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Personalization and context-sensitive user interaction of in-vehicle infotainment systems

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"Life is not a problem to be solved but a reality to be experienced"
- Soren Kierkegaard -

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At the beginning of writing a thesis it feels like standing in front of a big mountain that is supposed to be climbed. It feels very exciting but daunting. Climbing that mountain is like a journey towards learning a lot about the field of research and yourself as you experience its highs and lows, hard times and wonderful experiences. I am very grateful for this time.
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Publications and supervised theses

During this work, several publications have been published and presented at different conferences. A list of publications is below. The author of this thesis is first author or one of several as indicated.

Publications

- Siegmund, N., Altmüller, T., and Bengler, K. (2013). Personalized situation-adaptive user interaction in the car. In Adjunct Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI '13, pages 105-106.

- Zsebedits, D., Siegmund, N., and Meixner, G. (2014). Proof-of-concept einer adaptiven Benutzungsschnittstelle auf Basis einer Gesamtarchitektur zur Reduktion von Fahrerablenkung. In Proceedings of USEWARE 2014.

- Siegmund, N., Altmüller, T. (2014). Interaktionssteuerungseinrichtung und Interaktionssteuerungsverfahren, Patent application DE201410202234.

- Walter, N., Altmüller, T., and Bengler, K. (2015). Concept of a reference architecture for an extendable in-vehicle adaptive recommendation service. In Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI '15, pages 88-93, New York, NY, USA. ACM.

- Walter, N., Kaplan, B., Altmüller, T., and Bengler, K. (2015). Erhöhung der Transparenz eines adaptiven Empfehlungsdiensts. In Weisbecker, A., Burmester, M., and Schmidt, A., editors, Mensch & Computer Workshopband, pages 475-482. De Gruyter Oldenbourg.

- Walter, N., Kaplan, B., Wettemann, C., Altmüller, T., and Bengler, K. (2015). What are the expectations of users of an adaptive recommendation service which aims to reduce driver distraction? In Design, User Experience, and Usability: Interactive Experience Design - 4th International Conference, DUXU 2015, Held as Part of HCI International 2015, Los Angeles, CA, USA, August 2-7, 2015, Proceedings, Part III, pages 517-528.

- Walter, N., Altmüller, T. (2015). Verfahren und Vorrichtung zum Bereitstellen eines Empfehlungssignals zum Steuern zumindest einer Funktion in einem Fahrzeug, Patent application DE102015216484, WO application WO2017036629.

- Meixner, G., Haecker, C., Decker, B., Gerlach, S., Hess, A., Holl, K., Klaus, A., Lüddecke, D., Mauser, D., Orfgen, M., Poguntke, M., Walter, N., and Zhang, R. (2017). Retrospective and Future Automotive Infotainment Systems - 100 Years of User Interface Evolution, In Meixner, G., and Mueller, C., editors Automotive User Interfaces, pages 3-53. Springer.

In addition, the work has been accomplished with regard to the contents of several theses and internships. The theses in which the author has been the supervisor are listed below.

Supervised theses

- Zsebedits, D. (2014). Proof of concept for a situation based adaption of the graphical user interface based on an overall architecture to reduce driver distraction. Master's thesis, Hochschule Heilbronn.
- Kaplan, B. (2015). Erhöhung der Transparenz von Empfehlungen eines automotiven adaptiven Interaktionskonzepts. Master's thesis, Fachhochschule Reutlingen.
- Dogan, I. (2015). Konzeption und Implementierung eines Prototypen für einen adaptiven Empfehlungsdienst. Bachelor thesis, Hochschule Esslingen.
- Köhler, K. (2017). Entwurf und Realisierung eines Konzepts zur Demonstration eines adaptiven Empfehlungsdienstes unter Verwendung eines maschinellen Lernverfahrens. Bachelor thesis, Hochschule der Medien.
- Kopp, M. (2017). Evaluation maschineller Lernalgorithmen für einen Infotainment-Empfehlungsdienst. Master's thesis, Hochschule der Medien.

Further, several chapters were supported by the work of interns from Robert Bosch GmbH. All iterations within the user-centered design process, described in Chapter 6, have been supported. The prototypes were partially created by interns, as well as the realization of the different study environments and the pre-analysis of the collected data in the user studies. The high-fidelity prototype described in Chapter 7 was implemented according to the documented concept by interns and the team of the department RBEI/ECG1 of Robert Bosch GmbH. Interns also supported the implementation of the driving simulator study environment, described in Chapter 8, conduction of the study and pre-analysis of the collected data.

Abstract

Today, we are used to accessing information and use functions over the smartphone and other devices anywhere and at anytime. We also aim to do this while driving, which results in a conflict as driving and fulfilling these kind of secondary tasks at the same time compete for the same resources of the driver. This conflict can lead to increased driver distraction, which is addressed within this work.

To satisfy the above mentioned user needs infotainment systems provide more and more functions, so need to deal with the resulting conflict. In this work, the approach of an adaptive recommendation service, integrated into an infotainment system and taking over interaction steps to reduce driver distraction is pursued to tackle the described conflict. The adaptive recommendation service observes and learns the usage behavior of the driver, analyses it based on the context and deduces rules to provide recommendations when needed. The focus of this work is on the development of a software architecture integrated into an overall HMI architecture, an interaction concept developed based on a user-centered design process including several different user and expert evaluations, and the evaluation of a high-fidelity prototype in an early stage of development conducted in a driving simulator environment. The main requirement for the architecture and interaction concept is the extendability, so that all kinds of applications are supported by the adaptive recommendation service including those installed during run time.

One of the main challenges for the development of an adaptive recommendation service is to achieve user acceptance. The adaptive recommendation service can only have a beneficial impact when the reasons for its dynamic behavior based on personalized and current context specific adaptation, are transparent to the user, and an adequate level of control is offered.

Both the reduction of driver distraction and a high usability have been achieved with the described approach of this work. A driving simulator study was conducted to evaluate the high-fidelity prototype of the elaborated concept. Driver distraction is determined through a Detection Response Task, the analysis of driving behavior and task performance. A significant reduction of driver distraction is achieved by using the adaptive recommendation service. This effect comes together with a high usability due to the taken measures to improve the same in comparison to the state-of-the-art.

The adaptive recommendation service is a promising approach to satisfy the user needs to request information and access functions while driving in a safe way.

Kurzfassung

Heutzutage ist es möglich mit dem Smartphone oder anderen Geräten jederzeit und an jedem Ort auf Informationen zuzugreifen und gewünschte Funktionen zu nutzen. Sogar während dem Führen eines Fahrzeuges wird auf diese Möglichkeit zurückgegriffen. Dies führt zu einem Konflikt, da sowohl die Fahraufgabe als auch die Erfüllung dieser sekundären Aufgaben die gleichen Ressourcen des Fahrers binden. Dieser Konflikt kann zu einer erhöhten Fahrerablenkung führen, welche in dieser Arbeit adressiert wird.

Um dem Nutzerbedürfnis nach Informationen und Zugriff auf Funktionen während der Fahrt entgegen zu kommen bieten Infotainmentsysteme im Fahrzeug zunehmend mehr Funktionalität an. Aber auch hierbei muss der genannte Konflikt betrachtet werden. In dieser Arbeit wird ein adaptiver Empfehlungsdienst, der in ein Infotainmentsystem integriert ist, vorgestellt um diesen Konflikt zu adressieren und eine mögliche Fahrerablenkung zu reduzieren. Der adaptive Empfehlungsdienst beobachtet und lernt das Nutzungsverhalten des Fahrers, analysiert dieses unter Berücksichtigung des Kontextes und leitet Regeln ab um dem Fahrer passende Empfehlungen zu unterbreiten. Dadurch soll die Anzahl der Bedienschritte, die der Fahrer benötigt um auf die gewünschte Funktionalität zuzugreifen, reduziert werden. Der Fokus dieser Arbeit liegt auf der Entwicklung einer Softwarearchitektur für den adaptiven Empfehlungsdienst, welche in eine HMI-Gesamtarchitektur integriert ist, der Entwicklung eines Interaktionskonzeptes, welches mit Hilfe eines nutzerzentrierten Designprozesses unter Durchführung mehrerer Nutzer- und Expertenevaluationen entwickelt wird, und der Evaluierung eines realitätsnahen Prototypen in einer frühen Entwicklungsphase innerhalb einer Fahrsimulatorumgebung. Die Hauptanforderung für die Entwicklung der Softwarearchitektur und des Interaktionskonzepts ist die Erweiterbarkeit um zu ermöglichen, dass alle Applikationen vom Empfehlungsdienst unterstützt werden auch wenn diese erst während der Laufzeit installiert werden.

Eine Herausforderung bei der Entwicklung des adaptiven Empfehlungsdienstes ist die Akzeptanz zukünftiger Nutzer, denn nur wenn der adaptive Empfehlungsdienst von den Nutzern akzeptiert wird, wird er auch genutzt und kann einen positiven Effekt auf den Fahrer haben. Dafür ist es notwendig, dass dem Fahrer das sich ständig an den Nutzer und Kontext anpassende Verhalten transparent gemacht wird und er einen angemessenen Grad an Kontrolle über den Empfehlungsdienst hat.

Mit dem in dieser Arbeit beschriebenen Ansatz konnte sowohl die Fahrerablenkung signifikant reduziert als auch eine hohe Usability erreicht werden. Dies konnte durch die Untersuchung eines realitätsnahen Prototyps im Vergleich zum Stand der Technik innerhalb einer Fahrsimulatorstudie gezeigt werden. Der Grad der Fahrerablenkung wurde dabei mit Hilfe einer Detection Response Task, der Analyse des Fahrverhaltens und der Aufgabenperformance bestimmt.

Der adaptive Empfehlungsdienst stellt damit einen vielversprechenden Ansatz dar um zum einen die Bedürfnisse des Nutzers nach dem jederzeit möglichen Zugriff auf Informationen und Funktionen adäquat zu erfüllen und zum anderen die Fahraufgabe nicht zu gefährden.

"Computers are incredibly fast, accurate, and stupid:
humans are incredibly slow, inaccurate, and brilliant;
together they are powerful beyond imagination."
- Albert Einstein -

Contents

1 Motivation

A defining feature of this century is digitization. Our personal daily life changes through the ready availability of digital devices, the increasing offer of digital services and the ever-present media. Since the introduction of smartphones people have become used to accessing the Internet anywhere and at any time, from which follows the ubiquitous availability of information. This trend has also found its way into the vehicle. The number of available functions in a vehicle's infotainment system is continually rising. This is to an extent unavoidable and necessary, since alternatives, for example the usage of smartphones during driving, are forbidden because of their driving risk (Kubitzki and Fastenmeier, 2016). More and more displays or even larger displays, as in the Tesla Model S[1], are built into today's vehicles to show more content and more precise and personalized information for driver and passengers (Kuhlmann, 2017). Such a trend has its positive and negative effects. The main negative effect is a high risk of driver distraction. Of course, it is not the information and services that are the main problem but the resulting increase of interaction complexity while using them on the infotainment system. It is necessary to find a way to enable accessing of information and services as people are used to while still ensuring consistent driving safety.

1.1 Introduction

Somewhere between satisfying the desire for usage and potentially higher driver distraction due to an increasing interaction complexity, the two user needs of safety and comfort move into focus. Those two user needs can lead to a conflict when on one hand, users want to access provided media through smartphone or infotainment system, but on the other hand this usage leads to a higher distraction of the driver, being unable to control the vehicle safely. One might think that simply forbidding the usage of such content would solve this problem but people tend to underestimate the risk and overestimate their own driving skills, and will use it anyway. Many drivers want to use these functions while driving especially as they are used to being able to access the functionality everywhere else and at any time. Another solution, with a higher chance of acceptance, is to provide an infotainment system which supports the user by accessing the desired functionality but in a way the driver is still able to drive safely.

A second trend, personalization, is an approach to address this problem. A personalized solution depends on knowing the individual user needs and supporting the driver appropriately. Personalization is initiated either by the system or the user. Three different forms can be distinguished: Personalization through a direct input of the user; activation of pre-defined rules by user or system; and adaptive personalization. This last form involves the observation of the user, analysis of user needs and adaptation to them. In the case of the distracted driver, an adaptive infotainment system could either learn exactly which information the driver needs or which interaction steps it could take over for the user (Jameson, 2008). Both have the potential to relieve the driver and could be used as a complement for different use cases.

The focus of this work is on the reduction of interaction complexity through reducing the number of interaction steps needed to access a desired function. Therefore, the approach of an adaptive

[1] `https://www.tesla.com/de_DE/models`, last accessed on 05/12/2017

recommendation service; learning what functions the driver uses depending on the context and recommending them in a recurring context, is pursued. The thesis also explores whether this adaptive recommendation service can reduce driver distraction and be accepted by the users.

1.2 Structure of the Thesis

The two following chapters, Chapter 2 and Chapter 3, describe the state-of-the-art regarding infotainment systems, driver distraction, usability, and adaptive systems. Building upon this basis, Chapter 4 analyses the potential for and challenges of adaptive systems outlined in Section 1.1. Hence, the research questions and main challenges of this work are derived. The following chapters deal with the different aspects needed to conceptualize and develop an adaptive recommendation service as one possible approach to address personalized support to the driver. Chapter 5 describes the architecture, including components and interfaces of the adaptive recommendation service and how it is embedded in an overall HMI architecture. In Chapter 6 the user-centered design process including several user studies and the resulting interaction concept is outlined. Chapter 7 describes the implementation of a high-fidelity prototype on the basis of the described architecture and developed interaction concept. The evaluation of an adaptive system is a big challenge within the development process of the same. A method and the results of an evaluation of the adaptive recommendation service in a driving simulation environment are discussed in Chapter 8. Finally, in Chapter 9, the results are summarized and discussed, and an outline is given for future work.

2 Infotainment Systems, Driver Distraction and Usability

This chapter describes the basics and state-of-the-art according to vehicle infotainment systems, driver distraction, acceptance and usability. In the first section, infotainment systems and the integration of applications into these are described (see Section 2.1). The focus of this work is on developing a support system for the driver to reduce driver distraction by keeping user acceptance at the same time. Therefore, the topic driver distraction is handled in Section 2.2 and the topics acceptance and usability in Section 2.3.

2.1 Infotainment Systems

The first element of today's known infotainment systems, integrated into the vehicle in the 1930s, was the radio. This was followed by cassette, CD, and MP3 player, integration of the phone and navigation system, and in present times an Internet connection (Harvey and Stanton, 2013) as well as provided online services. Infotainment systems are including more and more functions for entertainment, information, assistance, and communication. The system boundaries blur and driver assistance and infotainment systems are partially merging, using all possible input and output devices in the vehicle. This all-in-one solution plays an increasingly important role in the vehicle (Meroth and Tolg, 2008).

2.1.1 Infotainment System: Human-Machine-Interaction in the Vehicle

In this section basics and definitions regarding infotainment systems are described to create a common understanding. An infotainment system is an interactive Human-Machine-System including an interface for the interaction with the vehicle occupants. Therefore, the following described definitions for *Interactive System*, *Human-Machine-System* and *Human-Machine-Interface* are used in this thesis.

Definition 2.1 - Interactive System.

A system is referred to as interactive if its work routine can be influenced by an operation of the user (Heinecke, 2012).

Definition 2.2 - Human-Machine-System.

An Human-Machine-System is characterized through the goal-oriented interaction between one or more humans and a technical system to achieve specific goals in best possible way. The main goals can be safety, efficiency, environmental compatibility as well as controllability, satisfaction and social compatibility (Johannsen, 1993).

An Human-Machine-System consists of three main elements: human operators, technical system and an interface between them as shown in Figure 2-1. The human operators interact with the technical system through a bidirectional interface called the Human-Machine-Interface as defined in Definition 2.3.

Definition 2.3 - Human-Machine-Interface.

An Human-Machine-Interface (HMI) is a component of an Human-Machine-System that enables a communication between human operators (user) and a system, either to provide information or to control the system (ISO 9241-110, 2006).

The HMI includes a dialogue level and presentation level. The dialogue level takes care of the information (what), that should be handled and the timing (when). The presentation level decides how this information should be presented and how to transform the control input of the human operators into system commands (Johannsen, 1995).

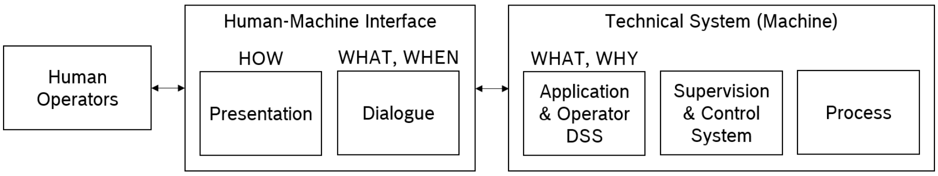


Figure 2-1.: An Human-Machine-System consists of three main elements: human operators, technical system (machine) and an interface between them. This interface is called Human-Machine-Interface and includes a presentation and dialogue component (according to Johannsen (1995)).

In the vehicle, the occupants are the human operators or users who interact with the infotainment system. The main goals of an infotainment system are to inform, assist, entertain and communicate (Meroth and Tolg, 2008). The interaction takes place via the Human-Machine-Interface over three different channels; the visual, haptic or auditory channel, as shown in Figure 2-2 (Reif, 2010). In the past, the interfaces of infotainment systems were limited to display and control elements in the center console. Today the system boundaries blur and infotainment systems use more input and output devices for interaction.

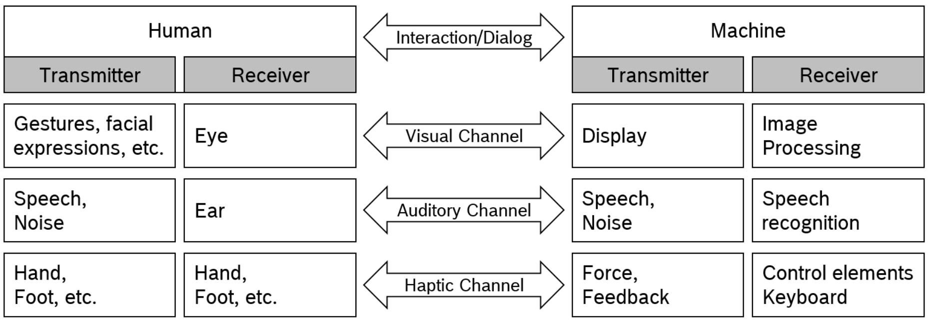


Figure 2-2.: In the vehicle three possible communication channels are available for communication between the vehicle occupants and the infotainment system. The three channels are the visual, haptic or auditory channel (according to Reif (2010)).

Visual Channel: The visual channel is most important for the information reception of humans (Heinecke, 2012). In the vehicle, visual information, for example navigation instructions, are shown on different displays. In current vehicles, like in the S-class model BR222 from Mercedes-Benz[1] shown in Figure 2-3, a free-programmable cluster display, head-unit display, head-up display, rear view and side mirrors are almost standard to display information for the driver. In addition, displays in the head-rests of driver and passenger seats are becoming more popular and in future vehicles displays for passengers will also be found.

[1] `www.mercedes-benz.com`, last accessed on 29/09/2016

Figure 2-3.: The cockpit of the S-class model BR222 from Mercedes-Benz includes a free-programmable cluster display and head-unit display. In addition, information can be shown on a head-up display or rear view and side mirrors[3].

Another trend is the increasing size of the displays in the vehicle, like for example the head-unit display in the Tesla[2] Model S as shown in Figure 2-4. The design of display elements needs to be done carefully as the visual channel is the main channel for the primary driving task (see Section 2.2.1). In order to observe the driving scenario and to control the vehicle safely the driver should not be distracted too much.
In the other direction, the vehicle uses sensors, e.g. a camera, and image processing algorithms to receive visual information in order to get information about the driver. Amongst others it is possible to recognize gestures (Zobl et al., 2001), eye gaze (Poitschke et al., 2011) or facial expressions (Gao et al., 2014) of the driver and passengers to be used e.g. for interacting with infotainment systems more intuitively.

Figure 2-4.: Tesla takes a new approach and integrates a large head-unit display in the Tesla Model S to display information for the vehicle occupants[4].

Auditory Channel: Spoken and non-spoken information can be communicated to the driver and the passengers through the auditory channel. Spoken information can include more complex information (e.g. navigation instructions) than simple non-spoken information (e.g. warning signal for low tire pressure) (Zhang, 2015). It is likely that the vehicle occupants have different needs regarding volume and communicated information over the auditory channel, for example the driver may sometimes need a quieter environment for concentration while the passengers want to listen to music. In future, different sound zones to provide individual audio output for each passenger will be available (Yanagidate et al., 2014). The driver can also communicate over the auditory channel through using voice command to interact with the infotainment system (Lo and Green, 2013).

[3] Source Figure 2-3: `https://www.mercedes-benz.com/en/mercedes-benz/vehicles/passenger-cars/s-class/the-new-s-class-coupe-gran-performer/`, last accessed on 29/09/2016
[2] `www.teslamotors.com`, last accessed on 29/09/2016
[4] Source Figure 2-4: `https://www.teslamotors.com/models`, last accessed on 29/09/2016

Haptic Channel: The vehicle can also communicate via the haptic or tactile channel. Haptical means that a person perceives an active contact whereas tactile refers to a perception through a passive contact in which the person performs no active movement (Grunwald, 2001). Vibrations on the steering wheel or a tightened seatbelt are tactile feedback (Reif, 2010), and touch displays with force feedback (Pitts et al., 2012) are haptic feedback for the driver. The driver and passengers can communicate both through mechanical (e.g. knob to adjust the volume) and electrical actuators (e.g. touch displays) with the vehicle.

In summary, a variety of input and output possibilities over different channels are available in current vehicles for communication between vehicle occupants and the vehicle. These communication channels are required for using the functions of the infotainment system.

2.1.2 Functions of Infotainment Systems

The word "infotainment" is a combination of information and entertainment, which describes the main functions of an infotainment system. But functions related to assistance and communication are also included (Meroth and Tolg, 2008). In Figure 2-5, exemplary functions of an infotainment system are listed regarding their affiliation to one of the mentioned categories. For more information, an overview and comparison of different infotainment systems and their functionality is given by Hansen and Kossel (2016a).

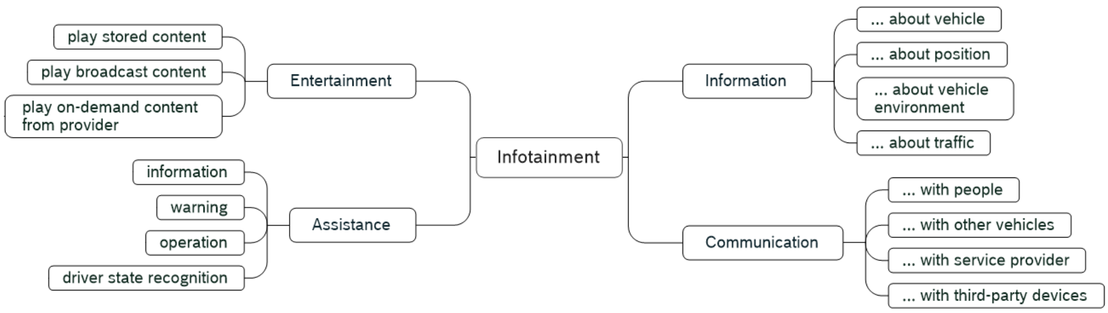


Figure 2-5.: According to Meroth and Tolg (2008) exemplary functions of an infotainment system are listed regarding their affiliation to one of the categories: information, entertainment, assistance, and communication.

Entertainment: Originally the infotainment system was only used to listen to music over the radio. Today it is possible to play content from different media sources like SD cards, USB drives, CDs or cloud storage. Figure 2-6 shows the media screen of the BMW[5] ConnectedDrive infotainment system, where the currently played title is shown. The media file can be on another device, which is connected to the infotainment system for example via an USB audio interface or Bluetooth (BMW, 2016). An additional functionality of infotainment systems is the digital radio. Also Internet radio or music streaming are becoming more popular in the vehicle as well (Harvey and Stanton, 2013) (Meroth and Tolg, 2008). The entertainment functions are not limited to listening anymore; they also include video content for vehicle occupants, e.g. via video on demand or DVD. Watching movies or TV, as well as playing games, is especially interesting for the rear seat passengers.

[5] `http://www.bmw.com`, last accessed on 29/09/2016

Figure 2-6.: The media screen of the BMW ConnectedDrive infotainment system shows the title of the currently played song, which is located on another device[6].

Information: The infotainment systems in today's cars also inform the driver about the current status of the vehicle, e.g. the tire pressure (see Figure 2-7), the surrounding driving environment, e.g. traffic information on the current route, navigation instructions or detection of traffic signs, and Points-of-Interest such as car parks or gas stations. In Figure 2-8 the cluster of an Audi TT is shown, displaying a navigation screen. Infotainment functions like navigation information are not only shown on the head unit in the center of the dashboard but also on the cluster or on other displays either additionally or as an alternative.

