnaire D18

Vraag 1

Begreep de gebruiker het configuratiescherm en was de gebruiker goed in staat het te bedienen? (ja/nee)

Opmerkingen: _____

Questionnaire D19

Vraag 1

Was de gebruiker goed in staat de werking van de ontworpen systemen te beoordelen in de verkeersscenario's? (ja/nee)

Opmerkingen: _____

Questionnaire D20

Vraag 1

Was je in staat om het gedrag van de gebruiker tijdens het genereren van ontwerpen te registeren? (ja/nee)

Opmerkingen: _____

Vraag 2

Was je in staat om het gedrag van de gebruiker tijdens het configureren van scenario's te registeren? (ja/nee)

Opmerkingen: _____

Vraag 3

Was je in staat om het gedrag van de gebruiker tijdens het testen van de ontwerpen in de scenario's te registeren? (ja/nee)

Opmerkingen: _____

Vraag 4

Was je in staat om de meningen van de gebruiker over de ontwerpen te registeren? (ja/nee)

Opmerkingen: _____

Questionnaire D21

Vraag 1

Werd de gebruiker voldoende *gestimuleerd* om zijn/haar mening te geven over de ontworpen systemen? (ja/nee)

Opmerkingen: _____

Vraag 2

Is de gebruiker voldoende *in de gelegenheid gesteld* om zijn/haar mening te geven over de ontworpen systemen? (ja/nee)

Opmerkingen: _____

Questionnaire D22

Vraag 1

Werd de gebruiker voldoende *gestimuleerd* om de meningen die hij/zij gaf nog eens te verifiëren in de rijnsimulator? (ja/nee)

Opmerkingen: _____

Vraag 2

Is de gebruiker voldoende *in de gelegenheid gesteld* om de meningen die hij/zij gaf nog eens te verifiëren in de rijnsimulator? (ja/nee)

Opmerkingen: _____

Questionnaire D23

Vraag 1

Werd de gebruiker voldoende *gestimuleerd* om de positieve en negatieve gevolgen van keuzes af te wegen? (ja/nee)

Opmerkingen: _____

Vraag 2

Is de gebruiker voldoende *in de gelegenheid gesteld* om de positieve en negatieve gevolgen van keuzes af te wegen? (ja/nee)

Opmerkingen: _____

Questionnaire D24

Vraag 1

Was je in staat om de van de gebruiker afkomstige informatie te gebruiken om het ontwerp vast te stellen dat het beste de behoeften van de gebruiker vervult, gegeven het technologische potentieel? (ja/nee)

Opmerkingen: _____

Questionnaire D25

Vraag 1

Was je in staat om een codeersysteem te ontwikkelen die gebruikt kan worden om de gegenereerde informatie te rangschikken in een hiërarchie? (ja/nee)

Opmerkingen: _____

Questionnaire D26

Vraag 1

Was je in staat de hiërarchie van informatie te gebruiken om een compromis tussen de voorkeuren van alle gebruikers te specificeren? (ja/nee)

Opmerkingen: _____

Questionnaire D27

Vraag 1

Werd je voldoende *gestimuleerd* om een compromis te vinden tussen de voorkeuren van alle gebruikers? (ja/nee)

Opmerkingen: _____

Vraag 2

Ben je voldoende *in de gelegenheid gesteld* om een compromis te vinden tussen de voorkeuren van alle gebruikers? (ja/nee)

Opmerkingen: _____

Questionnaire U5

Inleiding

In deze vragenlijst worden u een aantal persoonlijke vragen gesteld. De meeste vragen gaan over uw rijstijl in bepaalde verkeerssituaties.

Er zijn geen goede of foute antwoorden: het gaat steeds om uw persoonlijke situatie en uw mening. Dit staat geheel los van de officiële verkeers- en gedragsregels. De verstrekte gegevens worden vertrouwelijk verwerkt en anonimiteit is gewaarborgd.

Persoonlijke gegevens

Geslacht: _____

Geboortjaar: _____

Hoogst afgeronde middelbare schoolopleiding: _____

Aantal jaar in bezit van rijbewijs: _____

Gemiddeld aantal kilometer per jaar: _____

Vragen over uw rijstijl

Wilt u van elk van de volgende vragen aangeven hoe vaak het op u van toepassing is tijdens het autorijden?

Vraag	(bijna) nooit	zelden	soms	vaak	(bijna) altijd
1. Rijdt u snel?	0	0	0	0	0
2. Past u uw snelheid aan aan de snelheid van uw voorligger?	0	0	0	0	0
3. Rijdt u voorzichtig?	0	0	0	0	0
4. Rijdt u gejaagd?	0	0	0	0	0
5. Overtreedt u wel eens de snelheidslimiet?	0	0	0	0	0
6. Haalt u wel eens rechts in (afgezien van op- en afritten)?	0	0	0	0	0
7. Rijdt u zoveel mogelijk op dezelfde rijstrook?	0	0	0	0	0
8. Rijdt u wel eens door rood licht?	0	0	0	0	0
9. Neemt u wel eens voorrang terwijl u dat niet heeft?	0	0	0	0	0
10. Houdt u zoveel mogelijk afstand ten opzichte van uw voorligger?	0	0	0	0	0
11. Wisselt u vaak van rijstrook?	0	0	0	0	0
12. Voegt u kort in voor degene die u inhaalt?	0	0	0	0	0

Questionnaire U6

Vraag 1

Begreep u het configuratiescherm en was u goed in staat het te bedienen? (ja/nee)

Opmerkingen: _____

Questionnaire U7

Vraag 1

Was u goed in staat de werking van de ontworpen systemen te beoordelen in de verkeersscenario's? (ja/nee)

Opmerkingen: _____

Questionnaire U8

Vraag 1

Werd u voldoende *gestimuleerd* om uw mening te geven over de ontworpen systemen? (ja/nee)

Opmerkingen: _____

Vraag 2

Bent u voldoende *in de gelegenheid gesteld* om uw mening te geven over de ontworpen systemen? (ja/nee)

Opmerkingen: _____

Questionnaire U9

Vraag 1

Werd u voldoende *gestimuleerd* om de meningen die u gaf nog eens te verifiëren in de rijnsimulator?
(ja/nee)

Opmerkingen: _____

Vraag 2

Bent u voldoende *in de gelegenheid gesteld* om de meningen die u gaf nog eens te verifiëren in de rijnsimulator? (ja/nee)

Opmerkingen: _____