Figure 2-7.: Information about tire pressure of the vehicle's tires displayed in the 2016 Nissan GT-R[7].

Assistance: Originally driver assistance systems and infotainment systems were separated systems. Today's driver assistance systems communicate with the driver partially through the same user interfaces as the infotainment system; for example parameter settings for driver assistance systems are integrated directly into the menu of the infotainment system. The boundaries between them can no longer be strictly separated. In Figure 2-9, the picture of a rear-view camera, which belongs to an electronic parking assistance, is shown on the head unit display. In addition, the driver is informed more and more about his own status, for example a recommendation is given when the driver is drowsy and should take a break.

Communication: In addition to the before mentioned functions, infotainment systems provide a channel to communicate with other people or services. Mobile phones can be connected via Bluetooth to the hands-free phone system of the vehicle to enable phone calls. The main screen of a phone menu can look like the one shown in Figure 2-10 of a VW. Internet access is also becoming standard in current vehicles, granting access to Emails or different services like Facebook or Twitter. A web browser can be used to search for more information; the navigation systems get up-to-date traffic information; emergency services can be called for help in case of an accident or breakdown, and automobile repair shops can use a wireless communication with

[6]Source Figure 2-6: `http://www.bmw.com/com/en/owners/navigation/audio/introduction.html`, last accessed on 29/09/2016

[7]Source Figure 2-7: `http://www.nissanusa.com/sportscars/gt-r/versions-specs/version.black.html`, last accessed on 29/09/2016

Figure 2-8.: On the cluster screen of the Audi TT content of the infotainment system, as for example a navigation map, is shown in addition to the usually displayed information on a cluster display as speed[8].

Figure 2-9.: The picture of a rear-view camera, which belongs to an electronic parking assistance is shown on the head unit display of a Mercedes-Benz[9].

the vehicle to get a malfunction report. Some of the functions are only available while the vehicle is not moving in order to not distract the driver. In future, communication between vehicles will also become common.

Many functions are already integrated in an infotainment system. As mobile phones are our daily companion and users are used to the possibility to easily extend functionality, they want the same functions and flexibility in their vehicles. The latest infotainment systems provide the possibility to link mobile phones to access available functions on the phone over the infotainment system. Some infotainment systems even have their own app store in order to provide these features on the same level as integrated applications.

2.1.3 Integration of Applications in Infotainment Systems

The product life cycles of consumer electronics and vehicles diverge widely. The field of consumer electronics is very fast moving; new functions and products come onto the market very quickly, in contrast to the product life cycle of vehicles, which is significantly slower. In the case of in-vehicle infotainment systems both worlds are coming together. Today it is required to extend

[8]Source Figure 2-8: `https://www.audi-mediacenter.com/en/press-releases/audi-tt-is-connected-car-2014-418`, last accessed on 29/09/2016

[9]Source Figure 2-9: `http://techcenter.mercedes-benz.com/en/reversing_camera/detail.html`, last accessed on 29/09/2016

Figure 2-10.: The main screen of a phone application of a VW infotainment system shows available functions like speed dial options of the connected phone[10].

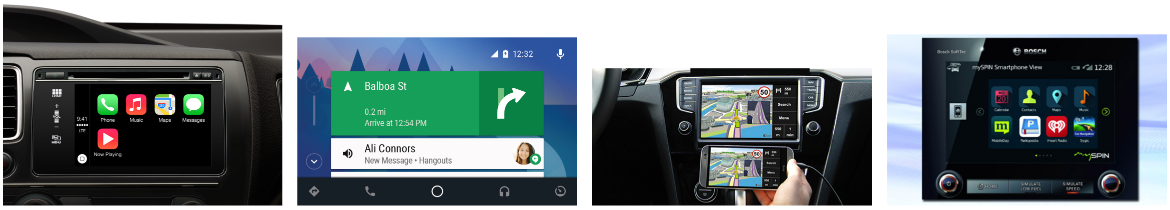
the functionality of infotainment systems as well, without replacing the whole device. This is already possible since infotainment systems have direct access to the Internet or at least through a mobile phone, and additional applications, shortly called apps, can be installed directly onto the infotainment system or on the linked and integrated mobile phone (Graf, 2012). Apps for music streaming, navigation with real-time traffic data, travel information or hotel booking are very popular for usage in the vehicle. In this section, different solutions to extend the functionality via apps are described. Only those solutions which use the same input and output devices as the infotainment systems are considered. More information about additional integration scenarios for mobile phones is described by Graf (2012).

Only a few infotainment systems have their own app store or the apps directly installed on the infotainment system as in the case of Renault R-Link or Mercedes Comand Online (Hansen and Kossel, 2016b). Renault R-Link, the infotainment system from Renault (see Figure 2-11), is an Android-based infotainment system with its own app store. Special apps adapted for the driving environment and approved through Renault can be downloaded directly over the Internet connection of the infotainment system or via a PC and installed with help of a SD card. More than 20 apps are available for this solution, and some are already pre-installed on the infotainment system. The apps can be operated over the touch screen or steering wheel buttons of the vehicle. Mail, SMS and traffic information can be read to the driver. The Internet connection is possible through a built-in SIM card, where the user has to pay a fee per year for usage (Renault, 2015).

Figure 2-11.: Renault R-Link, the infotainment system from Renault, provides an own app store to download and install applications[11].

[10] Source Figure 2-10: `http://www.volkswagen.co.uk/technology/communication/mobile-phone-compatibility`, last accessed on 29/09/2016

[11] Source Figure 2-11: `http://www.renault.de/renault-modellpalette/renault-pkw/clio/clio/#zubehoer`, last accessed on 29/09/2016



(a) Apple CarPlay (b) Android Auto (c) MirrorLink (d) Bosch mySPIN

Figure 2-12.: Solutions to display content of a smartphone on the infotainment system are provided by different suppliers. The most known solutions are Apple CarPlay (a), Android Auto (b), MirrorLink (c) and Bosch mySPIN (d)[12].

Another approach to extend the functionality of an infotainment system is based on the integration of a smartphone, therefore some OEMs have developed their own smartphone integration solution. Usually a special app provided by the OEM must be installed on the smartphone. If the smartphone is then linked to the infotainment system mainly over USB or Bluetooth, those apps can be accessed through the infotainment system and its control elements. The solutions from BMW, the BMW Connected Drive (BMW, 2012) and Opel, Opel Adam IntelliLink (Opel, 2015) are based on this concept. The BMW ConnectedDrive has both online services installed directly on the infotainment system and access to 3rd-party-apps on a connected smartphone. The difference is that the installed online services cannot be extended, and no further apps can be installed directly on the infotainment system. An expansion of the functionality is only possible over additional apps, which are installed on the smartphone (BMW, 2014) (BMW, 2012).
Apps that can be used in the vehicle are adapted to this context. For example the operation is possible over the vehicle control elements or mainly voice-control based to avoid distracting the driver. App developers get a Software Development Kit (SDK), which contains guidelines and tools to develop compatible apps for the BMW Connected Drive. Before apps can be used in a BMW they must undertake an approval process from BMW. Both platforms iOS and Android are supported (BMW, 2013).
Increasingly common are standardized solutions which are independent from the vehicle to display the content of a smartphone on the screen of the infotainment system. Apple CarPlay (Apple, 2014), Android Auto (Android, 2015) and MirrorLink (MirrorLink, 2015) are the most widely known and used solutions. The infotainment system must support such a particular solution that a smartphone can be connected, therefore, an app must be installed on the smartphone to be able to connect it to the vehicle. With this it is possible to operate apps provided by the smartphone over the control elements of the infotainment system. Android Auto is a special solution for Android devices (Android, 2015), Apple CarPlay for iOS (Apple, 2014) and MirrorLink for Symbian and Android devices (MirrorLink, 2015). All solutions support an increasing number of apps but the apps must be adapted to the driving context. For example long text input is not possible, so instead a hands-free communication over speech is provided. Another promising solution, which is based on the same principles and works for Android, iOS and Windows devices is mySpin from Bosch. This solution provides a SDK for app developers that can easily be adapted for use in the vehicle and enables the user to access the vehicle's information (Mlasko, 2015). More and more apps are provided but at the beginning of 2016 the number of adapted apps for the driving context was still far behind the number of offered apps in general.

[12] Source of Figure 2-12(a): `http://images.apple.com/v/ios/carplay/d/images/dashboard.png`, last accessed on 29/09/2016; Source of Figure 2-12(b): `https://play.google.com/store/apps/details?id=com.google.android.projection.gearhead`, last accessed on 29/09/2016; Source of Figure 2-12(c): `http://www.mirrorlink.com/apps`, last accessed on 29/09/2016; Source of Figure 2-12(d): `http://www.asmag.com/upload/pic/case/48095.895125.jpg`, last accessed on 29/09/2016

2.2 Driver Distraction

The rising number and variety of functions of the infotainment system can lead to an increase in driver distraction. This section explains why a driver might be distracted in this context, how driver distraction is described in literature and what methods exist to measure it. In addition, an overview of norms and guidelines that handle driver distraction is given, and approaches to reduce driver distraction, as described in literature that form the state-of-the-art, are summarized.

2.2.1 Human Information Processing and Driver Distraction

Driving a vehicle can be described with three different main tasks as shown in Table 2-1 (Bubb, 2003). The primary driving task consists of three sub-tasks: navigation, vehicle guidance and stabilization. The navigation task includes choosing a driving route and estimating the needed time. On this basis along with the traffic situation, the driver needs to choose a target course and target speed. This corresponds to the vehicle guidance. The stabilization includes the longitudinal and lateral dynamics. The driver ensures that the current course and current speed match with the target values (Donges, 2012). The secondary tasks come up with the primary driving task. They support the primary driving task by informing other road users about the driver's intentions or by reacting to external conditions, e.g. by actuating the indicator or the horn (Bubb et al., 2015). The tertiary tasks are not related to the primary driving task. The fulfillment of these tasks satisfies the need for comfort, information and entertainment (Bubb, 2003). For all tasks the driver needs to process information, which can be demanded either visually, auditory, manually, cognitively or using a combination of several ways.

Table 2-1.: Driving a vehicle can be splitted into three main tasks: primary, secondary and tertiary task (Bubb, 2003)

Task	Description	Example
Primary Driving Task	navigation, vehicle guidance, and stabilization	route planing, longitudinal and lateral dynamics
Secondary Tasks	Depending on the primary driving task	Actuating the indicator or the horn
Tertiary Tasks	Not related to the primary driving task	Climate controls, adjustment of the seat

Wickens et al. (2015) provide a model for processing the flow of information which typically appears when humans perform tasks. The model is shown in Figure 2-13.

First, information is received over the senses and is stored shortly in the short term memory. This is followed by the perception, which implies the interpretation of the sensory signal with the help from past experiences, which are stored in the long term memory. After perception, the information can be stored in the long term memory with help of the working memory. This includes not just storing but also the process of cognition. Another possibility is to react to the perceived situation as an immediate response or chosen from a broader range of possibilities. The executed response can change the environment and is perceived by the senses again. Fundamentally important for human information processing are the attentional resources. These play two different roles; filter of information and fuel for various stages of information processing (Wickens et al., 2015).

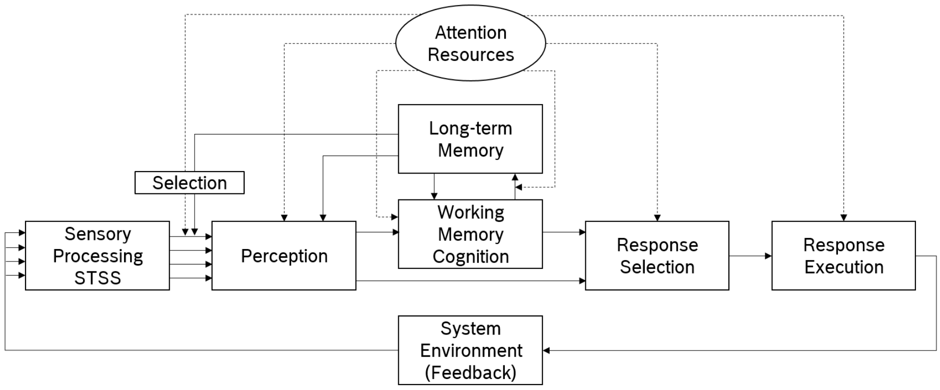


Figure 2-13.: Stages of human information processing are mainly perception, processing, and responding wherefore attentional resources are needed (Wickens et al., 2015).

The attentional resources are limited but are needed for information processing. Working on two different tasks, which both need attentional resources, can result in a conflict. Wickens et al. (2015) describe this conflict with the help of their model for multiple resources shown in Figure 2-14. The model consists of four dimensions. The first dimension describes the stages of information processing. The second refers to the first stage of information processing; the perception. In this model information can be sensed through visual, auditory or tactile modality. The visual modality is further divided into central (focal) and peripheral (ambient) visual perception, which build the third dimension. The last dimension is related to the processing code, which could be either manual/spatial or vocal/verbal. These two different types (codes) of information exist for each modality. For the auditory modality, information can be spatial in the form of sound, which can be located from a certain direction or verbal like speech. In accordance with the model of multiple resources from Wickens et al. (2015), a conflict arises if two in-parallel performed tasks bind the same resources of a dimension. For example, if both tasks involve visual perception, they interfere with each other, because there may be not enough resources available for both.

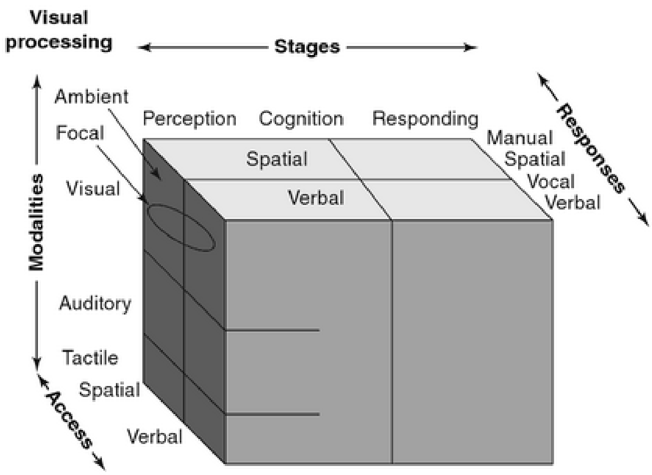


Figure 2-14.: The binding of resources in different dimensions during information processing is represented in the model of multiple resources (Wickens et al., 2015)

If the driver performs a tertiary task, e.g. operation of an infotainment system, in parallel to the primary driving task, then both activities involve the same resources, which results in divided attention. Both, the primary driving task and the operation of the infotainment system involve mainly visual perception of information on traffic signs or in the form of text on the screen. This leads to a negative impact on both tasks. In case of the primary driving task, this means that the driver can be distracted.

2.2.2 Definition of Driver Distraction

There exist several definitions of driver distraction in literature. Many efforts have been taken to find a standardized definition. Engström et al. (2013) worked on a taxonomy and detailed description, which are taken as a reference for this work. Driver distraction is often used in combination with the term inattention. In this work inattention is used as defined in Definition 2.4 and the relation to driver distraction is seen as shown in Figure 2-15.

Definition 2.4 - Driver Inattention.

Driver inattention is defined as insufficient attentional resource allocation of resources that are demanded by activities critical for safe driving (Regan et al., 2011) (Engström et al., 2013) (Lee et al., 2009).

According to Wickens' model of multiple resources, described in Section 2.2.1, in parallel performed tasks could lead to interferences if these activities bind the same resources (Wickens et al., 2015). If the attentional resources are misdirected by vehicle-external or vehicle-internal sources, the driver is distracted. In differences to misdirected attention an insufficient attention can be described e.g. as drowsiness.

Definition 2.5 - Driver Distraction.

Driver Distraction is the allocation of resources to a non-safety critical activity by the driver while "the resources allocated to activities critical for safe driving do not match the demands of these activities" (Engström et al., 2013) (Lee et al., 2009) (Binder et al., 2010).

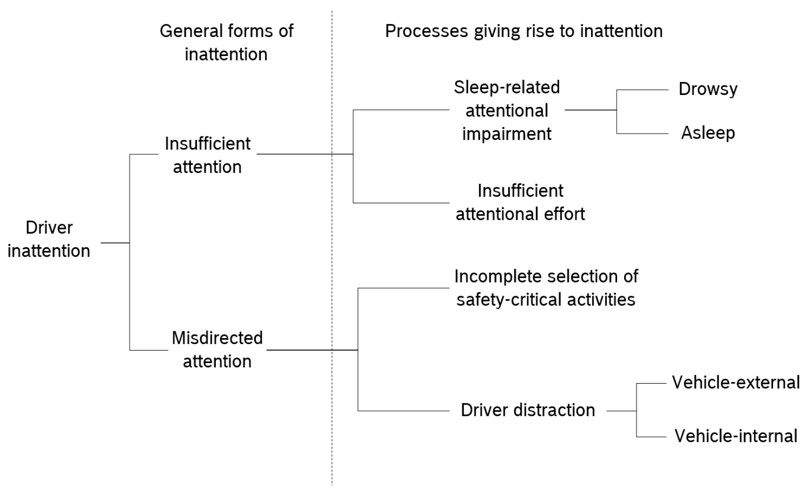


Figure 2-15.: Driver inattention can be distinguished in insufficient attention and misdirected attention. Both can be further divided. Driver Distraction is a form of misdirected attention (Engström et al., 2013).

Driver Distraction as defined in Definition 2.5 has multiple facets. Ranney et al. (2000) identified as a result of research activities of the National Highway Traffic Safety Administration (NHTSA) four different types of driver distraction:

- "Visual distraction (e.g., looking away from the roadway)"
- "Auditory distraction (e.g., responding to a ringing cell phone)"
- "Biomechanical distraction (e.g., manually adjusting the radio volume)"
- "Cognitive distraction (e.g., being lost in thought)"

The different forms cannot always exactly be distinguished as one activity can cause multiple types of driver distraction. The operation of an infotainment system can involve all four types of distraction. Visual distraction occurs as the driver needs to take his eyes away from the road to a display where content from the infotainment system is displayed. Auditory distraction occurs when sounds or speech are involved. As most infotainment systems use touch screens or knobs as input devices, the driver could also be distracted biomechanically. Cognitive distraction arises if the additional task binds mental resources.

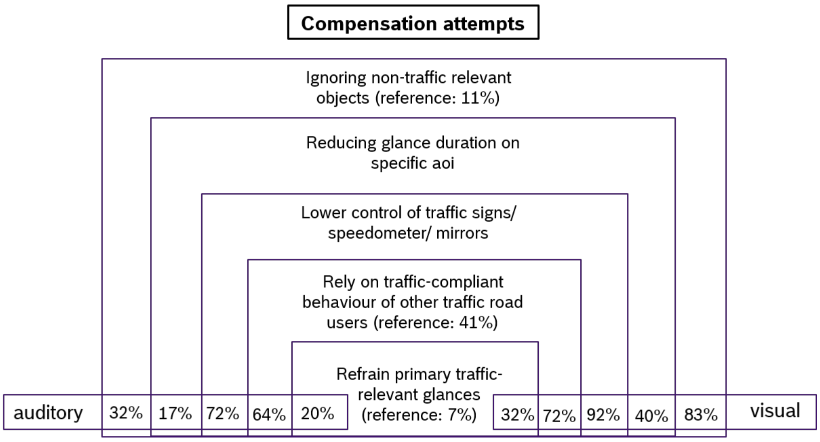


Figure 2-16.: Visual and auditory distraction can lead to compensation behavior. The frequency of recognized effects of visual and auditory distraction are compared to a baseline without distraction (Schweigert, 2003).

Drivers tend towards compensating behavior when they are distracted. They prioritize tasks and reduce or abort others which are less relevant (Schwalm et al., 2015). This compensation effect on gaze behavior was analyzed by Schweigert (2003). An example of compensating behavior is that the glances on non-traffic relevant objects is reduced with increasing complexity of the driving situation. Figure 2-16 describes different types of compensating behavior. With an additional task the compensating behavior is increased. The three inner shells, minimal control of traffic signs/speedometer/mirror, counting on rule-consistent behavior of others and refraining from main traffic-relevant glances, correspond to misbehavior and dangerous driving. In the example described in Figure 2-16, seven percent of the participants in the baseline refrained from main traffic-relevant glances, 32% showed the same behavior when they were distracted visually and 20% when they were distracted auditorily (Schweigert, 2003) (Bubb et al., 2015).

2.2.3 Methods to measure Driver Distraction

In recent years several methods to measure the different types of driver distraction, described in Section 2.2.2, have been defined and some have become standard. The methods described in this section can be conducted at different points within the development process to verify the new product or approach related to driver distraction. In Figure 2-17 several of these methods are set in reference to the development process and are assessed due to their validity. With increasing progress within the development process, methods with a higher validity due to increasing realistic conditions can be chosen (Milicic, 2010).

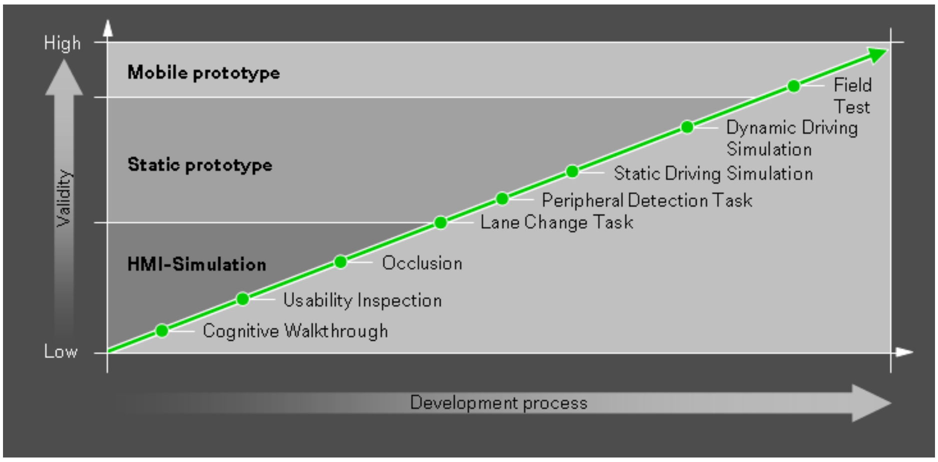


Figure 2-17.: Milicic (2010) sets evaluation methods in reference to the development process and assessed them due to their validity.

The methods range from simple lab experiments (e.g. occlusion method) to complex field operational tests over a longer period. A brief overview is given in this section. Additional information regarding evaluation methods for driver distraction is given by Vollrath and Krems (2011). The methods can be divided into subjective and objective methods to evaluate driver distraction. The subjective methods are based on the subjective assessment conducted by the participants themselves or the experimental supervisor. The most common questionnaire is the NASA-TLX (NASA Task Load Index) to assess the subjective perceived workload of a person depending on ratings on six sub-scales (mental demands, physical demands, temporal demands, own performance, effort and frustration) (NASA, 1986). High workload can lead to cognitive distraction. Other similar questionnaires are the RSME (Rating Scale Mental Effort) (Zijlstra, 1993) or the DALI (Driving Activity Load Index) (Pauzie, 2008). Objective methods collect objective measures as speed, reaction times, or distance to lane center for example in a driving simulator. These measures can be collected separately or within a standardized procedure e.g. lane change test (see below). For more information about measuring driving performance see Knappe et al. (2006) or about measuring eyes off road see ISO 15007-1 (2014) and ISO/TS 15007-2 (2014).
Three standardized methods are the occlusion method, the lane change test and the detection response task. All are already or will be in future described as an ISO norm.

- **Occlusion Method:** With the occlusion method visual distraction and interruptibility of a task, which is supposed to be performed in parallel to the main driving task, are measured. The participants need to wear shutter glasses that restrict their vision by toggling between a transparent and non-transparent state. This simulates the interruptibility of the task, which is needed in reality to provide enough attention to the primary driving task (ISO 16673, 2007). The Total Shutter Open Time (TSOT) represents the duration the participant needs to fulfill a task. The Total Task Time (TTT) corresponds to the time the participant needs for the same task without the shutter glasses. The relation between those measures gives an indication of how acceptably the task can be interrupted (Noy et al., 2004).
- **Lane Change Test:** The Lane Change Test (LCT) measures the distraction potential of additional tasks or more exactly the influence of the task on the primary driving task. The participants drive with constant speed within a driving simulation environment and need

to change lanes on a three-lane street. Which lane they should take is indicated by signs next to the road on the left and right side. They are doing this procedure with and without operation of an additional task. As a result the deviation between a reference route and the driver's driving performance is calculated. In addition, the reaction time and lane keeping quality are determined (ISO 26022, 2010).

- **Detection Response Task:** Effects on cognitive load by an additional task can be measured with the Detection Response Task (DRT). The focus is on tasks involving an interaction with a visual-manual, voice-based, or haptic interface. The participants need to respond, for example by operating a micro-switch, to a stimulus (e.g. LED), which is presented with a specified degree of temporal uncertainty. The response time as well as the hit rate is measured to make statements about the cognitive load of the driver (ISO/DIS 17488, 2015).

2.2.4 Norms and Guidelines

For the development of in-vehicle HMI driver distraction is one main topic. Guidelines and norms have been developed by different organizations containing rules for automobile manufacturers and suppliers for the development. Four major guidelines have been developed in Europe, Japan and USA to ensure that in-vehicle systems can be used safely. They provide best practices, evaluation methods and principles (Schindhelm et al., 2004) (Heinrich, 2013). All guidelines are voluntary but different groups have committed to complying with the guidelines.
This section provides a brief overview over the guidelines from JAMA (Japan Automobile Manufactures Association), ESOP (European Statement of Principles), AAM (Alliance of Automobile Manufacturers) and NHTSA (National Highway Traffic Safety Administration).

JAMA: The third version of the JAMA guideline was released in 2004. The scope of the guideline includes in-vehicle display systems installed in cars and visible to the driver. The guideline defines requirements for developers of human-machine interfaces for display systems, ergonomics and safety related issues. The recommendations are related to the installation of display systems, functions of display systems, display system operation while the vehicle is in motion, and the presentation of information to users (JAMA, 2004).

ESoP: The ESoP guideline provides safety aspects to promote a good HMI design with which the safe control of the vehicle in a complex and dynamic traffic environment should be ensured. It was released in 2006 and includes overall design principles, installation principles and information presentation principles to name just a few categories (European Union, 2006).

AAM: The main concerns of the AAM guideline are safety aspects for design and installation of in-vehicle information and communication systems used by a driver while the vehicle is in motion. The last version of the AAM guideline was published in 2006. It includes the same categories for the principles as the ESoP guideline (AAM, 2006).

NHTSA: The aim of the NHTSA guideline, which was published in 2013, is to reduce the number of crashes caused by a distracted driver. The focus is mainly but not exclusively on a list of tasks, which interfere with driving and evaluation methods to assess suitability (NHTSA, 2013).

The described guidelines are linked and build on one another, and include partially the same content but are published for different markets. There exist more guidelines as well as ISO norms, which should be considered when developing an in-vehicle HMI, e.g. ISO 15005 (ISO 15005, 2002),

ISO 15008 (ISO 15008, 2009), ISO 17287 (ISO 17287, 2003) or the ISO 9241-11 (ISO 9241-11, 1998). Some of these are related to usability aspects and are described further in Section 2.3.

2.2.5 Approaches to reduce Driver Distraction

Driver distraction caused by the use of infotainment systems can be reduced by a number of different measures. Approaches which address the input modality, interaction design, or output modality are possible. A selection of measures is described in Table 2-2. Each measure is assigned to one or several of the types of driver distraction, described in Section 2.2.2, which should be reduced. In addition, the limits of each measure are briefly described.

Table 2-2.: Overview of measures to reduce driver distraction caused by usage of the infotainment systems

Measure	Addressed Type of Distraction	Constraints
Output in the field of view of the driver e.g. head-up display, cluster (Götze and Bengler, 2015)	visual	limited space, overlap of information with the driving environment
Operation via voice control (Maciej and Vollrath, 2009) (Lee et al., 2001)	visual, biomechanical	input: inappropriate for certain operations e.g. search in lists, output: speech understanding difficult in some situations
Operation with steering wheel buttons (Osswald et al., 2011)	biomechanical (visual)	limited input options
Audio output instead of visual representation (Fung et al., 2007)	visual	needs also be suitable for hearing-impaired drivers
Multimodal operation (Müller and Weinberg, 2011)	visual, biomechanical, cognitive	high complexity, still under development
Different sound zones for different passengers in the same vehicle (Yanagidate et al., 2014)	auditory	still under development
Different concept for structure of the menu e.g. task-oriented (Spies et al., 2009) (Totzke et al., 2006)	visual, biomechanical, cognitive	unusual, not intuitive
Hide or deactivate functions while driving (Piechulla et al., 2002)	all types	lack of user acceptance
Adapt functionality to the driving context (apps) (Apple, 2014)	all types	reduced functionality
Provide favorites to access often used functions faster (SUV manuals, 2016)	visual, biomechanical, cognitive	limited number

Information filtering: show only relevant information (Stoter et al., 2011)	visual, cognitive	relevant information may missing, long ways to get right information if not available
Recommendation systems for functions (Garzon, 2012)	visual, biomechanical, cognitive	accuracy, user acceptance
Automation of vehicle functions (Bammel, 2007)	all types	behavior not as expected

There exist several approaches to reduce driver distraction but still driver distraction is a current issue. More research is needed to develop these further. In addition, a prerequisite for using the measures is their acceptance by the driver. This should be already considered within the development process.

2.3 Acceptance and Usability

A prerequisite for the usage of a function is usually the acceptance of the same. Therefore, acceptance and especially usability, one of the main criteria for user acceptance, must be taken into account when developing a new system. Both acceptance and usability are described in this section. This is followed by a description of the user-centered design process, which focuses on developing products according to user requirements, and a description of evaluation methods to evaluate a product in different stages of development.

2.3.1 Driver Acceptance

Success of a technology or system depends on the balance between satisfaction and the burden the technology or system offers. This is in general called acceptance (Schnell, 2009). Acceptance is a complex construct and depends on the technology, those who use it and the context (Regan et al., 2014). There exists no common understanding about the term “acceptance”, and different approaches have been made to define acceptance. Adell (2009) has analyzed definitions found in literature and categorized them in five categories as shown in Table 2-3.

Table 2-3.: According to Adell (2009), definitions considering acceptance can be categorized in five categories.

1	2	3	4	5
Using the word "accept"	Satisfying needs and requirements	Sum of attitudes	Willingness to use	Actual use

The definitions start with just using the word acceptance defining acceptance as "satisfying the needs and requirements" or "the sum of attitudes". Two definitions that go a bit further are "willingness to use" and "actual use" of the system or technology. Which definition is used depends on the current context and phase of development. When developing in-vehicle systems a subcategory of acceptance, driver acceptance can be used. Driver acceptance is a driver-centered view on the term acceptance whereby Adell (2009) has proposed an overall definition.

Definition 2.6 - Driver Acceptance.

"Acceptance is the degree to which an individual intends to use a system and, when available, to incorporate the system in his/her driving." (Adell, 2009).

This definition can be categorized in category "willingness to use" and "actual use" depending on the availability of the system. Therefore, this definition can be used as a starting point to evaluate acceptance during the development process when the system is not yet fully available. In order to assess driver acceptance of a new system more than a definition is needed. From the definition an assessment structure and acceptance model needs to be derived. The assessment structure describes how acceptance can be measured and the acceptance model represents the criteria which influence acceptance (Adell et al., 2014b). There exists a wide range of acceptance models, which explain how different input variables influence acceptance. An overview of different models is given by Schnell (2009). A well known model is the Technology Acceptance Model (TAM) (Davis, 1986) or the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003). Some models are developed for or adapted to the driving context, e.g. the models from Arndt (2011), Roberts et al. (2012) or Ghazizadeh and Lee (2014). The existing models are difficult to apply because some are too general, some too specific or not well evaluated regarding their validity. More research is needed in this field. In the meantime acceptance can be evaluated through asking people directly if they would use or buy a product and having a look at the criteria which are known to influence acceptance. These criteria can then be improved throughout the development process. Criteria that influence user acceptance are for example trust (Arndt, 2011), (Ghazizadeh et al., 2016), (Ghazizadeh and Lee, 2014), unobtrusiveness (Roberts et al., 2012), or usability (Arndt, 2011). Some of the criteria are partially interdependent, which is normally described through an acceptance model. Just as important as the already mentioned criteria are external variables like system or driver characteristics, context and social influence (Arndt, 2011) (Ghazizadeh and Lee, 2014) (Adell et al., 2014a).

2.3.2 In-vehicle HMI: Usability and User Experience

Two criteria that influence acceptance of a system and therefore the actual usage are usability and user experience. These terms are well-known in the field of human-machine-system development. General definitions are given in the ISO 9241-11 (1998) and ISO 9241-110 (2006) but to evaluate them they need to be considered in more detail. As acceptance, these terms are complex and based on interdependencies of different other terms.

Definition 2.7 - Usability.

"The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" is called usability (ISO 9241-11, 1998).

Usability, as defined in Definition 2.7, is based on effectiveness, efficiency and satisfaction users experience while applying a product to reach a goal. Users want to have a high accuracy and completeness when achieving their goals, which is described by effectiveness. Efficiency is the effort that must be taken to achieve this. Satisfaction refers to the positive attitude while using the system and the absence from discomfort (ISO 9241-11, 1998). Those criteria are on the other hand influenced by further criteria; for example the ISO 9241-110 (2006) describes dialogue principles which should be applied when developing an interactive system. The ISO 9241-12 (1998) describes recommendations for presenting information which influences the effectiveness, efficiency and satisfaction of using an interactive system. In Figure 2-18 the relation between

ISO 9241-11 (1998), ISO 9241-12 (1998) and ISO 9241-110 (2006) is shown. Furthermore there exist several more criteria depending on the system, context or user who use it, which influence the usability of a system. For the evaluation of usability or related criteria, questionnaires are a suitable method. For example the ISONorm questionnaire evaluates a system regarding the dialogue principles (Prümper and Anft, 1993), whereas the SUS (System Usability Scale) questionnaire consists of ten items, which are evaluated and combined to one usability score (Brooke, 1996).

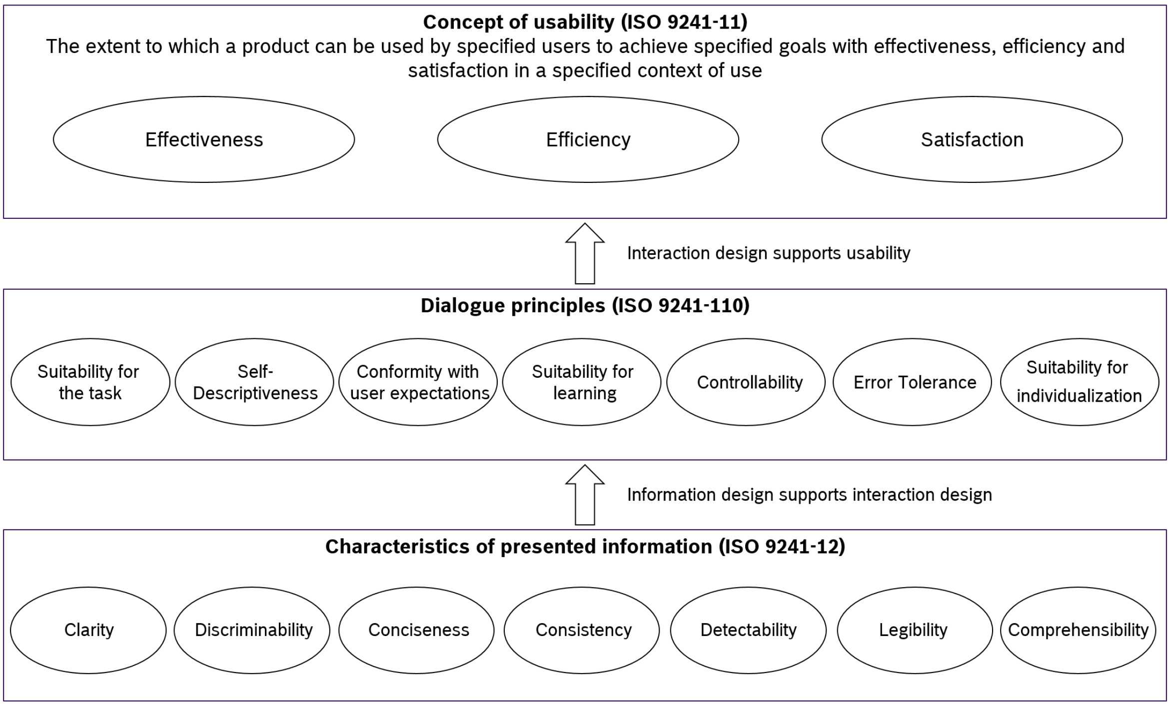


Figure 2-18.: ISO 9241-11, ISO 9241-110 and ISO 9241-12 build up on one another, describing usability and criteria influencing usability of a system (ISO 9241-110, 2006).

In addition to usability the term user experience is used. This term goes a bit further and covers even more criteria. It includes "all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviors and accomplishments that occur before, during and after use" (ISO 9241-210, 2010).

Definition 2.8 - User Experience.

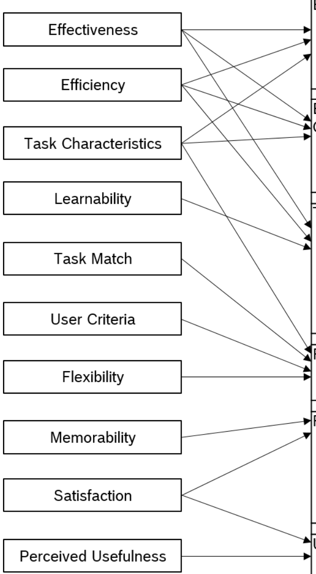
User experience corresponds to "person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service." (ISO 9241-210, 2010)

As for usability, questionnaires are a suitable tool to evaluate user experience. The questionnaire AttrakDiff covers usability as well as user experience. It distinguishes between the hedonic quality, the pragmatic quality and attractiveness. The pragmatic quality is equivalent to usability whereas hedonic quality describes the extension of capabilities, stimulation or communication of a desired identity. Stimulation is important for humans to improve their knowledge and skills and a product supports them expressing themselves. This is complemented by the evaluation of attractiveness; a global assessment based on the perceived qualities (Hassenzahl et al., 2003). The mentioned norms regarding usability are general, but also norms which are specific for the automotive context exist. For in-vehicle systems providing information to the driver, suitability in relation to the driving task is a focus of ISO 17287 (2003).

Definition 2.9 - Suitability.

Suitability is the degree to which the use of an in-vehicle information system "is appropriate in the context of the driving environment based on compatibility with the primary driving task." (ISO 17287, 2003)

Suitability according to ISO 17287 (2003) includes criteria like interference with the driving task, controllability, efficiency, and ease of use while learning about the system. These criteria focusing on the driving context, and overlap and complement the criteria for usability. Taking into account design guidelines for systems in the vehicle, as for example ISO 15005 (2002), to improve usability or user experience enables achieving those criteria. Additional or specific criteria need to be considered when developing interactive systems for the vehicle. Harvey and Stanton (2013) describe general usability criteria under driving oriented contextual factors. For example the dual task environment has an influence on the interpretation of the usability criteria. Key Performance Indicators (KPI) are derived from the usability criteria taking the driving context into account. These KPI are shown in Figure 2-19. The task structure that needs to be optimal for a usage while driving or minimized task times and error rates are just two of them (Harvey and Stanton, 2013). These KPIs need to be considered during the development process to develop a suitable in-vehicle system.



Contextual Factors	IVIS Usability Criteria	Key Performance Indicators (KPIs)
Dual Task Environment	Effectiveness of IVIS whilst driving	1. Task structure and interaction style should be optimal to minimise usability issues whilst driving
	Efficiency of IVIS whilst driving	2. IVIS task times and error rates should be minimised whilst driving
	Interference between IVIS and driving	3. Interaction with the IVIS should not affect primary driving performance
Environmental Conditions	IVIS effectiveness under varying driving conditions	4. Task structure and interaction style should be optimal to minimise usability issues under all driving conditions
	IVIS efficiency under varying driving conditions	5. IVIS task times and error rates should be minimised under all driving conditions
Training Provision	Effectiveness of IVIS with novice users	6. Task structure and interaction style should be optimal to support IVIS interaction for novice users, i.e., the IVIS should be learnable
	Efficiency of IVIS with novice users	7. IVIS task times and error rates should be minimised and usability issues should not be increased for novice users, i.e., the IVIS should be learnable
Range of Users	IVIS compatibility with full range of users	8. Interaction style and task structure should be designed to support the full range of user characteristics typical of the driver population
Frequency of Use	Short- and long-term satisfaction with IVIS whilst driving	9. User satisfaction on initial use and after prolonged use should be high for all aspects of the interaction
	Memoribility of iVIS interaction	10. IVIS task times and error rates should be minimised even after a period of nonuse of the device
Uptake	Satisfaction on first use of IVIS whilst driving	11. User satisfaction on initial use of the IVIS should be high for all aspects of the interaction
	Perceived usefulness of IVIS in driving	12. Users should report a high likelihood of using the device during real driving

Figure 2-19.: Special criteria regarding usability need to be considered for the development of in-vehicle systems. From these criteria Key Performance Indicators are derived (Harvey and Stanton, 2013).

Evaluating suitability of an in-vehicle system, the driving context must be taken into account. Suitable criteria for usability are workload, primary driving task performance, and behavioral adaptation. Except for the adaptation of the behavior, these criteria can be evaluated within a driving simulation environment (ISO 17287, 2003).

2.3.3 User-Centered Design and Evaluation methods

Developing interactive systems with the aim to reach high usability, good user experience and finally user acceptance is a challenge. It is important to have the users' needs and requirements in focus. This is the basis of the user-centered design process described in ISO 9241-210 (2010). The key principles of the user-centered design process are understanding the users, task and context within an iterative process where the design is refined by user-centered evaluations (Travis, 2011). Within this development process, the user is involved at a very early stage. Higher user acceptance and quality of the end-product can be achieved through incorporating the user's feedback in the iterations of this process, which may lead to higher usability, higher user experience and reduction of discomfort and stress (Jameson, 2008). The user-centered design process shown in Figure 2-20 consists of four steps. The first step is specifying the context of use, which includes the analysis of persons who should use the product and the environment where it should be used. The next step is the analysis of the requirements covering the identification of the relevant requirements of different stakeholders. This step is followed by the design realization step, wherein a design is developed based on the requirements, with the help of different prototyping methods, for example paper prototypes or click-through prototypes (Szekely, 1994). The final step of the user-centered development process is the evaluation, where the design is evaluated against the requirements. Afterwards a new iteration can be started, if needed, at any step of the user-centered design process (ISO 9241-210, 2010).

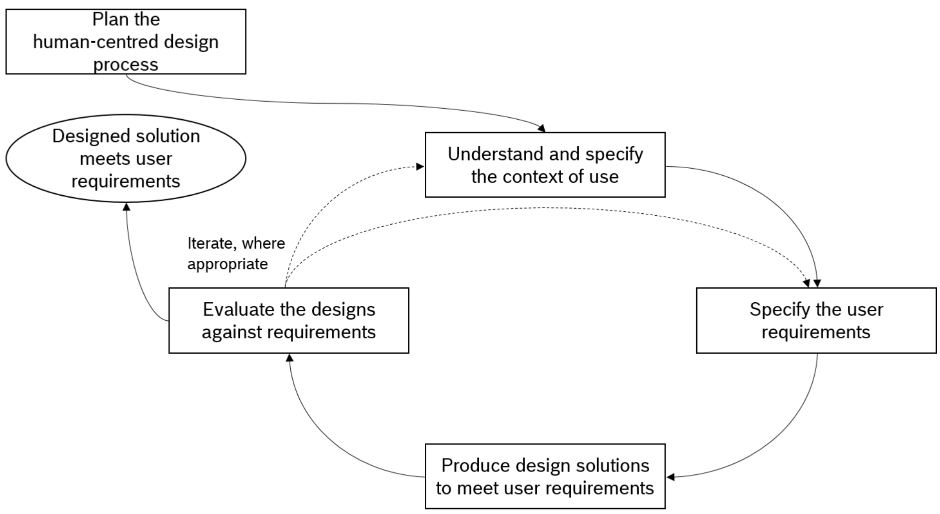


Figure 2-20.: The iterative user-centered design process described in ISO 9241-210 (2010) consists of four main steps: understand context of use, specify requirements, produce design and evaluate the design

Important for user-centered development is the early and steady involvement of potential users. Developed designs can be evaluated with the help of different methods depending on the stage of development and available prototype. In the following some common usability evaluation methods are described.

Interview: A simple technique to get an impression of the users perspective is a user interview. Users are questioned about their expectations or experience using a system. An interview can be conducted freely, with the help of a guideline or with pre-formulated questions. They are easy to set up but some effort is needed for analysis of the collected data. Interviews can be performed at each stage of the development process (Herczeg, 2005).

Cognitive Walkthrough: The cognitive walkthrough is a method executed by experts. The focus of this method lies on learnability. The experts empathize with potential users and explore the system behaviour by fulfilling tasks on their own. They compare each interaction step with the optimal solution and identify obstacles and opportunities with the help of guiding questions. A description and some sketches are sufficient for conducting this method (Sarodnick and Brau, 2006).

Heuristic Evaluation: Another method of usability analysis is the heuristic evaluation developed by Nielsen and Molich (1990). A number of experts are exploring a system and evaluating it with the help of given heuristics (Nielsen, 1994). The heuristics correspond to desired characteristics of the system. The goal is to identify usability problems. This method can be conducted at a very early stage of development as no specific prototype is needed.

Wizard of Oz: The Wizard of Oz experiment can also be conducted at different stages of the development process. The functionality of the prototype is simulated by a person, the so-called wizard, where the participants believe that they are interacting with the real system. This enables evaluation of the interface and interaction concept of a system before implementing the whole (Dow et al., 2005).

A/B Test: The A/B test is an empirical method to compare two concepts of a system with each other. The two concepts are identical except for one variation. Therefore, A/B tests are a simple form of multivariate testing. The participants are separated into two groups and experience either variant A or variant B (Moser, 2012).

In some methods the participants are experts and in others potential users take part. On one hand experts bring knowledge and experience in their field of expertise, on the other they empathize with potential users and evaluate the method from their point of view. Nevertheless it is also valuable to do evaluations with potential users. It must be defined who the potential users are and what characteristics they have. The sample group must be representative of the target group (Färber, 2005) (Harvey and Stanton, 2013). In addition, the size of the sample group must be determined. For the heuristic evaluation, Nielsen (2012) found out that five participants offer the best cost-benefit ratio. To get statistically significant results in a quantitative study at least 20 participants should be tested (Nielsen, 2012). A recommended size for the sample group is 30 participants. The exact size can be calculated depending on the significance level, effect size and power of the test (Färber, 2005).

3 Adaptive Systems

The number of functions of infotainment systems is rising along with the demand to take advantage of them. But at the same time the resources of humans remain limited, which can lead to driver distraction. Humans need support to handle the quantity of information or manage the complexity of operating a system. In Table 2-2 in Section 2.2.5 different approaches to reduce driver distraction are described. A promising approach are adaptive systems, which adapt their behavior or presentation to the environment, user or task. These support the driver by filtering information, giving recommendations, or automating vehicle functions. Adaptive systems and their application in the driving context are described in this chapter. Relevant basics and the state-of-the-art of in-vehicle adaptive systems for infotainment functions are described in Section 3.1. Developing an adaptive system for an infotainment system includes several subtopics. A more detailed description of the topics architecture (see Section 3.2), user modeling and machine learning (see Section 3.3), and interaction concepts (see Section 3.4) are given in the respective sections.

3.1 Basics of Adaptive Systems

"Adaptive system" is a general term summarizing different types of adaptive systems. The description of these types, their differences and challenges regarding user acceptance provide the main content of this section. In addition, the state-of-the-art of in-vehicle adaptive systems for infotainment functions is described.

3.1.1 Definition of adaptive system and adaptive user interface

Already common in our everyday lives are adaptable systems; the predecessors of adaptive systems. Both systems adapt their characteristics to the user's needs, but in an adaptable system users can explicitly tailor the system characteristics to their personal preferences (Jameson, 2008) (Oppermann, 1994), whereas an adaptive system takes over this part for the user, as described in Definition 3.1.

Definition 3.1 - Adaptive system.

An adaptive system changes its characteristics automatically according to the user's needs (Oppermann, 1994). It changes its behavior or characteristics when it is not accomplishing what it is intended to do, or when better functionality or performance is possible (Laddaga, 1998). This involves some form of learning, inference, or decision making (Jameson, 2008).

Depending on whether the system adapts to the environment, user or task, it is called user-adaptive, situation-adaptive or task-adaptive. All can be summarized as context. Context in the automotive field includes all parameters that can be used to characterize the current overall situation of driver, environment and vehicle and which are the source of knowledge needed for context-sensitive behavior of the system (Hoch, 2009). It describes all kind of information relevant to the interaction between user and system (Dey, 2001).
The terms "knowledge" and "information" are often used synonymously. In this work the terms

are distinguished. Information about the user or the situation can be collected implicitly by the system, e.g. with the help of sensors, or explicitly through the input of the user. Information is stored in a model, as for example all information about the user is stored in a user model. From this information knowledge is derived. Knowledge represents interpreted information, which is also stored in a model (Hoch, 2009) (Kobsa, 1995). This knowledge can be for example the goals, experience or preferences of a user or information about the environment such as location (Li et al., 2007).
Adaptive systems are often called intelligent systems. “Intelligent system” is a widely used term and no general definition is available. In this work adaptive systems are understood as intelligent systems because they cover aspects referring to artificial intelligence such as knowledge representation and learning (Alvarez-Cortes et al., 2009).
Interactive systems can be split into two parts: the business logic (system) and the user interface. An adaptive system must not necessarily have an adaptive user interface but the boundaries between both are not always clearly defined. This relationship is shown in Figure 3-1. The user interface can be static although the system is adaptive. An adaptive user interface adapts its presentation visible according to the user needs (Alvarez-Cortes et al., 2009).
This work focuses on adaptive systems with adaptive user interfaces, as defined in Definition 3.2.

Definition 3.2 - Adaptive User Interface.

Adaptive user interfaces are human-machine interfaces that adapt "their displays and available actions to current goals and abilities" of the user by considering the current context (Gulla et al., 2014) (Rothrock et al., 2002). They "aim to improve the efficiency, effectiveness and naturalness of the human machine interaction" (Maybury, 1999).

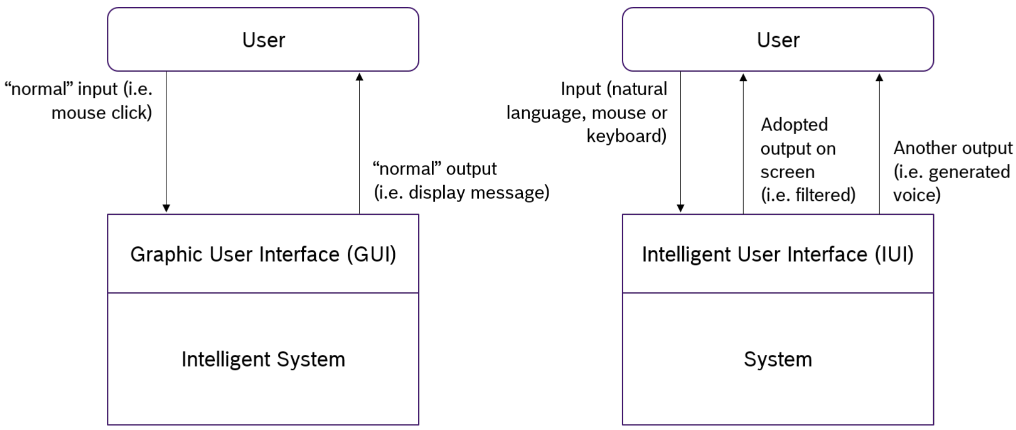


Figure 3-1.: An adaptive system can have a static user interface although the system is adaptive. An adaptive user interface adapts its presentation visibly according to the user’s needs but the underlying system must not be adaptive (Alvarez-Cortes et al., 2009).

There exist different possibilities for an adaptive system to improve the efficiency, effectiveness and naturalness of the human machine interaction. In the next section different types of adaptive systems with adaptive user interfaces are described.

3.1.2 Types of adaptive systems

The last three entries of Table 2-2 in Section 2.2.5 refer to different forms of adaptive systems with the aim to reduce driver distraction. However, there exist many more forms of adaptive systems. According to Jameson (2008) there exist in general two types of adaptive systems; those who support the user using the system and those who support the user by acquiring information.

The first type includes five categories, which describe how the user can be supported to operate a system more successful or effective. The first category refers to adaptive systems that take over parts of routine tasks for the user automatically. Parasuraman et al. (2000) describe different levels of automation, which can be transferred as adaptation levels to explain how much the user is supported by the adaptive system. The spectrum runs from very low support by showing a selection of decision or action alternatives from which the user can choose to very high support by taking over decision and action for the user. One example of this category is the intelligent mail sorter of Crawford et al. (2002) that learns rules to automatically sort mails. The second category describes adaptive systems that adapt their interface as for example the shown icons in the start menu of Windows[1]. The third category corresponds to adaptive systems that support the user using the system by offering information about how to use it. The second last category refers to adaptive systems that mediate the interaction with the real world, e.g. by blocking phone calls when a driver is in a demanding situation (König et al., 2003). The last category describes adaptive systems that adapt the system's dialog strategy, primary seen in case of natural language dialogs.
The second type of adaptive systems, those who support the user by acquiring information, can also be divided into five categories. The first category includes adaptive systems that help the user finding information, e.g. articles of web blogs, which are of interest for the user. The second category refers to those which recommend products best known from Amazon[2]. Tailoring information presentation is included in the third category. These adaptive systems select and present information in a very beneficial way for the user with the goal to make the interaction more efficient, for example active buyer guides where the adaptive system shows tailored information depending on the preferences of the user, so the user needs less effort to judge how well a product meets his requirements. Supporting collaboration that enables more effective group work is referred to adaptive systems in category four. To achieve this the adaptive system needs models of a large number of users to understand how they match or complement each other. Category five describes adaptive systems that adapt to users' learning level, type or speed to support their learning process. Examples and detailed description for each type and category are given by Jameson (2008).

One subtype of adaptive systems are recommender systems. These can be classified in different categories of the described support forms depending on their focus of support. Recommender systems recommend actively a "useful" subset of a given number of entities to the user based on the current context (Klahold, 2009). The support can be categorized into one of the above described categories depending on the type of entity, for example if the recommender system recommends information it helps the user to find suitable information, or if the system recommends a preconfigured function in form of a link to this function, it supports the user by taking over parts of tasks. Recommender systems are often found in online stores for product recommendations which might be of interest for the user, based on data collected in the past and the data from other users. The goal is to provide recommendations for products or in general entities the user finds interesting and are unknown to the user. However, recommendations can also contain entities already known by the user, for example often used functions by the user can be presented as recommendations to reduce the number of operation steps to access them. To distinguish these two forms within this work, systems of the first form are called recommender systems and systems of the second form are called recommendation systems.

[1] `http://windows.microsoft.com/en-gb/windows/start-menu-overview#1TC=windows-7`
[2] `www.amazon.com`, last accessed on 23/06/2018

3.1.3 Challenges of adaptive systems

Adaptive systems are a promising approach to improve the efficiency or effectiveness of a system. On the other hand, when developing an adaptive system some challenges need to be faced, which are described in the following.
A main challenge of adaptive systems is to gain **trust**. A user will not be willing to use the support of an adaptive system if he/she does not trust the abilities of the adaptive system (Hartmann, 2009). Gaining trust is deeply linked to achieving acceptance (Evers et al., 2010); however a general model for acceptance is missing even though many factors and their relationship to trust have been researched, for instance by Höök (2000), Evers et al. (2010), Hartmann (2009) and Nothdurft et al. (2012).
One factor which has a great influence on trust, and therefore is a challenge to deal with when developing adaptive systems, is **traceability**. This includes two aspects: predictability and comprehensibility. The user needs to be able to both predict the effects of his action and comprehend the system's actions (Jameson, 2008). To increase the traceability of the system behaviour of an adaptive system it is important to make it transparent to the user. The terms transparency and traceability are often used as synonyms, but in this work we use the definitions as described by Walter et al. (2015b). Transparency is the ability of a system to convey knowledge about the trigger of a certain behaviour or about the behaviour itself to the user. Traceability is the possibility for the user to understand the behaviour of the system. This is possible because the user already has knowledge about the system or it provides information where the user can derive this knowledge. The relationship between transparency, traceability and acceptance is shown in Figure 3-2. Traceability of the system behaviour has a great influence on the amount of trust the user has into the adaptive system (Hartmann, 2009). As stated earlier, one way to increase trust is to generate transparency (Bellotti and Edwards, 2001). Understanding the system functionality and trust in the system then have an influence on user acceptance (Arndt, 2011).

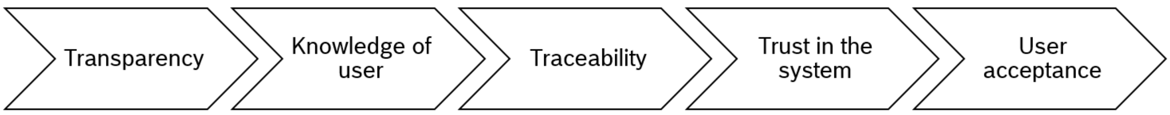


Figure 3-2.: Transparency, traceability, trust and user acceptance are dependent on each other (according to Walter et al. (2015b)).

Another threat is that users **treat the adaptive system as they might treat fellow beings**, as described by Höök (2000). The user needs to understand the abilities and also importantly the limits of the adaptive system to set the right amount of trust into it.
A further challenge developers need to face is the diminished **controllability** an adaptive system can affect. The user should feel in control of the system, which means having the ability to influence or prevent the system status or actions (Jameson, 2008) (Hartmann, 2009). A possibility to integrate the user in the control loop is to let the user approve or disapprove the system's actions. The degree of control should be determined individually depending on the context (e.g. task or user) (Hartmann, 2009).
In addition, an adaptive system with a high **obtrusiveness**, e.g. when it places demands on the user's attention, can be a problem. This can conflict with the primary task of the user (Jameson, 2008). The amount of distraction needs be minimized (Hartmann, 2009).
The adaptive system can be a part of an existing system. Therefore, the **design of the interaction** of the adaptive system needs to be integrated into the existing layout without influencing the normal use of the system negatively (Hartmann, 2009). If an adaptive system provides several support forms, as described in Section 3.1.2, all must be integrated in one interface.

The user needs to experience the adaptive system and its support forms as one intelligent system (Console et al., 2002).
Over time the user gets used to the adaptive system, which can result in a **diminished breadth of experience**. This can lead to problems in case the user needs to use the system without adaptive support. One possibility to solve this issue is to leave the decision to the user whether he/she wants to learn more about the given domain or wants to delegate the task to the adaptive system (Jameson, 2008).
Adaptive systems need to collect information and derive knowledge about the user to support him in an efficient way, which may harm their sense of **privacy**, especially when shared with other users or applications. The data of the user should be anonymized and the user should have control about the data acquisition (Jameson, 2008) (Höök, 2000) (Hartmann, 2009).
Another challenge related to adaptive systems is the support of **adaptivity to different contexts**. An example is the adaptation to different users or situations (Hartmann, 2009). A user who uses an adaptive system in different environments wants to take it with him/her rather than train the system multiple times therefore a **transfer of the user model** must be possible (Console et al., 2002).
Another major challenge is the **accuracy** of an adaptive system (Hartmann, 2009). The support of the adaptive system must fit to the context and must be provided at the right moment. This is a challenge especially at the beginning when the user is just starting to use the adaptive system. This is also called the learning phase of the adaptive system. The algorithms of an adaptive system must work accurately even when they have **little usage data** available (Hartmann, 2009) (Console et al., 2002). The user can not be requested to explicitly enter all necessary information; it needs to be collected over time and the algorithms need to deal with uncertainty. Another aspect related to this is the **changing user behavior** the adaptive system needs to take care of (Hartmann, 2009).
These challenges are all important when developing an adaptive system. The usability and therefore acceptance of the adaptive system depends on how well these challenges are solved.

3.1.4 State-of-the-Art of In-vehicle Adaptive Systems for Infotainment Functions

Adaptive systems are becoming more and more common in vehicles. Usually the goal is to increase safety by reducing driver distraction and to increase comfort while using the functions. In this section an overview is given about different adaptive systems, described in literature. The focus is on adaptive systems associated with functions of the infotainment system.
There are some adaptive systems which influence the driver status directly through an active action. The adaptive system described by Piechulla et al. (2003) filters information according to situational requirements; for example phone calls are automatically redirected to the voice mailbox when the workload level of the driver exceeds a certain threshold, so the driver can direct full attention to the driving situation. This is similar to the approach described by Remboski et al. (2000), where amongst other activities the driver's stress and attention level is analyzed and used to determine whether information should be displayed to the driver or should be temporarily retained while the driver focuses on the traffic situation. This can be personalized by the driver; for example instructions of the navigation system only being displayed when reaching unfamiliar parts of a route.
Another approach is described by Nasoz (2004) and Nasoz et al. (2010). Here the adaptive system recognizes the driver's affective state, e.g. emotions or sleepiness, based on a user model created for each individual user. The goal is to provide feedback about driver state to the driver and take actions to influence the driver state in a positive way, e.g. change the radio station, roll down the window or splash some water on his/her face.
The adaptive system from Amditis et al. (2010) is integrated in an overall HMI architecture which integrates different systems, e.g. smartphone, infotainment system, cluster, into a whole system,

so the driver perceives them all as one complete interactive system. The adaptive part of this system adapts the amount and format of information given to the driver depending on the situation; for example the timing and intensity of warnings can be adapted or information rescheduled to noncritical situations when the driver is under less demand.

Some adaptive systems are specialized for one function of the infotainment system. The adaptive systems described by Rogers et al. (2000), Hofmann et al. (2001), and Torkkola et al. (2007) refer to the navigation function. The adaptive route advisor from Rogers et al. (2000) plans routes depending on general preferences and specific knowledge about the user. Normally drivers have the option to choose between the fastest, most fuel-efficient or most attractive route. Here, more factors are taken into account to determine the optimal route for the driver. This is based on a user model, which is trained by monitoring the selected routes out of a set of options. In case of the adaptive system from Hofmann et al. (2001) the driver is supported with the destination input. The destination is entered via a speech dialogue and the correct destination is predicted based on the driver's previous destinations and the usual radius of action. With this support clarification dialogs and system callbacks should be avoided. Additionally, instead of showing the last destination as new destination at the beginning of a trip, a destination is recommended if the last destination matches the current location. Once the driver has already started the trip the adaptive system described by Torkkola et al. (2007) could provide support with traffic advisories. The adaptive system automatically predicts the destinations and routes based on the user's travel history. It then analyzes the traffic flow on the route to determine whether traffic jams are ahead, and provides advisories accordingly.

Another possibility is to support the driver during the selection process of points-of-interest. Two adaptive systems which support the driver this way are described by Bader et al. (2010) and Ussat (2011). Bader et al. (2010) want to reduce the interaction with the driver by providing proactive recommendations depending on the context, e.g. fuel stations when the fuel tank is nearly empty. Particular to their system is the provided explanation about the reason why a certain recommendation is given (see also Bader et al. (2011) or Bader et al. (2012)). Ussat (2011) analyzed different support levels in this context ranging from adaptable support to adaptive high level support. The driver can either choose from a choice of fuel stations selected on explicitly or implicitly determined factors or be supported by the adaptive system, which takes over this selection process. The adaptive system would choose one fuel station and start the navigation to this destination automatically. Ussat (2011) comes to the conclusion that a combination of the different support levels would be best to provide a high support level and sufficient degree of control.

The above described adaptive systems are specific for one function of the infotainment system but there also exist adaptive systems related to multiple functions of the infotainment system; systems that support accessing information and those taking over interaction steps for the driver. An adaptive system, which can be assigned to the first category, is the one described by Blanco et al. (2010). This system is an adaptive user interface for head-up displays. The benefit of head-up displays is that information can be displayed directly in or next to the field of view of the driver. The described approach includes the adaptation of the displayed information. Information is grouped and displayed in different modes, based on the context. Only elements of current interest for the driver should be displayed to enable an efficient and less distracting interaction. Another adaptive system that determines interesting content for the driver is the adaptive news reader from Rogers et al. (2000), which recommends and reads news stories to the driver. The news are chosen based on the driver's feedback and user preferences. Not only visually displayed information can be distracting for the driver, but information communicated through speech can also be demanding. The dynamic content summarization system from Rosario et al. (2011) delivers an adapted amount of information only during low demand situations, e.g. when the driver waits at a stop light. The adaptive system summarizes text and delivers it as speech

output tailored into time slices. A special feature of this system is the ability to respond to sudden changes in the situation.
In the following described adaptive systems belong to the second category and support the driver by taking over interaction steps for different functions of the infotainment system. The approach of Ablaßmeier (2009) is based on adaptive agents. Different agents like a fuel agent and a contact agent are developed based on a basic structure of an agent system. The agents learn from the behaviour of the driver to give recommendations with relevant content at the right moment. The agents can be activated by the user or by themselves. The fuel agent for example works in a similar way as the adaptive system described by Bader et al. (2010). The idea here is to develop different agents for different tasks of the infotainment system to simplify the interaction. Further adaptive systems supporting the driver related to different functions are the ones described by Lavie (2007) and Garzon (2013). Whereas the adaptive system from Garzon (2013) is based on the approach introduced by Lavie (2007). Both developed a recommendation system for multiple functions of the infotainment system. The recommendations are given in different forms. Lavie (2007) described three levels of support. The first level is called "User Selection" where the driver can choose out of a choice of recommendations. The next level, which supports the driver a bit more, is called "User Approval". The driver gets a recommendation and needs to agree or disagree. The last level "Fully Adaptive" executes the preconfigured functions of the infotainment system automatically for the driver. The levels with a high support are suitable for routine situations. Routine situations are situations which the driver experienced already in the past. A routine situation or routine behaviour is learned when the driver executes functions multiple times in the same situation, e.g. starting the navigation to the office every workday morning. In non-routine situations when the driver needs to override the actions of the recommendation system he/she would be faster with the lower level support (see also Lavie and Meyer (2010)). In order to provide a beneficial support but not disturb the driver too much in a non-routine situation an intermediate level should be chosen. Garzon (2013) has implemented the first support level as a list of shortcuts and combined the other two levels into one. The preconfigured function is automatically executed for the driver but the possibility is given to abort the execution within the first seconds over a dialog. Garzon (2013) and Lavie (2007) evaluated the different levels separately and did not integrate them into one system.

3.2 Software Architecture of In-vehicle HMI

Software architecture describes a system's software structure, components, features and relationships (Vogel et al., 2009). In this section important aspects of the architecture of adaptive systems are described. This work focuses on adaptive systems that are integrated in an infotainment system. An infotainment system and its applications as well as integrated applications which are running on another device, e.g. a smartphone, form a distributed system integrated in an overall HMI architecture. Therefore, the architecture of an infotainment system and principles of an overall HMI architecture are described as well.

3.2.1 Architecture of adaptive systems

In-vehicle adaptive systems for functions of the infotainment system described in Section 3.1.4 are build up differently and consist of different components. These differences depend for example on the type of adaptive system or use case for which it was developed. Looking at the components at an abstract level, the following five components, as shown in Figure 3-3, can be found in almost every adaptive system.

Input: An input component of an adaptive system receives different input from different sources. Sources can be sensors or other components which transfer information or knowledge about user, system or environment. For example, a video stream provided by a camera which monitors the driver as described by Sun et al. (2010) can be one form of input.

Knowledge base: Received information from the input component needs to be processed to derive knowledge. The available information needs to be analyzed, correlations have to be recognized, knowledge derived and stored in a model. This component is a central knowledge base, which provides interfaces for other components to request knowledge about the context (Hoch, 2009) (Sun et al., 2010). The video stream received from a camera can be processed e.g. to identify the degree of drowsiness of the driver.

User Needs: An adaptive system changes its behavior or characteristics automatically to adapt to the user needs. Therefore, it can use context data from the knowledge base, recognize user pattern and predict the user's intention in the current context (Liu et al., 2003). The component for user needs could for example determine that the driver prefers to listen to lively music when he/she is drowsy.

Adaptation determination: Depending on the detected user needs, the adaptive system decides how it adapts its characteristics (Blanco et al., 2010) and takes suitable actions (Ma and Kaber, 2005). This is the role of the adaptation determination component. A suitable action could be for example to "start playing a playlist with lively music" when the system has detected that the driver is drowsy. It could occur that the system might detect more than one user need or suitable action for the current context, in which case priority management would be needed as part of the adaptation determination (Stoter et al., 2011) (Amditis and Polychronopoulos, 2004).

Output: The determined action or adaptation is applied, handled by the output component and can be recognized in some form by the user. It can be presented to the user by one of the output channels, e.g. playing the songs of the playlist will be transferred over the auditory channel.

The exact structure of an adaptive system can differ, and the components can exist independently or be merged together. This depends on the actual implementation. However, it is recommended to keep the components and their functionality separated to reduce complexity and enable a replacement of the individual components.

Figure 3-3.: Adaptive systems for infotainment functions basically consist of five different components. These components can exist independently or can be merged together.

The topics user modeling and identification of user needs, which belong to the components "Knowledge base" and "User needs" are described in more detail in Section 3.3. Interaction concepts of adaptive in-vehicle systems, which correspond to the "adaptation determination" and "output" component, are described in Section 3.4.

3.2.2 Architecture of infotainment systems

The architecture of an infotainment system can be represented as layered architecture divided into five layers as described by Kocher and Kleiner (2008) and shown in Figure 3-4. The exact structure of each layer, especially of the ones which include application specific content, are individually modeled by the automobile manufacturers (Kocher and Kleiner, 2008).

Here, the bottom layer of the infotainment system is called **Hardware Layer** and includes hardware components like the ECU (Electronic Control Unit) and memory or graphic card. For communication, this layer provides bus systems like CAN Bus (Controller Area Network Bus) or MOST Bus (Media Oriented Systems Transport Bus).
The layer above is the **OS layer**, which is equal to the operating system of the infotainment system. It provides basic functionality to manage the physical components and is interface between physical components and application software.
The **Middleware layer** combines shared used functionality of the applications of the infotainment system, as e.g. network communication, online services, media, and graphic data.
The next layer is the **Application layer**, including the business logic of all applications, e.g. navigation, entertainment, or telephone. The graphical interface of each application is addressed in the above arranged **HMI layer**. In addition, this layer includes one or several interfaces for the communication with the user, as for example a touch and speech interface.
For communication between the layers, an additional communication system is used as for example D-Bus[3]. These layers exist in general in every infotainment system but it is not always possible to distinguish exactly between those layers.

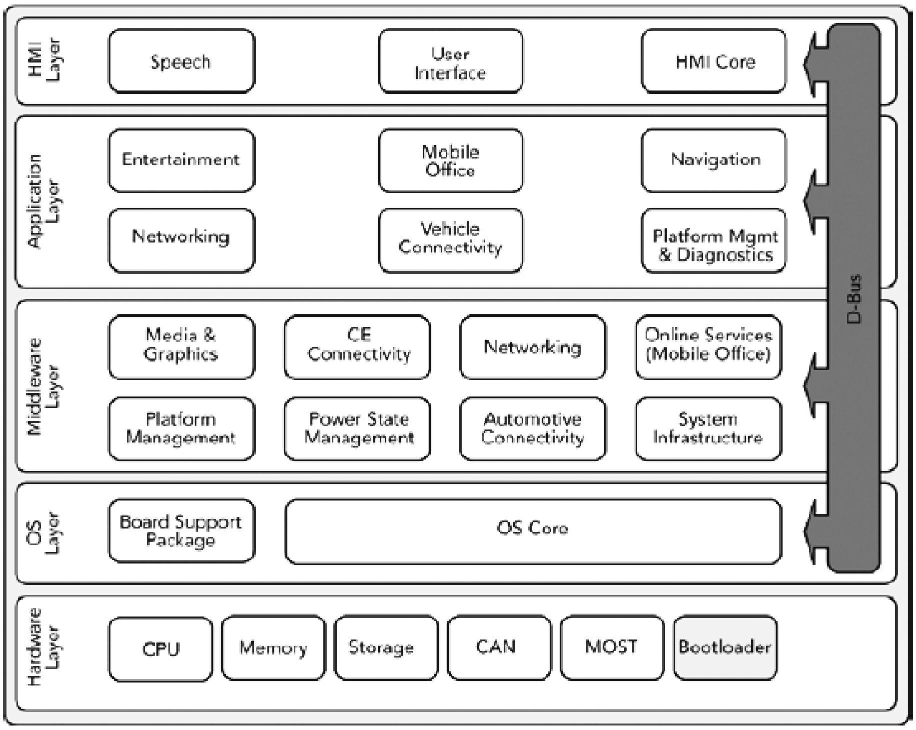


Figure 3-4.: Infotainment systems can be represented as layered architecture consisting of five different layers and a communication component for communication between the layers (Kocher and Kleiner, 2008).

3.2.3 Overall HMI architecture in the vehicle

In most vehicles, each of the integrated functions and systems have their own input and output devices, e.g. a specific knob for the regulation of the air condition or speed information is shown only on the cluster display. These system boundaries increasingly blur. Information about speed for example is also shown on the head unit display or content of the infotainment system as the currently played song on the cluster display. The development moves towards an overall

[3]`www.freedesktop.org/wiki/Software/dbus/`, last accessed on 23/06/2018

HMI, where the HMI is managed centrally for all applications and input and output channels are shared. Therefore, an overall HMI architecture is needed. Amditis et al. (2010) describe an overall HMI architecture for the vehicle, which they have developed in the public funded project AIDE (Adaptive Integrated Driver-vehicle Interface). The goal of the project was to integrate different systems into one system, with respect to their interaction with the driver. All input and output is coordinated via shared in-vehicle controls. The amount as well as format of information given to the driver is managed depending on the situation.

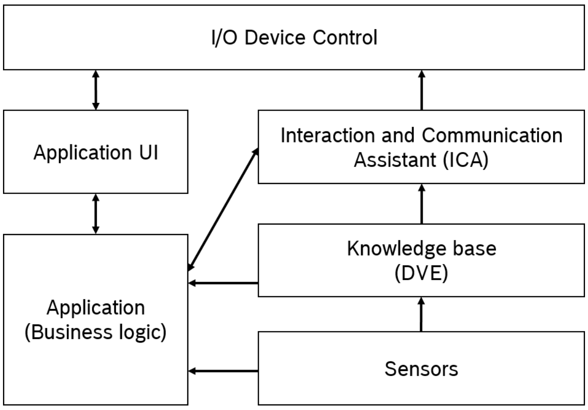


Figure 3-5.: The overall HMI architecture in the vehicle is a central component that coordinates all input and output from and to the user. The structure of an overall HMI architecture according to Amditis et al. (2010) is shown.

Figure 3-5 shows the overall HMI architecture of Amditis et al. (2010) in a simplified form. It consists of different components: one exemplary application divided into business logic and user interface (UI), sensors, knowledge base, interaction and communication assistant (ICA), and input/output (I/O) device control. The applications run on the infotainment system or on a separate device. All of them want to communicate their content over the available output channels and receive user feedback over input channels; therefore they request access to the I/O channels over the ICA. The ICA manages the format and amount of information given to the driver. It prioritizes information and assigns available input and output resources. This is done based on the current situation, which is analyzed and provided as context by the knowledge base also called DVE (Driver Vehicle Environment). The knowledge base gets information from available sensors as input. Also the applications have access to information from sensors and in addition knowledge from the knowledge base. The I/O device control is the interface to the input and output devices available in the vehicle.

3.3 Models and Machine Learning for Adaptive Systems

The process of adaptation faces several challenges, which includes processing data of user, vehicle or environment. As described in Section 3.2.1, an architecture of an adaptive system includes a knowledge base and a component to identify the user needs. In the next sections, approaches to address the related challenges of context and user modeling, and machine learning algorithms are described.

3.3.1 Context and User modeling

The basis for adaptation is information, which is processed to derive knowledge and identify complex correlations. This management of data is done with the help of a model. Such a model takes over the task of acquiring information from different sources as for example sensors, performing interpretation of information, or carrying out dissemination of knowledge. Therefore, an ontology is useful to represent the shared understanding of a domain, which includes a set of entities, description of relations, functions, axioms and instances (Gu et al., 2004). For an adaptive system, that adapts to the user and the context, at least a user model and context model is needed. However, it is difficult to make a clear distinction between the two models. In this work the terms user model, vehicle model and environment model are used. Each model includes information and knowledge about the related domain. In the following, the focus is on the description of user models, because they play an important role for a user-adaptive system. There exists no general user model. User models must be generated for a specific task or use case. Therefore, the complexity varies from very simple user models, which are equal to a simple user profile, to complex user models including a representation of expert knowledge. User models can be static or dynamic. Static models are created once, whereas dynamic models include a learning process to update the user model based on the input data. Models can be created based on data from an individual user or a group of users, which are called stereotypes. Where they are created based on the data from a group of users, the individual user is assigned to one category based on different criteria and associated with the corresponding stereotype model. Data for creating a user model can be acquired explicitly, for example by requesting this information before the first usage of a system with the help of a questionnaire, or implicitly by observing the user while interacting with the system (Johnson and Taatgen, 2005).

3.3.2 Identification of User Needs

A user-adaptive system first learns the needs of a user, for example based on the context and observation of the user interaction with the system. It must recognize the context where it has identified a certain user need and adapt its system characteristics accordingly. Both tasks can be handled statically with the help of static rules or by using dynamic approaches as for example machine learning algorithms. Also a mixture of both, static and dynamic approaches, is possible. Since the amount of available data is increasing and therefore the complexity, machine learning is a suitable approach.

Recommender systems usually make recommendations for products including data of other users. For this, algorithms as collaborative filtering or content-based filtering are suitable (Aggarwal, 2016). The goal for those recommender systems is to find an entity from a set of possible entities unknown to the user. In this section the focus is on recommendation systems, which are also one form of adaptive system (see Section 3.1.2). Recommendation systems learn user preferences based on the user's experience, employing usage data from the past as the training data set for the machine learning algorithm. Machine learning algorithms can be categorized into supervised and unsupervised learning algorithms. The difference is that for supervised learning approaches a training data set is necessary. The algorithm trains the parameters of a function, which maps the given input data to the associated output data, whereas for unsupervised learning no training data set is available and the algorithm tries to find a structure in the given input (Sammut and Webb, 2011). As training data is available and should be used to learn user preferences, only supervised learning algorithms are described in more detail in this section. Supervised learning algorithms can be divided into two categories: classification and regression. In the category classification, the output variable can be ordered into categories, whereas for regression the output variable is continuous (Ng, 2015). Applied for recommendation systems classification means to identify a suitable recommendation e.g. recommending to play a specific song, and regression is referred to find a suitable value, e.g determining the volume of the audio output. There exists a big variety of machine learning algorithms for both classification and regression. The most commonly known are Linear Regression, k-Nearest Neighbor, Self-Organizing Map, Decision Trees, Bayesian Algorithms or Artificial Neural Network Algorithms. A more detailed description of each algorithm is given by Brownlee (2013).

3.4 Interaction Concepts for In-vehicle Adaptive Systems

A main component of an adaptive system is its output component or interface as described in Section 3.2.1. If the interface is adaptive as well, it is called an adaptive user interface as defined in Section 3.1.1. Most of the challenges described in Section 3.1.3 refer to the interaction with the user. Measures, which address these challenges, affect mostly the user interface. In this section the interaction concepts and user interfaces of in-vehicle adaptive systems described in Section 3.1.4 are considered with focus on the measures to improve their usability. Secondly, the evaluation of in-vehicle adaptive interfaces and related challenges are described.

3.4.1 User Interfaces of in-vehicle adaptive recommendation systems

In Section 3.1.4 the state-of-the-art of in-vehicle adaptive systems is described. There exists a variety of adaptive systems and some of them are already specialized for the field of infotainment systems. Only a few include a description of the user interface of the adaptive system. In this section, the focus is on recommender systems and recommendation systems; subtypes of adaptive systems which are integrated in infotainment systems. The user interfaces are observed regarding traceability, controllability and obtrusiveness.
Bader et al. (2012) describe a recommender system for points-of-interest, such as gas stations, for the driver. The recommender system can be recognized by an icon in the right lower corner on the screen as shown in Figure 3-7. It can be inactive, active without recommendations or with recommendations (see Figure 3-6). If the recommender system is active but without showing recommendations, the availability of recommendations can still be recognized by changing the color of the icon. In the second case, active recommender system with recommendations, the recommendations are shown automatically without any request of the driver. With this configuration the driver can control the obtrusiveness of the system.

Figure 3-6.: Different icons show the status of the recommender system from Bader et al. (2012): inactive, active without recommendations and active with recommendations

In the system of Bader et al. (2012), recommendations are given to the driver via a pop up as shown in Figure 3-7. The pop up is displayed on top of the current view of the infotainment system. For the implemented use case of showing points-of-interest it is shown on top of the navigation map.

Figure 3-7.: In the recommender system of Bader et al. (2012) a recommendation is shown as a pop up on top of the current view of the infotainment system. Different choices are given from which the user can choose. For each the driver gets explanatory information.

In the pop up, the recommendations can be shown in different levels of detail. Figure 3-8 shows on the left the lowest level with all categories to which active recommendations exist and on the middle the highest level with details about the recommended point-of-interest. To understand why a recommendation is given to the driver the current situation is described and made transparent to the driver as shown in Figure 3-8 on the right. A presented recommendation for a point-of-interest consists of several choices from which the driver can choose. In Figure 3-7 three different gas stations are recommended and a reason for the recommendation "the gas level is low" is given. In addition information about each of the different choices is displayed directly next to them. Hereby the driver gets criteria to choose one of the recommended items. For example choosing the first recommended gas station implies a detour but a lower price whereas the second recommended gas station is on the route but a bit more expensive. If the displayed items are not suitable for the driver's situation, he/she could request more recommendations over an extra button at the bottom of the shown pop up. This presentation enables the driver to understand why recommendations are given in the current situation and distinguish between the different choices to find the best fitting one.

Figure 3-8.: Recommended items can be shown in different levels of detail. This ranges from very few details (left) to detailed description (middle). Additional information about the situation is provided (right) (Bader et al., 2012).

The recommendation system described by Garzon (2013) is based on the work of Lavie (2007) and oriented on the user interface of the infotainment system COMAND APS NTG4 from Mercedes-Benz[4]. Recommendations for different functions of the infotainment system are given based on the current context and learned user preferences from the past. Garzon (2013) described two variants of the system. The first variant presents recommendations as shortcuts in a shortcut bar as shown in Figure 3-9. In the second variant the recommendations are executed automatically with a short dialog at the beginning providing the possibility to cancel the system action as depicted in Figure 3-10.
The shortcuts in the shortcut bar consist of an icon representing the recommended function and descriptive text related to the configuration of the function. The first icon shown in Figure 3-9 shows a navigation arrow and the text below includes the address to which the navigation should be started. Up to four recommendations can be given to the driver in the shortcut bar. The actual number of the presented recommendations complies with the number of associated recommendations for the current situation. With the shortcut bar the driver can choose from different options and has control about the executed function.

Figure 3-9.: The recommendation system from Garzon (2013) presents recommendations in form of shortcuts in a shortcut bar. This is one of two possible variants for recommendation presentation.

In the second variant of the recommendation system the recommendations are executed automatically. A dialog is shown before a recommendation is executed with informative text about the

[4] http://www.mercedes-benz.de, last accessed on 23/06/2018

functionality and a timer to inform the driver when the recommendation is executed. In addition, a button to cancel the automatic execution of the preconfigured function is shown. This button gives the driver control over the system although the actions are triggered by the system and not by the user.

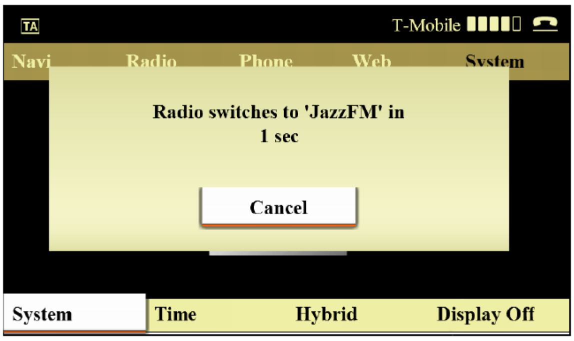


Figure 3-10.: Before a recommendation is executed automatically a dialog with informative text about the functionality is shown. In addition, a timer shows when the recommendation is executed and a button to cancel this action is provided (Garzon, 2013).

If the system has learned a new preference of the driver in the second variant, it indicates this by displaying a little mortarboard at the top bar as shown in Figure 3-11 on the left. In addition a menu is available, where more information about each recommendation is shown. The recommendations are categorized according to the related applications. Newly created recommendations for an application are indicated by a label "new" in front of the corresponding application as shown in Figure 3-11 on the right. The recommendation system can be activated or deactivated via the option "Activate".

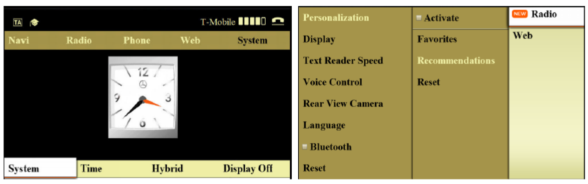


Figure 3-11.: An icon indicates newly learned preferences of the recommendation system of Garzon (2013) (left). All learned preferences can be looked up in a list shown in the feedback view (right).

The driver can enter a feedback view by clicking on one of the application names in the list shown in Figure 3-11 on the right. In this view, all recommendations related to an application are listed. For each recommendation, a detailed view is available (see Figure 3-12) including the configuration of the recommendation (e.g. the name of the radio station "JazzFM"), a descriptive label of the action (e.g. "radio turns to radio station if...") and a description of the context wherein the recommendation is executed (e.g. showing a map with a marked area). Through this menu the driver is informed about the preferences the system has learned and depending on what parameters they are executed.

User interfaces of adaptive systems in the vehicle must not only meet the criteria of useful adaptive systems (see Section 3.1.3) but also the criteria for in-vehicle user interfaces (see Section 2.3.2). In addition, criteria regarding driver distraction described for example in different norms and guidelines (see Section 2.2.4) must be satisfied. The driver should not be distracted by the given recommendations. Attention should be paid to provide less obtrusive recommendations, which in addition should not place heavy demands on the driver.

Figure 3-12.: The recommendation system of Garzon (2013) includes a detail view where each learned preference of the user is shown with the related situation.

3.4.2 Evaluation of In-vehicle Adaptive Systems

For developing an interaction concept for an in-vehicle adaptive system a user-centered design process as described in Section 2.3.3 is suitable. This process includes iterative evaluation of the design in different stages of development taking various criteria into account. However, the evaluation of adaptive systems in the vehicle entails a number of challenges. A big challenge is finding the right balance between a realistic and artificial evaluation. To get statistically significant results, the conditions for each participant should be the same (Mulwa et al., 2011). But an adaptive system first needs to learn the parameters it should adapt to and has than an individual behaviour depending on different factors as for example the environment or the user. It is difficult to control all parameters on one hand but create a realistic experience on the other. Especially when the usability of an adaptive system is evaluated, it should behave as realistically as possible otherwise the results are distorted. Another challenge is the choice of the control condition. Most studies include the comparison between adaptive and non-adaptive systems where the adaptive support is only switched off for simulating the non-adaptive system (Lavie et al., 2005) (Mulwa et al., 2011). As a result, an artificial system is created that would never be developed in that way. Also considered important are the variables, which influence the result of a study. Lavie et al. (2005) created an overview of the variables, which they regard as important for the evaluation of an adaptive system (see Figure 3-13). For example the task that is performed by the participants in a study is important, as the adaptive system might be more beneficial for one task than for another.

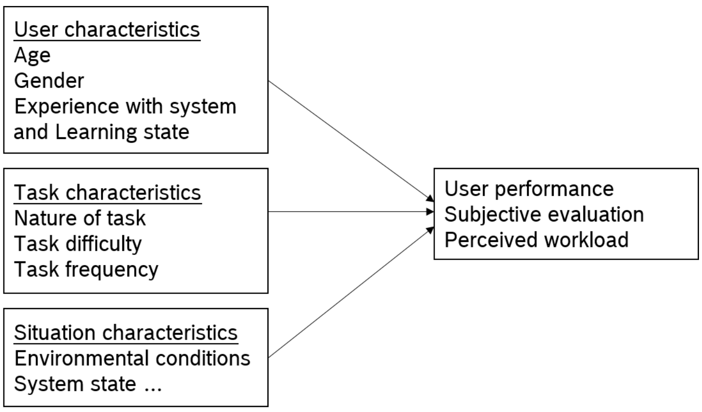


Figure 3-13.: Different factors influence the evaluation of an adaptive system regarding user performance, subjective evaluation or perceived workload (Lavie et al., 2005).

For an evaluation in general and therefore also for the evaluation of adaptive systems, it is important to determine the focus of the evaluation (Lavie et al., 2005). Most studies evaluate the effectiveness, e.g. reduction of driver distraction, or usability of an adaptive system. Several methods known from other fields can be used also for the evaluation of adaptive systems. If necessary, the chosen method needs to be adapted for the individual use case. An overview of used methods for user-centered evaluation of adaptive and adaptable systems is given by Van Velsen et al. (2008). Only a few in-vehicle adaptive systems have been evaluated in a driving simulator environment or under real-world driving conditions (Lavie et al., 2005). In general little is known about the suitability of established methods for the evaluation of adaptive systems (Van Velsen et al., 2008). A few examples are evaluations from Tchankue et al. (2011) (focus: usability and driver distraction, environment: driving simulator), Bader et al. (2011) (focus: usability, environment: real world study), Bader et al. (2012) (focus: usability, environment: user interview with desktop prototype), Garzon (2013) (focus: usability and driver distraction, environment: driving simulator study) and Lavie and Meyer (2010) (focus: driver distraction and effectiveness, environment: driving simulator study).
When planning an evaluation and choosing methods it is important not only to focus on summative evaluations but also on formative ones, that identify problems and explain how to improve a system (Mulwa et al., 2011).

3.5 Conclusion of the State-of-the-Art

The amount of available functions in infotainment systems increases, for example due to the integration of apps in the vehicle, as described in Section 2.1.3, and the possibility to install the apps during run time. The increasing amount of functions combined with the expectation of drivers to use these functions even during driving can result in an increasing driver distraction. The resulting driver distraction can be explained with the help of Wicken's model of multiple resources as described in Section 2.2.1. Both the primary driving task and tertiary task, the operation of the infotainment system, demand the same resources. This results in a conflict, that can lead to a negative impact on one or both tasks. In case of the primary driving task this leads to a distracted driver.
Many operation steps are needed to access the functions of the infotainment system. In total this includes the interaction steps needed to navigate to the function through the menu, the interaction steps needed to configure the function and the interaction steps to use the content of the function. Especially the operation steps needed to access and configure the functions of the infotainment system are problematic because they build the main part of the operation.
Also guidelines as the ones mentioned in Section 2.2.4 address this problem. For example the NHTSA guideline claims to reduce the time needed to access a function to a maximum total glance time of twelve seconds with a single glance time of maximum two seconds (NHTSA, 2013). Simply forbidding the usage of the functions during driving is no sufficient solution as drivers might then illegally use their smartphone directly. Following the user needs, it is necessary to provide a solution that supports the driver using these functions while driving in a safe way, which the driver accepts. Different approaches, described in Section 2.2.5, exist to reduce the resulting driver distraction but none of them is sufficient so far. This work focuses on the further development of the approach of an adaptive system that supports the driver by taking over interaction steps as introduced in Section 3.1.4. The goal is to reduce the increasing driver distraction with an approach that is accepted by the driver. Most of the solutions reach their limits facing the increasing number of available functions. Therefore, an adaptive approach must be followed up to meet the requirements. An adaptive recommendation system, which is one type of adaptive system (see Section 3.1.2), learns the recurring usage behaviour of the driver related to a context and recommends preconfigured functions, if the system identifies one of these contexts

again. The adaptive recommendation system must support different applications at the same time and needs to be extendable to support also functions that are installed during run time. In Section 3.2, Section 3.3 and Section 3.4 the main parts of an adaptive system, architecture, algorithms and interaction concept, are described. All of those topics entail a number of challenges. The architecture describes the components and interfaces of a system and the interfaces to the environment. The challenge hereby is to design an architecture that meets the determined requirements as for example the extendability for the support of functions that are installed during run time. In addition, it needs to be considered, that the adaptive recommendation system is part of an overall HMI architecture, as the one described in Section 3.2.3. With regard to the algorithms the challenges are the fusion of the sensor data to describe the context on a semantic and syntactic level. Another challenge are algorithms to identify the user needs, which adapt the behaviour of the adaptive recommendation system dynamically during the time according to the usage behaviour of the driver. Besides that an effective algorithm that manages and prioritizes the recommendations based on the context is needed. Finally, the challenges regarding the interaction concept are mainly supporting extendability of the functionality and user acceptance of the interaction with the system. Measures to improve usability and therefore user acceptance need to be applied and evaluated. This leads to the next challenge which deals with the evaluation of an adaptive system to get authentic but reliable feedback.

4 Development of an Adaptive Recommendation Service

This chapter addresses the development of an adaptive recommendation service, which is one form of adaptive system. It is called a service rather than a system because it is integrated in an infotainment system as a subsystem but available for all applications as a service. The potential of such an adaptive recommendation service in comparison to other similar approaches is discussed in Section 4.1. Looking at the state of the art and basic principles regarding driver distraction, user acceptance, and adaptive systems, Section 4.2 describes open issues and challenges regarding the development of an adaptive recommendation service, from which the objectives of this work are derived. In Section 4.3 an overview of the approaches and methods to deal with the objectives is given; to be described further in the following chapters. In order to motivate the use cases of the following chapters, Section 4.4 deals with the results of a survey addressing the question of which applications users want to use in a vehicle.

4.1 Potential of adaptive systems

Due to the integration of apps in the vehicle, as described in Section 2.1.3, and the possibility to install the apps also during run time, the amount of available functions in infotainment systems increases. Drivers are mainly interested to use functions related to driving that either support the driving task, e.g. functions that support finding the quickest route, or to entertain them, e.g. playing individual media content as stated in Section 4.4. In order to access a function of the infotainment system, many operation steps are needed. One problem is the needed operation steps to navigate to the function through the menu and to configure the function. They are the main part of the operation steps. For example, using the navigation function to navigate to a certain address includes the operation steps to navigate through the menu to open the navigation application, select the menu entry to enter a new address, fill in the fields with the address data for the configuration of the navigation function, and one or multiple clicks to start the navigation to the intended address. Afterwards no additional operation steps are needed while the content is presented. The complexity depends on the complexity of the menu of the infotainment system itself and the complexity of the interaction within the function. With an increasing number of available functions, the complexity of the infotainment system's menu rises as well.
In summary, the increasing number of functions results in an increase in the complexity of the interaction. This circumstance combined with the expectation of the driver to use these functions during driving can result in an increasing driver distraction.
Guidelines such as those mentioned in Section 2.2.4 address this problem. For example the NHTSA guideline claims to either reduce the time needed to access a function or lock-out the function while driving (NHTSA, 2013). Per se lock-outs are not a satisfactory solution, as drivers want to use the offered functions during driving. This can result in a high dissatisfaction and drivers finding an alternative way to use the functions while driving, e.g. illegally using their smartphone. Further approaches (as described in Section 2.2.5) to reduce driver distraction exist but so far they are not sufficient. A solution that supports the driver using these functions in a safe way while driving and is accepted by the driver is needed.
This work focuses on the further development of the approach of an adaptive recommendation service. The adaptive recommendation service supports the driver by taking over interaction

steps, as introduced in Section 3.1.4. It learns the recurring usage behavior of the driver related to the context and recommends preconfigured functions if the system identifies the context again. It is important that the adaptive recommendation service supports different applications at the same time and is extendable to support functions that are installed during run time.
There are also other solutions which take over operation steps for the driver. Some of these solutions are more simple than adaptive systems and don't need to face challenges such as traceability, controllability or obtrusiveness (see Section 3.1.3). A solution is efficient when the driver is less distracted in comparison to a manual operation, so that the driver can concentrate on the driving task and use the needed function at the same time. Many criteria influence how useful such a solution is, as shown in Figure 4-1.

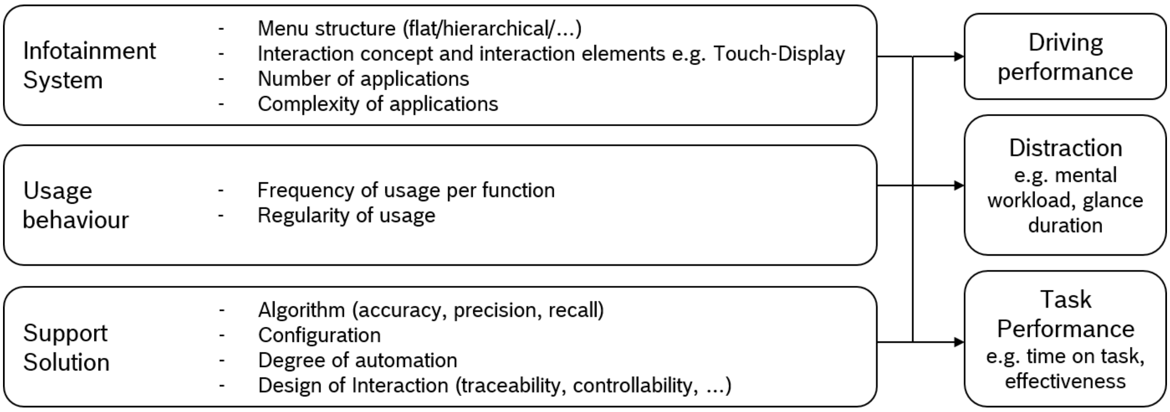


Figure 4-1.: The usefulness of a solution depends on different criteria according to infotainment system, usage behavior and the solution itself.

First of all the usefulness depends on the solution itself. The chosen algorithm that adapts the system to the user needs; its accuracy as well as precision and recall are decisive factors. The configuration is the part the user can contribute to make the solution suitable, e.g. providing additional information via an extra menu. The degree of automation and design of the interaction influence each other mutually. A higher degree of automation can be beneficial, if the driver still has the feeling of being in control over the system and understands the system's actions. Achieving both is the task of the interaction concept. The usefulness of a solution is additionally influenced by the usage behavior of the driver. For example the more regular (regularity) and often (frequency) a usage behavior occurs, the better the user needs can be foreseen. Both the solution and the usage behavior are directly interdependent from the underlying infotainment system. Here, criteria as the menu structure, interaction concept and available interaction elements, number of available applications, and the complexity of the applications influence the usefulness of the solution. The usefulness is measured by the performance of the driver regarding driving task (driving performance) and tertiary task (task performance) as well as the degree of distraction.
Emphasizing the potential of an adaptive recommendation service, three different solutions are compared in the following. The focus is on visual support solutions, not on solutions with speech interaction. Voice control is a promising approach, but not suitable for all tasks and in all situations. For example when multiple options as recommendations should be presented to the driver, this can result in a very long speech dialogue. An optimal structured visual presentation could be more beneficial. An adaptive recommendation service should act proactively, and an unexpected speech output could disturb the driver more than a displayed message on the screen. Therefore an alternative to the speech dialogue is always needed. However a combination of both an adaptive recommendation service with speech interaction might be beneficial.
Here, a static list of favorites configured by the user, a dynamic list of the last used functions,

and a simple adaptive recommendation service are compared. All of these provide recommendations in form of shortcuts and have three available spots.
The static list of favorites is completely configured by the user, therefore a very limited number of recommendations, in this case three, is supported. It conforms totally with the users' expectations as nothing is changed until the user changes the configuration.
The second solution is a dynamic list of the last used functions. The degree of expectation conformity is less than of the static favorite list, but still understandable, as only the last usage is taken into account. More functions can be supported because the items in the list are adapted to the usage behavior.
The last solution is a simple adaptive recommendation service that observes the usage behavior related to the context. Meeting the expectations of the user is a challenge, but a high number of functions can be supported, as the displayed items change depending on the context
Figure 4-2 shows the different behavior of all three solutions. The usefulness of a solution depends on whether the recommendation is displayed, which meets the user need within the current context. For the static list of favorites the success depends on whether one of the configured recommendations corresponds to the user need, as for example within the context A, B or D in Figure 4-2. The probability of success is the ratio between the number of available recommendations and the number of possible user needs. The items of the dynamic list change with the current usage. The success of providing the desired function depends on whether it is one of the last used functions, as for example within the context A or D. The adaptive recommendation service observes the usage behavior in the past related to the context and gives recommendations according to the current context. Only if the user has used the desired function in the same context before it will be recommended, as for example in the context A, B or C. If the user uses a function for the first time within an unknown context, or a new combination of both, then the adaptive recommendation service first needs to learn the usage behavior. This can be seen in the context D of Figure 4-2.

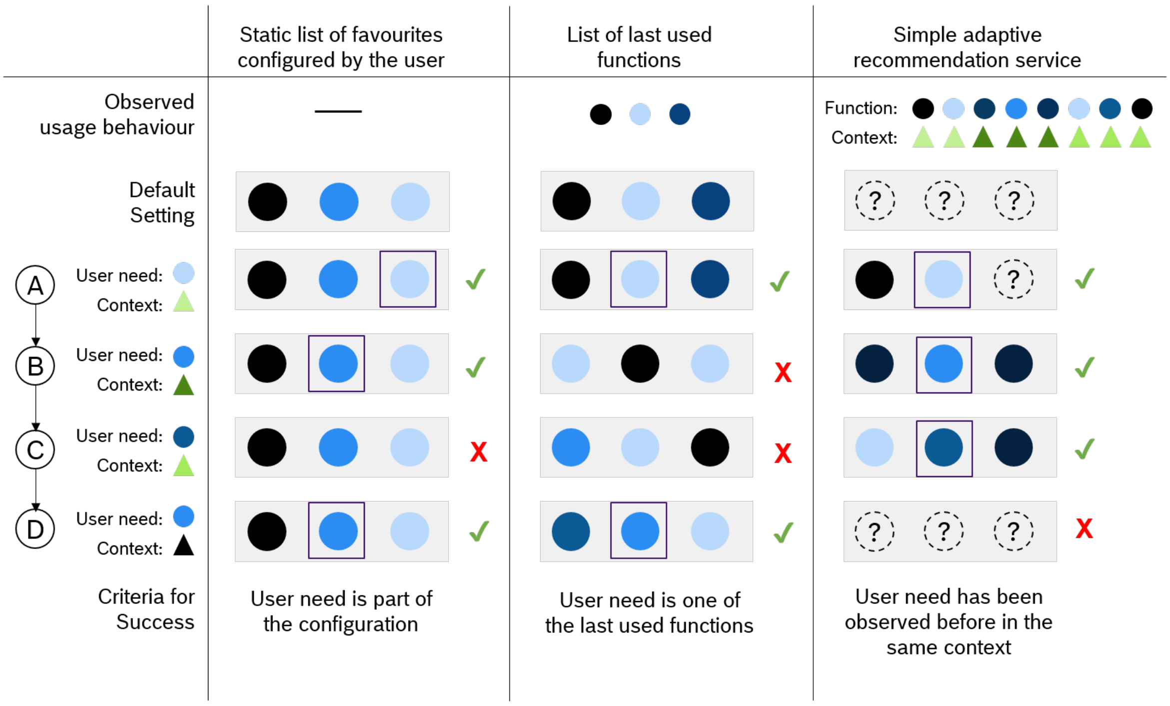


Figure 4-2.: Comparison of three different solutions which provide recommendations in the form of a list for the user for a low number of available functions: list of favorites configured by the user, list of last used functions, and a simple adaptive recommendation service.

The usefulness of a solution depends on whether the user need is correctly foreseen for the current context and the corresponding recommendation is displayed. A large number of functions and their possible configuration requires a sufficient number of parameters to be able to distinguish between all possible different user needs. The more user needs to be distinguished; the more complex is their identification. The different solutions described in this section differ in the number of parameters taken into account for the adaptation. The static list is not adaptive and therefore doesn't take into account a parameter for adaptation. The dynamic list adapts to the user's usage behavior, and the adaptive recommendation service takes into account two parameters; usage behavior and context, as shown in Figure 4-3.

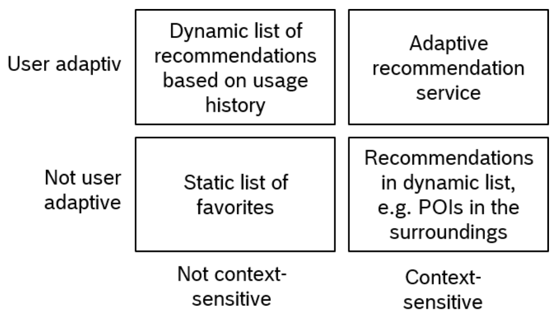


Figure 4-3.: Classification of solutions, static list, dynamic list and adaptive recommendation service according to their considered parameters to distinguish different user needs.

With a higher number of parameters, more user needs can be distinguished. In Figure 4-4 the limitations of the static list and the dynamic list of last used functions are described. The difference between Figure 4-2 and Figure 4-4 is the higher number of available functions and therefore higher number of different user needs. In comparison to the adaptive recommendation service, the two other solutions can handle only a lower number of different user needs.

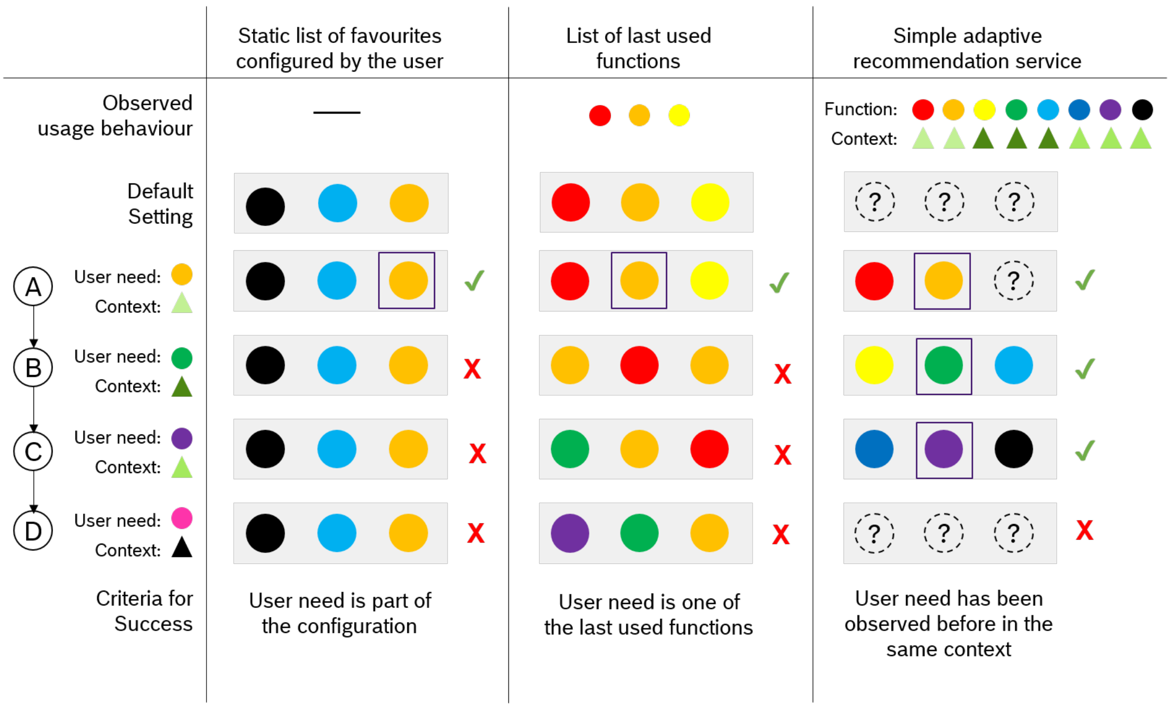


Figure 4-4.: Comparison of three different solutions which provide recommendations in form of a list for the user for a high number of available functions: list of favorites configured by the user, list of last used functions, and a simple adaptive recommendation service.

The behavior of the adaptive recommendation service can be seen as a complex configuration. The complexity of this configuration rises with the amount of considered parameters and their number of possible states. From a certain point on this complexity can be handled reasonably only by an intelligent system, which learns this configuration. The acceptance of the solution by the user is addicted to the challenges of adaptive systems, as for example the degree of traceability, obtrusiveness and controllability.

4.2 Research questions and main challenges of adaptive systems

The potential of an adaptive recommendation service, one form of an adaptive system, is described in the previous section. The potential reduction of driver distraction has already been shown, for example in studies conducted by Lavie and Meyer (2010) or Garzon (2013). But there are still several open challenges for adaptive systems.
In Section 3.2 to Section 3.4 the main parts of an adaptive system, architecture, algorithms and interaction concept, are described. All of those topics entail a number of challenges, which will be described briefly in the following.
The architecture describes the components and interfaces of a system and the interfaces to the environment. The challenge therefore is to design an architecture that meets the determined requirements. This includes for example the extendibility for the support of functions that are installed during run time. In addition, it needs to be considered that the adaptive recommendation service is part of an overall HMI architecture, as is the one described in Section 3.2.3.
With regard to the algorithms, the challenges are the fusion of the sensor data to describe the context on a semantic and syntactic level. Other challenges are to develop algorithms that identify user needs and dynamically adapt the behavior of the adaptive recommendation service to the driver's usage behavior, and that can effectively manage and prioritize recommendations based on the context.
Finally, challenges regarding the interaction concept are mainly in enabling extendibility of the functions during run time and user acceptance of the interaction with the adaptive system. Measures to improve the usability and therefore the user acceptance need to be applied and evaluated. This raises the next challenge, which deals with the evaluation of an adaptive system to get authentic, reliable feedback.

Derived from this, the primary research questions for this work are the following:

- Is an extendable adaptive recommendation service likely to reduce driver distraction and be accepted by the user?
- Can user acceptance and by extension the usability of the adaptive recommendation service be improved by measures described within the state-of-the-art for the automotive domain?

Considering the state-of-the-art, three main challenges are addressed within this work:

- Extendibility as a requirement for the software architecture and the interaction concept
- Application and evaluation of measures improving the usability within the automotive domain
- Evaluation of an adaptive recommendation service regarding driver distraction and usability enabling an authentic experience

An overview of algorithms for adaptive systems is given in Section 3.3. This topic will not be considered in more detail within this work.

The overall objective of this work is to further develop the approach of an adaptive recommendation service within the automotive domain, with the goal to reduce driver distraction and reach user acceptance. According to the previous described challenges, based on the state-of-the-art, the objectives of this work are the following:

- Design of a reference architecture including requirements analysis, description of components and interfaces, integrated in an overall HMI architecture. The main requirement is the extendibility during run time to enable the support of later installed applications (see Chapter 5).
- Development of an interaction concept, which includes measures to achieve a high usability and therefore user acceptance. It must support the extendability of the functionality during run time (see Chapter 6).
- Implementation of a proof-of-concept build up on the designed reference architecture and the developed interaction concept (see Chapter 7).
- Evaluation of the further developed adaptive recommendation service regarding driver distraction and usability focusing on traceability, controllability, and obtrusiveness. A method for the evaluation of an adaptive system to get authentic feedback is developed (see Chapter 8).

4.3 Approach and Methods

This section briefly describes the applied approaches and methods to face the challenges and reach the objectives outlined in Section 4.2. An overview of the following chapters is shown in Figure 4-5, and an outline of chapters five to eight given below.

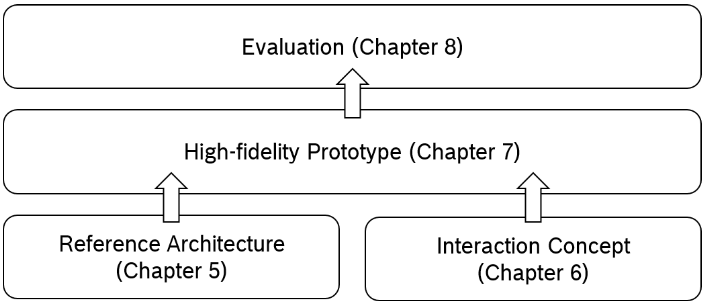


Figure 4-5.: Structure of the Chapters 5 to 8

Chapter 5 focuses on the development of the reference architecture of the adaptive recommendation service. For developing a reference architecture first a requirement analysis has to be done to identify the requirements for it. Based on the identified requirements, the components and their interfaces can be designed. The starting point is the components already described in literature (see Section 3.2.1), but common architecture patterns and the architecture of related systems, like an infotainment system (see Section 3.2.2), should also be taken into account. After these two steps, the third step is to integrate the reference architecture of the adaptive recommendation service into an overall HMI architecture. Therefore an existing approach for the overall HMI architecture, which is described in Section 3.2.3, is taken as a basis.
Chapter 6 describes the development of the second part of the adaptive recommendation service; the interaction concept. Existing approaches for an interaction concept are described and evaluated. These approaches, which represent the state-of-the-art (see Section 3.4.1), are taken as a starting point to derive a first version of the interaction concept. Within a user-centered

design process (see Section 2.3.3) the interaction concept is further developed. In multiple iterations users are involved right from the beginning. The focus is on traceability, controllability and obtrusiveness, which are some of the main challenges of adaptive systems, described in Section 3.1.3. Measures, described by Jameson (2008) and partially applied within the state-of-the-art, as described in Section 3.1.4 are applied to improve those usability criteria. For evaluation of the effect of those measures on the usability of the recommendation service, methods as described in Section 2.3.3 are used.
Both the reference architecture and the interaction concept are integrated in a proof-of-concept as described in Chapter 7. This high-fidelity prototype covers defined use cases related to the applications identified in the survey described in Section 4.4. The implementation builds up on an existing infotainment system, using the hardware and software used to develop infotainment systems in industry.
The proof-of-concept is then used as high-fidelity prototype for the evaluation of the adaptive recommendation service regarding user acceptance, usability and mitigation of driver distraction (see Chapter 8). An evaluation method to get authentic feedback is therefore developed. The starting point is existing best practice and lessons learned from previous evaluations described in literature (see Section 3.4.2). Standardized methods for the evaluation of usability (see Section 2.3.3) and for evaluation of driver distraction (see Section 2.2.3) are also taken into account.
The result of this work is a further developed approach of an adaptive recommendation service for the automotive domain, evaluated regarding user acceptance and minimisation of driver distraction.

4.4 Use Cases of Functions for Use while Driving

People are used to being able to use their smartphone functions anywhere and at any time. This also involves the time they spend in their vehicles. In Section 2.1.3 approaches for the integration of apps in infotainment systems are described, but the question is what functions are of interest for drivers. At the moment the number of available applications for usage in the vehicle, is limited. The interface of those applications is normally adapted and the content limited for safe operation during driving. Which applications are available for usage in the vehicle depends on the developers that are willing to adapt their applications accordingly. Starting from the other point of view of user demand, an online survey to identify applications potential users would want to use in the vehicle has been conducted. In this survey people were asked about their usage behavior regarding their smartphone applications and their choice of applications for usage in the vehicle. The results of the survey are published in Zsebedits et al. (2014) and Zsebedits (2014).
The online survey consisted of 15 questions. In the first step the participants filled out socio-demographic data, were asked if they had a driver's license, and used or owned a nomadic device. All participants with a driver's license further answered questions about their driving habits, e.g. number of driven kilometers per year or frequency of car usage. Afterwards, all participants that owned or used a nomadic device such as smartphone or tablet answered questions about their usage behavior; in particular the functions they most commonly used on their nomadic devices. They were also asked for a list of functions they wanted to use in the vehicle as an open-ended question. The last step in the survey for all participants was to rate a list of 22 functions on whether they wanted to use them in the vehicle or not on a 4-point-scale ("yes", "rather yes", "rather no", "no"). The list was created according to lists of most used functions on the smartphone published by O2 (2012) and Radwanick (2011), and was extended by functions that are related to driving.
In this survey, 95 participants (N = 95) took part; 25 female and 70 male. Most of the participants, 76%, were between the ages of 25 and 30; 6% under the age of 25 and 18% over the age of 30. A university degree was held by 87% as their highest educational level. All participants had

a driver's license, 85% using their own vehicle when driving and 61% using their car every day. Regarding device ownership, 95% of the participants owned at least one nomadic device and 38% of them had already connected their smartphone to the car via cable, bluetooth or docking station.

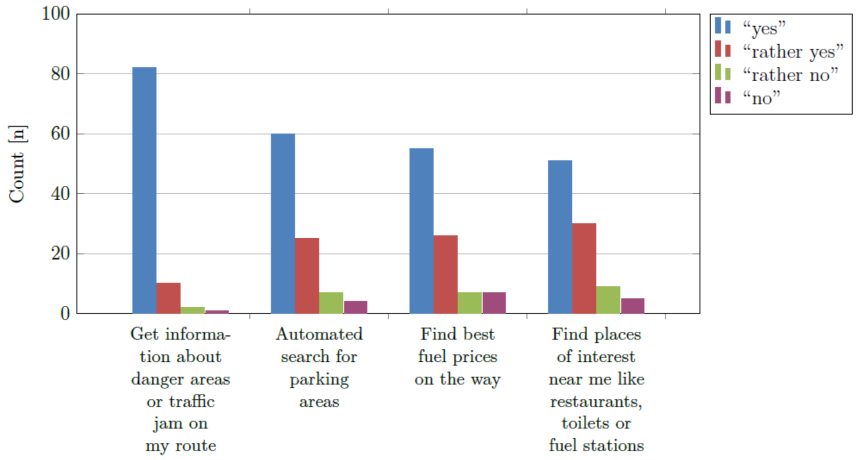


Figure 4-6.: Survey outcome: Functions related to driving are rated positively for the usage while driving (Zsebedits, 2014).

The result of the survey shows that the most used function on the smartphone was sending text messages via SMS, email or chat clients like WhatsApp. This was followed by functions as surfing the web, making phone calls, using navigation services and listening to music. This result corresponds with the list of most used functions on smartphones published by O2 in the UK (O2, 2012). The rating of the 22 functions on the given list showed that functions related to driving, like getting information about danger areas or traffic jams, automated search for parking areas, finding the best fuel prices on the way or finding places of interest, are mainly rated better than functions not related to driving. Figure 4-6 shows those top rated functions related to driving. For example, 97% of the drivers wanted to be informed about danger areas or traffic jams on their way.

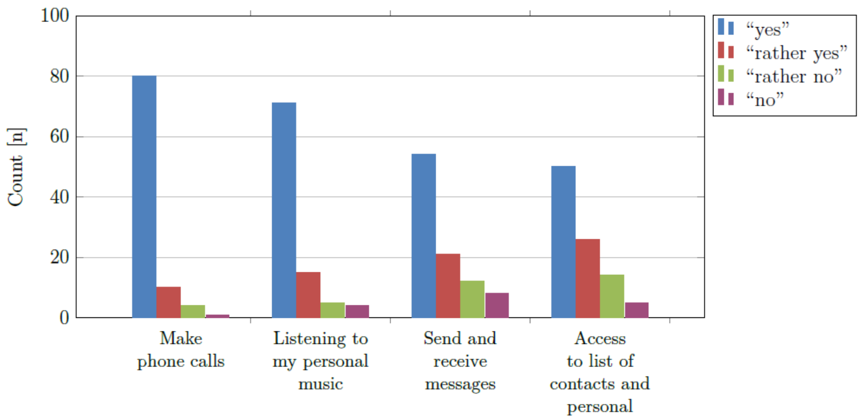


Figure 4-7.: Functions not related to driving but already integrated in modern infotainment systems are rated positively regarding usage while driving (Zsebedits, 2014).

It is also interesting to note that functions already integrated into many modern infotainment systems, like making phone calls (95%), listening to personal music (91%) and the access to contacts and calendar (80%) got a high number of "yes" and "rather yes" votes, as shown in

Figure 4-7. However, the most used function on the smartphone, sending text messages, was voted positively only by 79% of the participants for usage while driving. This is still a high number but behind the rating of the functions related to driving.
Most of the functions, which are not related to driving, are rated negatively, as the examples shown in Figure 4-8. Functions like surfing the Web, taking pictures or videos, read and share posts on the social networks and online shopping are not the functions the participants prefer to use while driving. Although the participants were told to ignore safety aspects, this could have still influenced them regarding their rating. Therefore the result needs to be interpreted with caution.

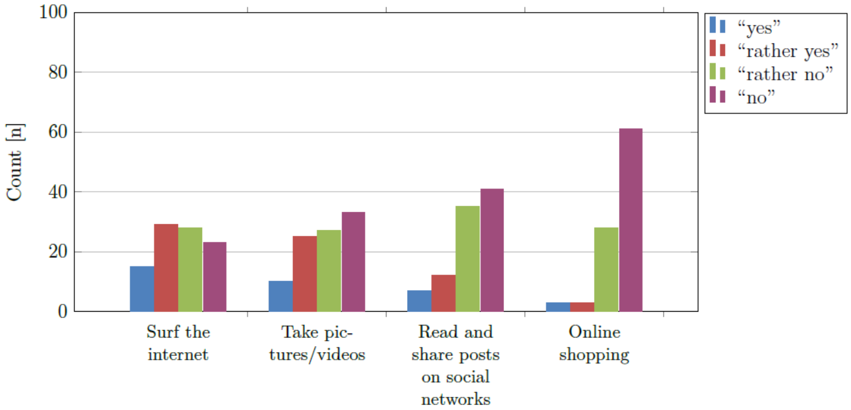


Figure 4-8.: The participants rated functions like "surfing the Web" or "taking pictures or videos" negatively for usage while driving. These functions have in common that they are not related to driving (Zsebedits, 2014).

In summary, the functions from the smartphone can be divided into three groups, based on the described results. The first group represents the functions related to driving; the second group those not related to driving but already integrated in modern infotainment systems; and the third group the remaining functions, which are not related to driving. The first and second groups were rated positively; the third group rated negatively. Therefore the focus for adaptive systems should lie on support for those functions with a positive rating. But as this survey does not have a representative number of participants and the distribution regarding age and educational level is not sufficient, the qualitative results can only be considered as an indication for the selection of use cases and to get a feeling for this topic. Therefore, no list and ranking of all functions is published to avoid misinterpretation of the data.

5 Reference Architecture

A reference architecture is a software architecture that combines basic knowledge about architecture with specific knowledge of a domain; describing the components and their relationships for a defined problem area (Vogel et al., 2009). For the adaptive recommendation service, this reference architecture represents the system design. It explains the functionality, involved components, and their interfaces between each other and the environment. The goal is to get a common understanding of the requirements and objectives of the different components. In addition, it is the basis for future implementations.

Parts of the content of this chapter were published in Siegmund et al. (2013), Zsebedits et al. (2014) and Walter et al. (2015a).

5.1 Requirement Analysis

Before a system design can be developed its requirements need to be determined. The requirements define the functionality, which prescribes the behavior of the adaptive recommendation service and therefore has to be covered by the reference architecture. Figure 5-1 shows the steps of an adaptive recommendation service for recommending functions of the infotainment system.

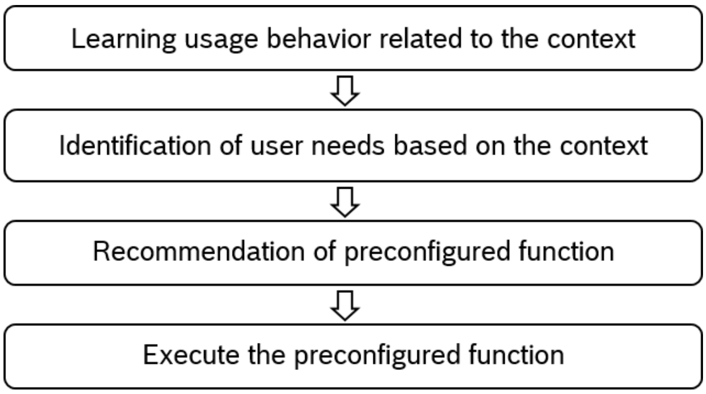


Figure 5-1.: Steps of an adaptive recommendation service from observing the user behaviour until executing a preconfigured function for the driver (Walter et al., 2015a)

The adaptive recommendation service supports the driver by taking over interaction steps. These interaction steps are normally needed to navigate to a function through the menu and configure the function manually, so the adaptive recommendation service observes the user behavior of the driver over a certain period. If it observes repetitive activities in the same context, it memorizes these activities according to the context, so when the driver is in the same context again the adaptive recommendation service recognizes it and determines a recommendation based upon the previous observed behavior. This recommendation is presented to the driver in a designated form. The goal is the execution of the preconfigured function that meets the needs of the user according to the context, so the driver needs fewer operation steps and therefore is less distracted. This describes the basic functionality of the adaptive recommendation service. In addition, the adaptive recommendation service needs to support different functions, including those installed during run time of the system, so needs to be extendible during run time. Equally important is the modularity of the architecture of the adaptive recommendation service. As the adaptive recommendation service and its parts, including especially algorithms, architecture and user interface are current research topics, fast progress on single parts of it is expected in the future. Therefore a simple way to exchange individual parts of the service, without huge changes on the remaining architecture, must be ensured. This requires a suitable division and structure of the functionality of the adaptive recommendation service.

In summary, the main requirements regarding functionality and non-functionality are:

- Observing the usage behavior of the driver according to the context
- Identification of user needs based on the context
- Determining a beneficial recommendation
- Executing the recommended preconfigured function
- Integration of functions during run time (extendibility)
- Ensuring components of the service are easily exchangeable (modularity)

The mentioned requirements are the main requirements for the design of the architecture. Other, mainly non-functional requirements, are described in the ISO/IEC 25010 (2011) and taken into account, for example within the development of the interaction concept.

5.2 Reference Architecture of the Adaptive Recommendation Service

On the basis of the identified requirements in the previous section, the reference architecture is designed. The approach builds up on basic architecture components, identified in the state-of-the-art described in Section 3.2.1, and architectural patterns. The described elements of an adaptive system are adapted to the specific domain of an adaptive recommendation service for infotainment systems. The functionality of the reference architecture needs to be encapsulated in separate components to ensure a sufficient modularity and interchangeability of the components. The specified functionality will be divided in sub-functionalities as has already been done in the requirements analysis. This followed approach is a top-down approach to design a software architecture (Gharbi et al., 2014). In doing so the architecture can be described at different levels of detail, resulting in a rough design of the architecture including a description of the system's structure and specification of the subsystems and interfaces. This architecture is independent from any implementation language or platform.

5.2.1 Components and their interfaces

The architecture design is based on a three-tier-architecture consisting of three layers: presentation, logic and data; each developed independently and with access only to the underlying layers, making them more flexible regarding modifications. The lowest layer is the data layer, managing the data. Above this is the logic layer, which can access the data of the data layer to modify it and contains the business logic. The top layer is the presentation layer including the user interface (Lipinski et al., 2016). The derived reference architecture of the adaptive recommendation service which builds upon such a three-tier-architecture is shown in Figure 5-2.
The data layer of the recommendation service encloses two components: the Driver-Vehicle-Environment Context Model (DVE) and the Usage Model (UM). The **DVE** is the knowledge base

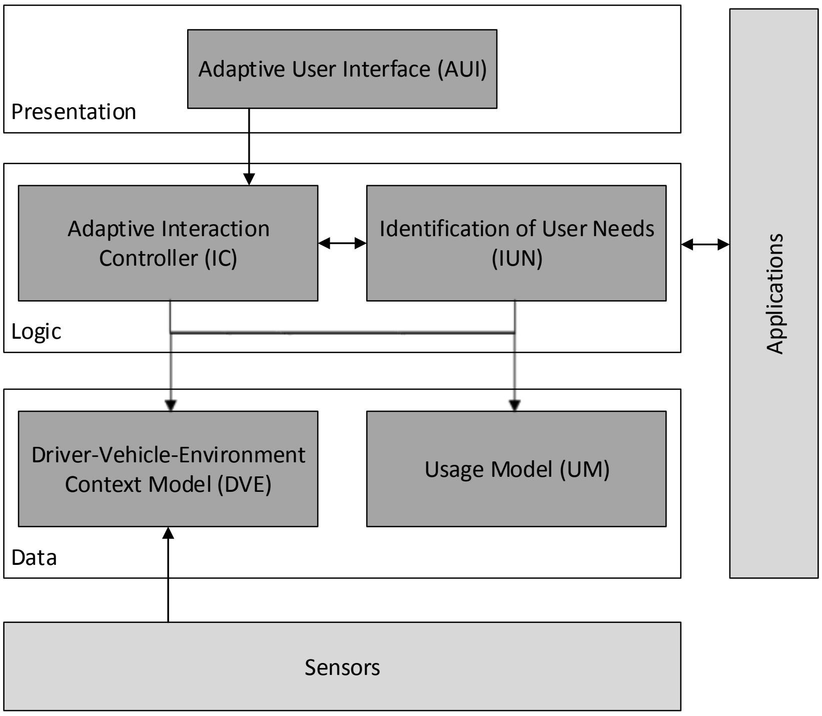


Figure 5-2.: Blog diagram of the reference architecture of an adaptive recommendation service based on a three-tier-architecture

of the adaptive recommendation service, which delivers the current context representation and can be separated into two components; one responsible for data storage and the other for data processing. From the perspective of the adaptive recommendation service only the data storage providing the representation of the current context is in focus. Therefore, it is located in the data layer. The context analysis (not shown in the diagram) takes sensor data as input, combines and analyzes the data to derive the current context representation. More components and interfaces would also be needed, and would mainly be located in the logic layer. The second component in the data layer, next to the DVE, is the **UM**. This is a database that stores analyzed and non-analyzed data regarding the user's usage behavior.

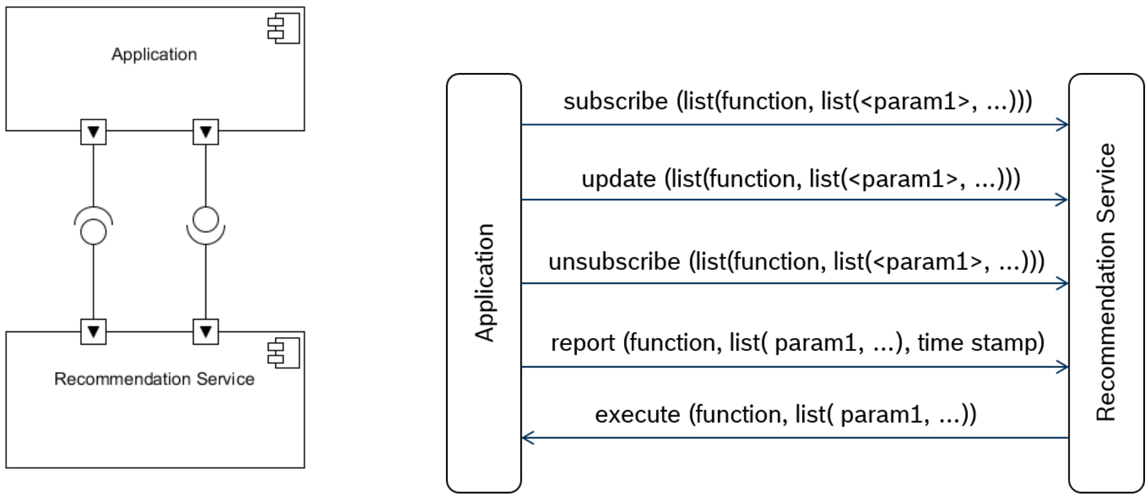
The layer above the data layer is the logic layer. This includes two components, representing the business logic of an adaptive recommendation service. The first component is called **Identification of User Needs (IUN)** and is in charge of the processing and analysis of the user needs. The applications mainly interact with this component to subscribe, update and unsubscribe their functions and report usage of a function with corresponding configuration values. Based on this data, which will be stored in the UM along with a context representation, IUN can derive the usage behavior according to the context. It uses machine learning algorithms to analyze the data and derive rules or a trained model. In the following the derived rules are focused. These rules are transferred over the UM to the second component of the logic layer; **Adaptive Interaction Controller (IC)**. The IC determines the adaptation, which will be presented to the user, based on the current context. Therefore it uses the rules from IUN, requests the current context from the DVE to get a list of user needs for the current context. The IC prioritizes and determines an appropriate presentation form for the recommendations.

The **Adaptive User Interface (AUI)** is the output component of the adaptive recommendation service and part of the presentation layer. It requests regularly a list of recommendations from the IC, which includes the needed content to display a recommendation in an appropriate form.

Depending on the interaction concept it may be necessary for the user to accept the displayed recommendation. This is reported to the IUN over the IC to send a message to the application, which will then execute the function with the corresponding configuration.

5.2.2 Interfaces to Applications

One of the requirements listed in Section 5.1 is extendibility. It must be possible to support applications that are installed during run time. To execute a preconfigured function of an application, it is necessary to have direct access to this function and interfaces need to be provided to configure it accordingly. Applications, especially if they run in a separate environment, are encapsulated modules with defined interfaces. Therefore it is not possible to access the functions of an application directly when no interfaces are provided. This is also a problem for getting information about the usage behavior of the user. There is no knowledge available about internal states of the application outside of it. The provided functions of an application are not known and therefore also not the function the user has used along with the configuration. To solve this problem interfaces are defined for the communication between the applications and the adaptive recommendation service as shown in Figure 5-3(a) and Figure 5-3(b), which need to be implemented by the recommendation service and each app.



(a) Interfaces (b) Functions

Figure 5-3.: Interfaces between the adaptive recommendation service and applications. Both share the roles of client and server. The adaptive recommendation service provides an interface to subscribe, update and unsubscribe functions and in addition to report usage of a function. The application provides an interface to execute an application (Walter et al., 2015a).

The communication has been derived from a Client-Server-Model, where the client calls functions over interfaces provided by a server. Both can be distributed over different platforms (Schill and Springer, 2012). The applications and the adaptive recommendation service take over both roles at the same time. Both provide interfaces for the communication between each other. The adaptive recommendation service offers one interface as a server with the following functions: subscribe, update, unsubscribe and report. The applications can subscribe their functions along with a formal description of the list of configuration parameters. The application "navigation" for example subscribes the function "navigate to" with its parameters street name, house number, zip code and city name. If the list of functions or their parameters change, the application can send an update request to the adaptive recommendation service or unsubscribe a function from the list of available functions. Whenever the user uses a function, the application reports this

information to the adaptive recommendation service along with the chosen configuration values. The applications also take on the role as a server and provide an interface to execute preconfigured functions. If the adaptive recommendation service wants to execute a function, it needs to send an "execute" request to the application containing the name of the function and a list of values for the needed parameters. The application can then internally call the function.
In summary, these are the interfaces between applications and the adaptive recommendation service.

5.2.3 Interaction of components: Learn user needs and give recommendations

Two main functionalities of the adaptive recommendation service are learning user needs and giving recommendations. Figure 5-4 and Figure 5-5 describe the process and communication that happens between the components of the adaptive recommendation service internally and externally.
Learning the needs of the user starts with the registration of the function of an application and its configuration parameters. Therefore the application subscribes its functions at the component IUN. For example the application "navigation" subscribes its function "navigate to" and the configuration parameters like the street name. IUN saves this information in the UM in the list of available functions along with the information that is needed to send an execution request to this application, such as an IP address. Whenever the user uses a function of the application, the application reports the usage to the IUN. In case of the navigation application, it reports the usage of the "navigate to" function with the used address as configuration values whenever it is used. The IUN requests the current context from the DVE to save the information about the function and its parameters, and the current context, in the UM.

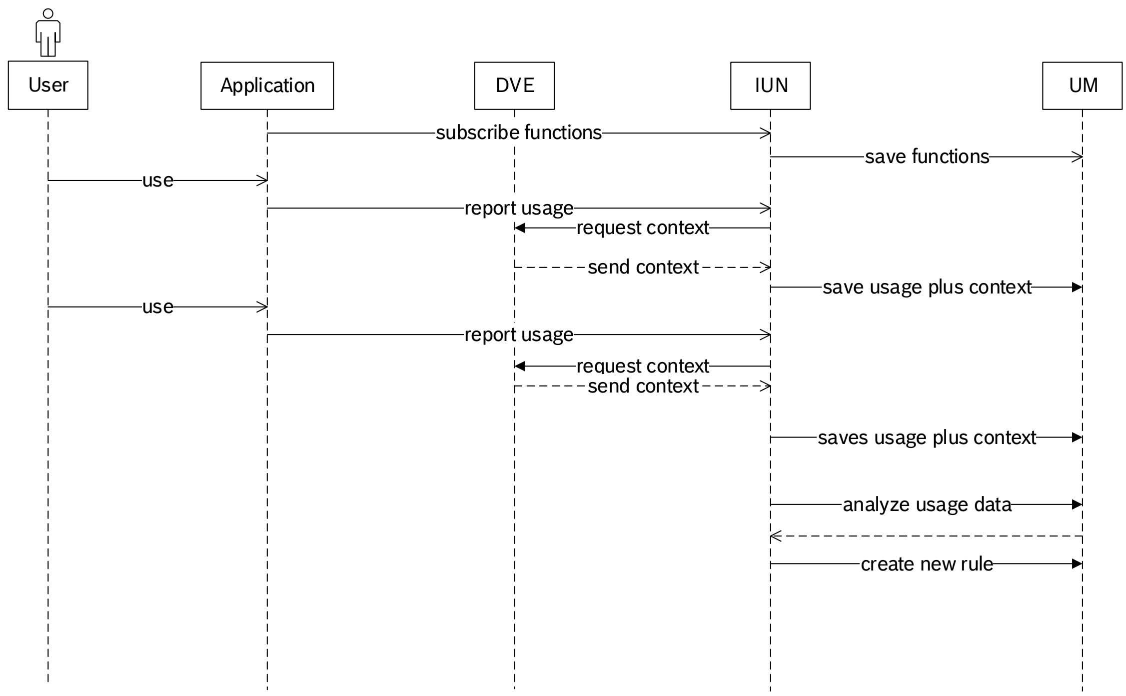


Figure 5-4.: Components and interfaces of an adaptive recommendation service are shown according to the process to learn the needs of a user applicable to the context.

Part of the context could for example be the GPS position or current time: The user uses the "navigate to" function of the navigation application with the address of his office when it is 8:00am and

a GPS position near his home. This is done multiple times. In defined intervals the IUN analyzes the saved usage data and derives rules, e.g. with the help of machine learning algorithms. These rules represent the learned usage behavior of the user. The rules can also be represented by a trained model (for an example, related to the same approach, see Köhler (2017) or Kopp (2017)). A rule for the example can be that the driver uses the "navigate to" function with the address to his office between 7:30am and 8:30am when he is within a radius of one kilometer around his home according to the GPS position.
After the process of learning the needs of the user, the adaptive recommendation service is ready to give recommendations. A sequence of interacting with the help of the recommendation service is described as follows: At specified intervals the IC requests the current context representation from the DVE. According to this context representation it checks the rules stored in the UM to identify the ones which are valid or active in this specific context. The elements of this list of active rules need to be prioritized, and for each the presentation form needs to be determined. This presentation determination can happen once or each time the rule is in the list of active rules again. From the list of active rules the recommendations are derived enriched with the form of presentation that the AUI requests. This can be handled in different ways, e.g. the AUI is informed whenever the list of recommendations is changed, or when it requests the list at specific time intervals. The AUI displays the recommendations accordingly. It may be necessary for the user to accept a recommendation or choose one out of a list of choices, depending on the interaction concept and presentation form. The AUI reports the selection or approval of a recommendation to the IC. While the IUN is responsible for communication with the applications this information is forwarded to it. The IUN requests information about the application and function such as the IP address from the UM, and calls the function with the corresponding values afterwards.

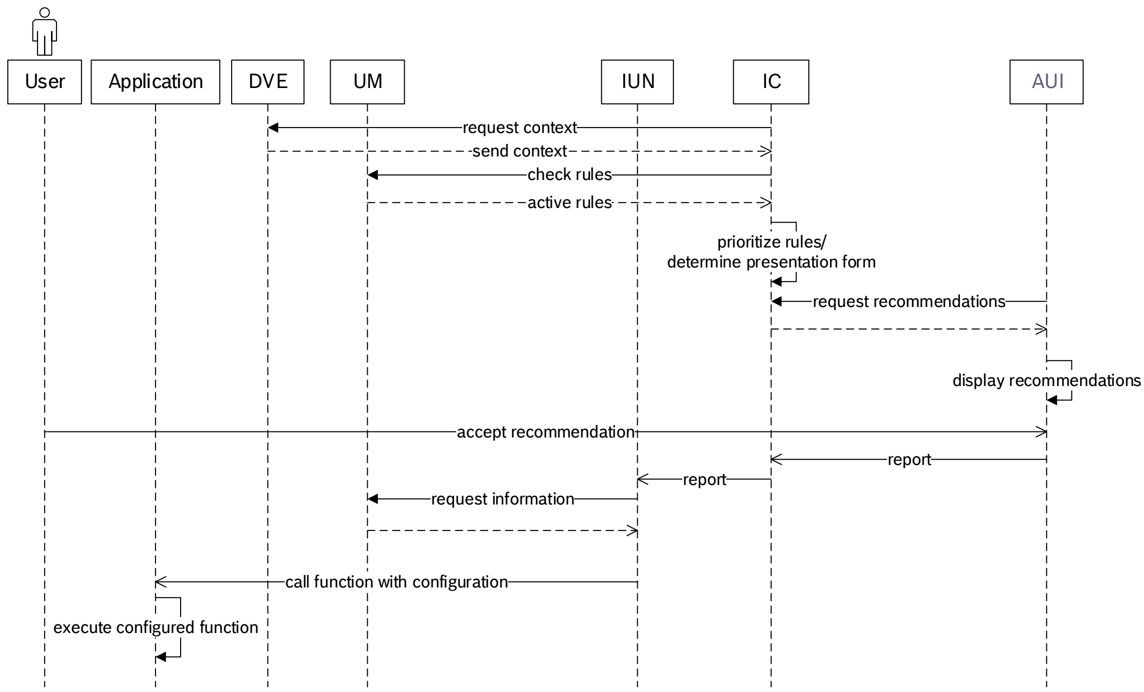


Figure 5-5.: Components and interfaces of an adaptive recommendation service are shown according to the process to give a recommendation to a user applicable to the context.

For example, if the context representation includes that it is 8:00am and the GPS position is within the radius of one kilometer around the GPS position of the user's home, this would activate the previously learned rule. This might be the only active rule, which makes prioritization easy and the recommendation is displayed by the AUI. The user accepts the recommendation of starting the navigation to the office. The IUN calls the "navigate to" function of the navigation application after getting the stored information from the UM. The navigation application then executes the function with the transferred values including the address to the office. The component diagram along with the description of the interfaces and sequence diagrams describes the reference architecture. According to this an implementation can be realized.

5.3 Integration in an Overall HMI Architecture

The HMI in the vehicle will in the future no longer be separated into single HMI modules like cluster or head unit, where each includes its own applications. Input and output channels will be shared between all applications into one overall HMI managed by a central component. Addressing this, Amditis et al. (2010) have developed an overall HMI architecture for the vehicle within the project AIDE. This architecture is described in Section 3.2.3. The advantage of the overall HMI architecture is a centralized management of the communication with the driver and a centralized knowledge management. The architecture is extended by the components and functionality of the adaptive recommendation service, as shown in Figure 5-6. Some components are extended; others will be merged, as described in the following:

The context module of the adaptive recommendation service is merged with the central knowledge base of the overall HMI architecture. This central knowledge base is also called DVE.

A central component of the overall HMI architecture, the Interaction and Communication Assistant (ICA), is responsible for the communication with the user. It determines the amount, time and form of each piece of information communicated. It is a central point of decision-making to ensure a coordination of the communication with the driver. The ICA is a component that supports the driver by coordinating the communication with him. It is extended by the functionality of the adaptive recommendation service, the IUN, IC and UM of the adaptive recommendation service and its interfaces, as described in Section 5.2.

After learning the user needs (IUN) and determining the recommendations for the current context (IC), these recommendations are not forwarded directly to the AUI; instead a request is forwarded to the workload manager. The workload manager is aware of all content that should be communicated to the driver, which is the former functionality of the ICA. It prioritizes the content according to the current context and determines when and how, and in which modality, it will be presented to the driver. It assigns time and device to the AUI of the recommendation service over the resource manager to present the recommendations. The resource manager manages the input and output devices and executes the request of the workload manager by granting access to the determined device.

The integration of the adaptive recommendation service in an overall HMI architecture ensures the compatibility with future development. It is not an additional separated component; rather it fits into the overall design of the in-vehicle HMI architecture.

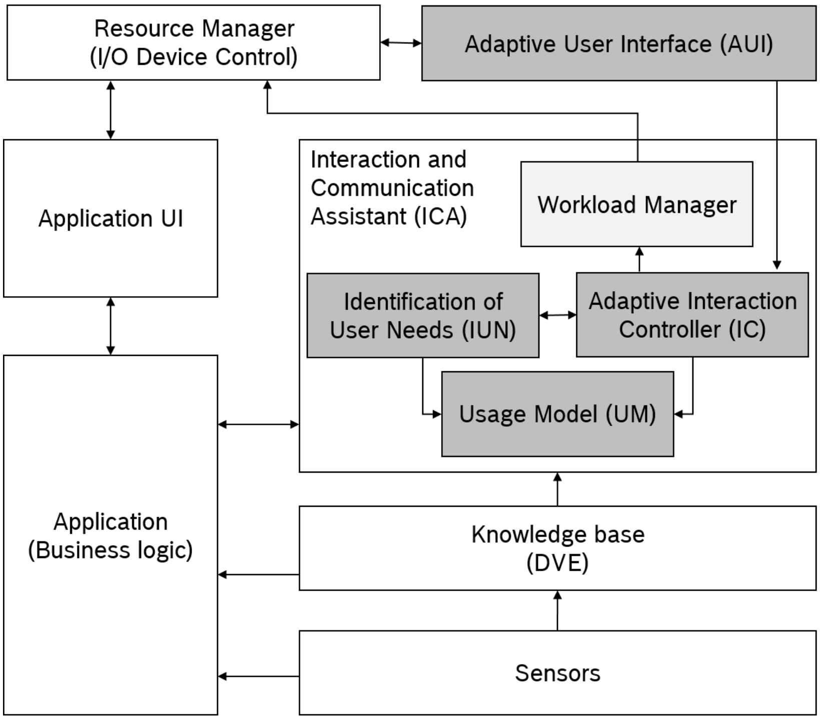


Figure 5-6.: The adaptive recommendation service integrated in an overall HMI architecture that is derived from the AIDE architecture (according to Walter et al. (2015a))

6 Development of an User Interface

An important part of the adaptive recommendation service is its user interface. Especially for adaptive systems it is important to gain acceptance by the user, which can be achieved by addressing the challenges like transparency, controllability, or obtrusiveness, mentioned in Section 3.1.3. Measures suggested for example by Jameson (2008) are mainly related to the user interface or communication between adaptive system and user. One measure is to provide enough information about the functionality and to make the behavior of the adaptive system transparent to the user. In addition it is important to enable the user to control the system behavior in a sufficient degree.
This chapter describes the development of a user interface respectively interaction concept for the adaptive in-vehicle recommendation service, which also includes additional measures to improve the user acceptance. A user-centered design process including different evaluation methods is applied. In Section 6.1 the whole process applied for the adaptive recommendation service is described. In the following sections; Section 6.2 to Section 6.5, each iteration within the user-centered design process is outlined. The resulting interaction concept is described in Section 6.6. Finally, the applied methods for prototyping and evaluation are discussed in Section 6.7.

6.1 Approach and User-Centered Design Process

The starting point for the development of a user interface is the result from the conducted online survey, described in Section 4.4, and the approaches described in the state-of-the-art in Section 3.4.1, especially the concepts from Lavie (2007) and Garzon (2013). Achieving high acceptance by the user and addressing user needs is very important. Therefore a user-centered design process is applied, where the user interface is developed within multiple iterations incorporating feedback of users. Different methods for the evaluation, as those described in Section 2.3.3, are selected and implemented. During the development the focus is on enabling traceability, controllability and avoiding obtrusiveness of the adaptive behavior of the recommendation service. Measures, described by Jameson (2008) are interpreted for application in the vehicle and applied to improve those usability criteria.
In Figure 6-1 the five iterations and included steps of the user-centered design process are illustrated. The first iteration (Section 6.2) starts with sketches, which are mainly representing the state-of-the-art determined by the approaches from Lavie (2007) and Garzon (2013). Sketches are a quick and simple way to communicate an idea and describe the context where the future system is intended to be used. They are used to explain the idea of an adaptive in-vehicle recommendation service to the participants of the user interview, which has been applied as a first method of evaluation and also used to identify the users' expectations and requirements.
Those requirements are included in the overall requirements defined at the beginning of the second iteration (Section 6.3). They are complemented by the results of a literature research. Based on those requirements, the sketches are further developed and realized as click-through prototypes. Click-through prototypes are more interactive than sketches. Following this, a heuristic expert evaluation is conducted to identify usability problems. These problems can be addressed before the next user evaluation to further improve the concept.

An important element of the user interface is the explanation menu, which makes it transparent to the user what the adaptive recommendation service has already learned about him/her, giving the user the possibility to change the parameters of future recommendations. This explanation menu is introduced and developed mainly in the third iteration of the user-centered design process (Section 6.4). First, requirements are identified for an explanation menu in this special use case. Based on the requirements the click-through prototypes of the adaptive recommendation service are extended by different forms of an explanation menu. Afterward, the different forms are evaluated by users to identify the one that matches the requirements in the best way.
In the fourth iteration (Section 6.5) the prototype is getting more realistic. A prototype for a Wizard of Oz experiment is developed, which is also a form of click-through prototype. In addition to the previous functionality, a person, the wizard, has the opportunity to control some features of the prototype, e.g. trigger recommendations. The Wizard of Oz experiment is conducted in a driving simulator, making the experience of the adaptive recommendation service more realistic. The results of the evaluation are integrated in the next iteration of the user-centered design process. The concept is developed further and the resulting user interface of the adaptive recommendation service after the fourth iteration is described in Section 6.6.
In the fifth iteration, this user interface is realized as one element of a functional prototype, integrated in an existing infotainment system, described in Chapter 7. This functional prototype is applied in a driving simulator study, where the adaptive in-vehicle recommendation service can be experienced by the participants on the basis of a user story (see Chapter 8).

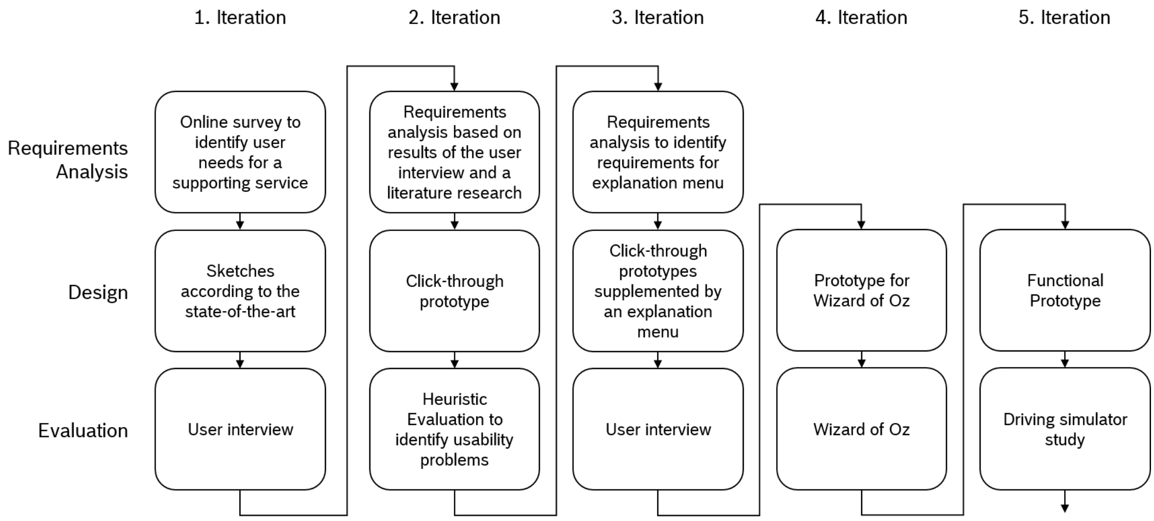


Figure 6-1.: Five iterations within the user-centered design process have been applied with different prototypes and evaluation methods.

In the next sections the different steps of each iteration are described in detail.

6.2 First Iteration

In the first iteration within the user-centered design process, prototypes of first ideas are realized to get feedback from users. The main goal is to get a deeper understanding of the domain. Section 6.2.1 describes the first prototypes of the adaptive recommendation service, followed by Section 6.2.2, where the first user interview is described.

The content of this section has been published in part in Walter et al. (2015c).

6.2.1 First Prototype - Sketches

The first prototype builds on the state-of-the-art. As already described by Lavie (2007) different levels of support are provided to the user. The realization of the different levels is inspired by the work from Garzon (2013). Four different levels are distinguished as previously mentioned in Section 3.1.4. The behavior of the adaptive recommendation service is described with the help of the use case "navigate to the office".

Use Case - Scenario description

"The driver enters his vehicle on a Monday morning at 8am. There are no further entries in his personal calendar. The driver wants to use the navigation application of the infotainment system to start the route guidance to the office. He is identified by the system and the user profile is loaded."

The scenario as well as the interaction with the infotainment system to start the route guidance is explained to the participants in form of high level sketches. They observe the infotainment system with activated and deactivated adaptive recommendation service and in case it is activated, different levels of support.

Level 1: Manual Usage

The first level, which is shown in Figure 6-2, represents the manual usage, where no support is provided to the user. First, a start screen is displayed (Figure 6-2(a)). The next screen represents the identification of the driver by the system after which his user profile is loaded (Figure 6-2(b)). Afterward, the home screen of the infotainment system is shown (Figure 6-2(c)) from where the driver can start his interactions. The following screen shows available applications on the infotainment system, where the navigation application has already been selected (Figure 6-2(d)). Next, the driver is asked where he wants to navigate to (Figure 6-2(e)) which indicates the address input. Last, a picture of a map is shown representing the active route guidance to the intended address (Figure 6-2(f)).

For the next three levels of the infotainment system with activated adaptive recommendation service, the use case starts with the same two screens, as shown in Figure 6-2. In the next Figures only the sketches, which differ from the first level are illustrated.

Level 2: User Selection

In the second level, shown in Figure 6-3, the system provides a set of preselected items in a shortcut list the user can choose from. In this use case the system presents two recommendations to the driver, "navigate to the office" and "play album drive" (Figure 6-3(a)). According to the use case, the first option is chosen to start the navigation to the office (Figure 6-3(b)). This level is called "User Selection" (US) because the driver can select one option from a variety of choices.

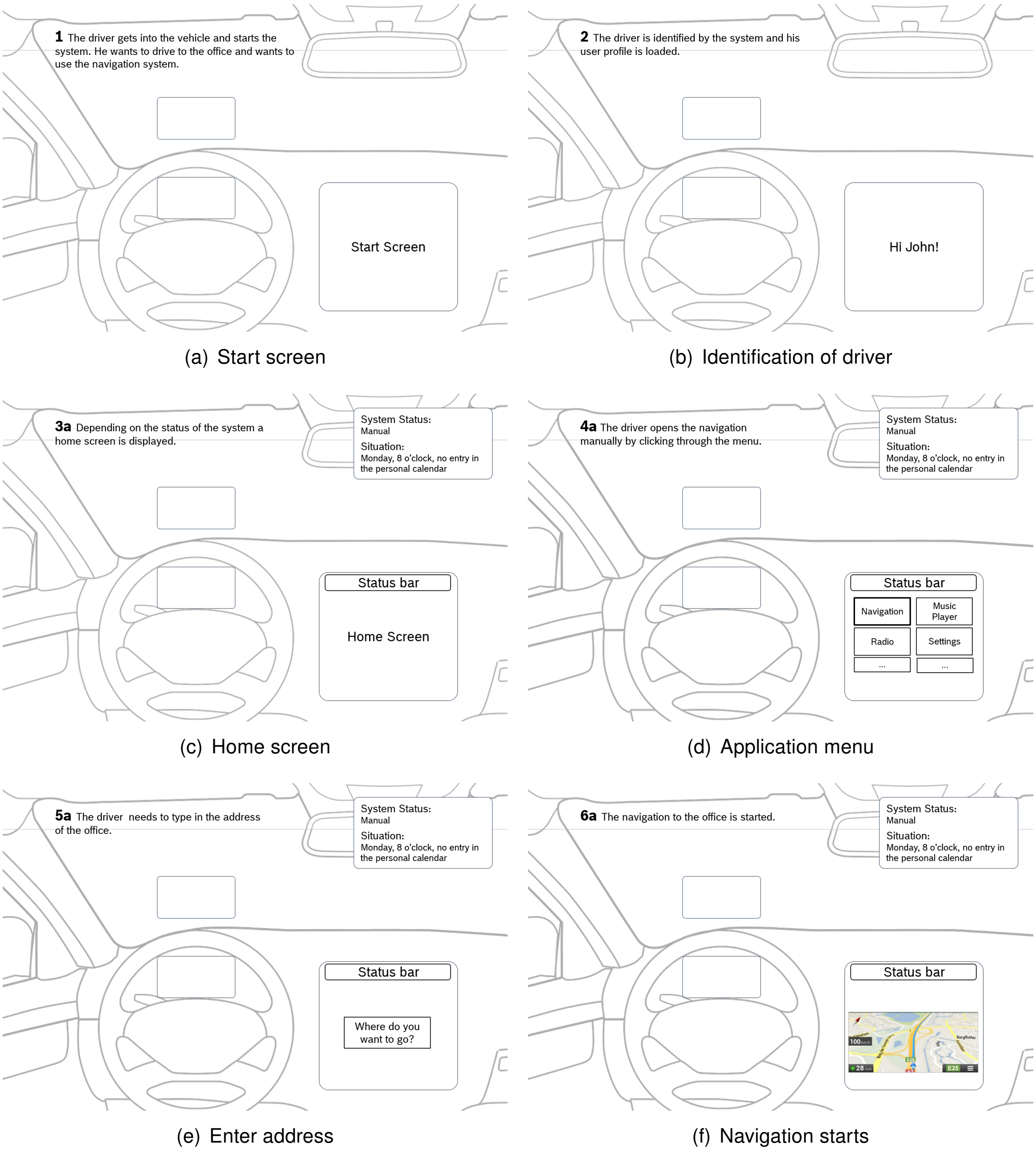
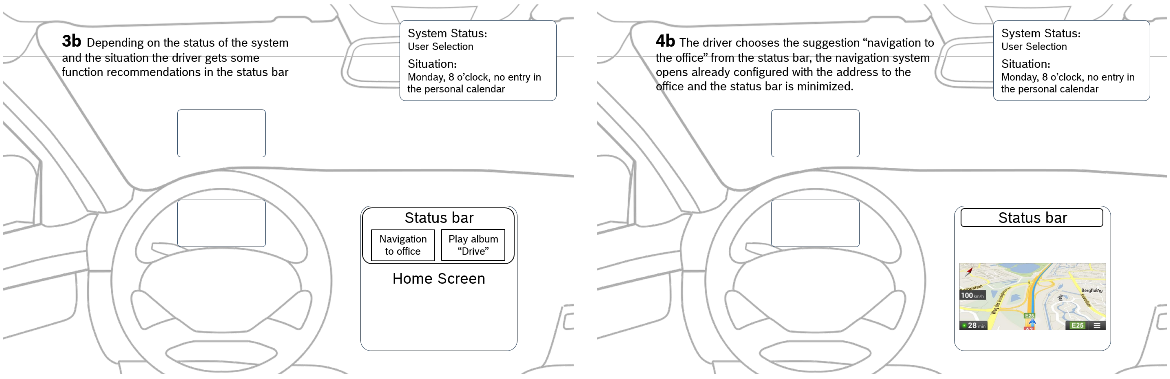


Figure 6-2.: Sketches of the manual usage of an infotainment system. The user enters his vehicle at a Monday morning at 8am and wants to start the navigation to the office: start screen (a), identification of the driver (b), home screen (c), application menu (d), enter address (e) and start navigation (f).

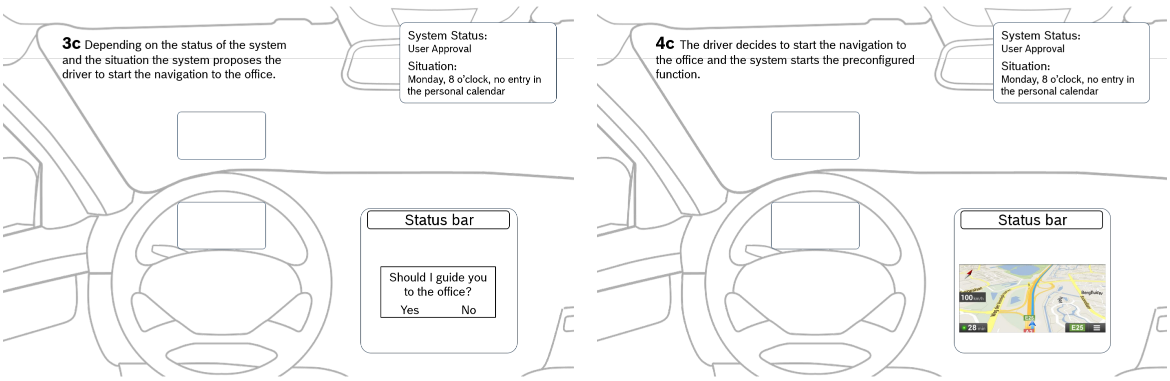


(a) Shortcut list (b) Preconfigured application

Figure 6-3.: The level "User Selection" presents recommendations to the user in form of shortcuts (a). The user can select one option from a variety of choices to start the preconfigured application (b).

Level 3: User Approval

The third level is called "User Approval" (UA), as the user gets one option, which he needs to approve or decline. In Figure 6-4(a) a pop up with the question "Should I guide you to the office?" with a "Yes" and a "No" button to select is shown. The driver can accept this recommendation to start the navigation to the office (Figure 6-4(b)).



(a) Popup menu (b) Preconfigured application

Figure 6-4.: The support level "User Approval" provides a pop up message with a preselected option as a recommendation, which the user can approve or decline (a). If the user approves the recommendation, the preconfigured application will start (b).

Level 4: Fully Adaptive

The degree of automation increases from the first until the fourth level. The fourth level, called "Fully Adaptive" (FA), selects the best option for the driver and starts the navigation to the office without approval. This is illustrated in Figure 6-5.

The sketches are the first prototypes of the adaptive recommendation service. The interaction with the driver is explained with the help of a use case. These sketches can be used as a paper prototype to explain the idea of the adaptive recommendation service, for example to potential users, as described in the next section.

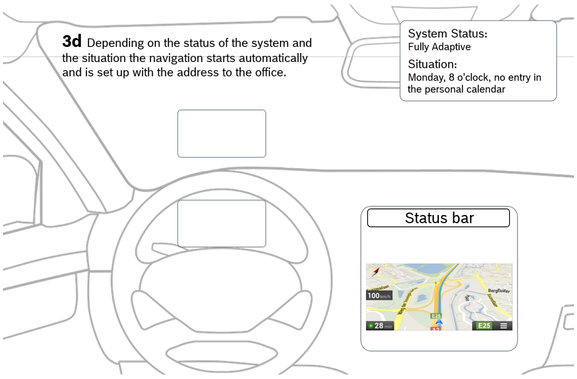


Figure 6-5.: In the level "Fully Adaptive" the preconfigured application starts fully automatically.

6.2.2 User Interview

One option to identify requirements of potential users is to conduct an interview, as described in Section 2.3.3. This method has been chosen to get into a dialog with the participants and especially to get a deeper understanding of their needs. The interviewer is led by a guideline but free in diving deeper into certain aspects. The interview about the adaptive recommendation service starts with general questions and continues with questions in the direction of an adaptive support. An interview guideline was prepared to provide a framework for a conversation but is not intended to strictly answer questions of a questionnaire. In addition to the requirements, feedback is received according to the presented prototype.

6.2.2.1 Experimental Design

The interview is divided into three parts. The **first part** starts with a demographic questionnaire (age, gender, attitude towards technology, etc.) and questions about the infotainment system the participants normally use. Afterward, the interviewer asks the participants about the functions of their infotainment system in detail. They are asked which functions they use most, what they like or dislike and which functions are missing (e.g. functions already known from the smartphone). The interviewer questions the participants what they are doing while driving and how they are supported to use these functions while driving.
In the **second part** of the interview, the interviewer wants to know more about how the participants want to be supported. The participants were asked to imagine that the vehicle can adapt itself to their needs and were asked how they would benefit from this. These two parts were conducted in the vehicle of the participants.
The **third part** took place outside of the vehicle either at the home of the participants or in the office of Bosch in Leonberg. The interviewer introduced the sketches described in Section 6.2.1 to the participants. The different levels of support are presented as three different interaction concepts in form of paper prototypes: The support level US is a dynamic list of shortcuts, UA a pop up message and FA the automatic execution of a preconfigured function. The concepts are always presented in this order. Previously, the use case had been presented to the participants as shown in Figure 6-2 in form of the first level representing the manual usage of the infotainment system. The use case "navigate to the office" is maintained through the whole interview and repeated for every concept. The sequence of the concepts is the same for all participants because it starts with presentation of the concept with the lowest level of support (level 1) and the level of automation increases with each presented concept (level 2 to level 4). After each presentation of the use case, with help of the different concepts, questions are asked to address the general usability of the concepts, the challenges of adaptive systems and driver distraction. For example, the participants are asked whether they have experienced the operation as easy

or not and whether they perceived the concept useful while driving. Finally, the participants compare the different concepts and choose the one they like most.
This interview is recorded on audio. The interview guideline and demographic questionnaire can be found in Appendix A.

6.2.2.2 Results

Six participants (N = 6; 4 male, 2 female) took part in this interview. Following to Nielsen (2012), the best cost-benefit ratio, still addressing up to 80 percent of the usability problems to be identified, can be reached with five to six participants. Four of the six participants were male and two female. Two of the participants were under the age of 30, two between 30 and 50 and two older than 60 (M = 44, SD = 18.21). The participants regularly use a modern infotainment system including at least media player and navigation system. All described themselves as technically orientated and all are smartphone users.
The interview started with discussions about the participants' current infotainment systems, usage behavior and experiences of using them while driving. Most reported avoiding operating the infotainment system while driving and when they needed to do it, feeling distracted. They wanted to be supported and were strongly related to solutions already known to them as speech dialogues.
The interview continued talking about the idea of an infotainment system adapting to the user to provide support, and presenting the ideas of an adaptive recommendation service. The result of this interview provide the main contribution to the requirements shown in Section 6.3.1. In addition, there are also findings related to each concept: The participants described the operation of the manual infotainment system as distracting due to the number of needed operation steps. The concept US was rated as simple by the participants and they could imagine using it while driving. The concept UA is assessed nearly equally as the concept US but the question of what happens when a recommendation is rejected or not replied occurred. There should be the possibility of being able to choose the recommendation again later, or to configure the behavior for this case. In summary the participants liked the concepts for the adaptation levels US and UA, but not the concept for the adaptation level FA. The concept for FA should be extended by an option to cancel the automatic execution of a function or by a one-time approval of a recommendation, then the user would feel more in control of the adaptive recommendation service. The opinions of the participants about the FA concept were very contradictory. Some participants noted that they would consider using it when the accuracy is high enough and others would never use it. In addition, the system behavior was not transparent to all participants, e.g. the reason why a function is recommended was unclear. Therefore, the traceability needs to be increased for all support levels.

6.2.2.3 Discussion

The goal of the user interview was to gain a deeper understanding of the user requirements and to get feedback according to first ideas of an adaptive recommendation service. Therefore, it was beneficial to conduct the first and second part of the interview in the vehicles of the participants. The current usage behavior could be explained and demonstrated instead of just describing it, by having the infotainment system directly in front of the participants. As a result more pain points according to the current usage behavior were addressed by the participants, which are also taken into account for the requirements.
In the second part of the interview the participants were asked about their ideas of an infotainment system that adapts to their needs in order to support them. This question was difficult for them and they referred to already known solutions, as for example speech interaction. Therefore, it was beneficial to present first sketches of the adaptive recommendation service to get

feedback according to this idea. They used the sketches as a starting point to reflect this idea. A more enhanced prototype was not required. Sketches enabled the participants to discuss the idea and not any details of the realization. In addition the use case supported the understanding of the idea and interaction with the system.
In summary, the user interview was helpful at this stage of development. The idea of an adaptive recommendation service has high potential and the concepts for the different support levels must be further developed within the next steps of the user-centered design process according to the findings and identified requirements.

6.3 Second Iteration

In the first iteration of the user-centered design process a user interview was conducted amongst other data-gathering activities to collect requirements for an adaptive recommendation service. The second iteration starts with the analysis of the collected requirements complemented by requirements from an extensive literature research. Then the concept of an adaptive recommendation service is further developed and realized as click-through prototypes. Finally, a heuristic expert evaluation is conducted to identify usability problems.

The content of this section has been published in part in Walter et al. (2015c).

6.3.1 Requirement Analysis for an Adaptive In-vehicle Recommendation Service

An important step in the user-centered design process is to understand the requirements of the users according to an adaptive recommendation service. Fulfilling those requirements is the prerequisite to gain user acceptance. As already mentioned, the requirements for the adaptive recommendation service are deduced from literature and complemented by the results of the user interview conducted in the first iteration. Both are important since on one hand the number of participants within the user interview is not representative, and on the other there is no literature available for the specific case of a user-adaptive context-sensitive extendable recommendation service in the vehicle.

6.3.1.1 Literature Research

Only a few approaches of an adaptive in-vehicle recommendation services exist in the literature. Examples are the work from Bader et al. (2012), Garzon (2013) or Lavie (2007). Therefore, literature from related fields, such as adaptive systems (Evers et al. (2010) and Jameson (2008)), interactive systems (Shneiderman and Plaisant (2010)) and recommendation systems (Shani and Gunawardana (2011)), needs to be considered. In addition, the work from Hartmann (2009) deals with several of these topics and is also included. Further, guidelines, as described in Section 2.2.4, are taken into account (NHTSA (2013), JAMA (2004) and ESoP (European Union, 2006)). Also ISO standards, ISO 9241-11 (1998), ISO 9241-110 (2006), ISO 9241-12 (1998), and ISO 15005 (2002), are considered. The results of this literature research, complemented with the results of the user interview conducted in the first iteration of the user-centered design process, are described in the next section.

6.3.1.2 Requirements of an Adaptive Recommendation Service

The identified requirements from literature research and the user interview are combined and described in Table 6-1. The requirements are categorized in seven categories: distraction, traceability, configuration, controllability, user experience, personalization & adaptivity, and recommendation. The categories represent the challenges of adaptive systems and the challenges gained from the automotive field. An isolated analysis of the requirements for an adaptive recommendation service is not possible since it is always part of an infotainment system and embedded in the driving context.

Table 6-1.: Requirements for an HMI with focus on an adaptive recommendation service in the vehicle according to Walter et al. (2015c)

Distraction	The adaptive recommendation service supports the driver while driving. The operation of the adaptive recommendation service should have no negative impact on the primary driving task.
Simplicity	The driver should be able to capture relevant information with a few glances.
Single-Handed	Single-handed operation should be possible.
Occlusion & Priority	Vehicle controls, displays and warning messages required for the primary driving task should not be obstructed by the adaptive recommendation service.
Sound level	No sound that masks warnings from inside or outside the vehicle should be produced, to avoid causing distraction.
Legal restrictions	Functions not allowed while driving shouldn't be recommended.
Traceability	The user should be able to understand the system's status and actions.
System behaviour	The user should be able to understand the system's behavior.
Device status	The current status and detected malfunction with an impact on safety should be presented.
Introduction	There should be a tutorial introduction to explain the usage of the adaptive recommendation service.
Intuitive	The user should be able to understand the system status and behavior intuitively.
Configuration	The user should be able to configure the adaptive recommendation service.
Presentation	The form of presentation should be configurable by the user.
Parameters	The parameters that determine the behavior of the adaptive recommendation service should be adjustable.
Switch off	The driver should be able to switch off showing non-safety related information, including the output of the adaptive recommendation service.

Table 6-1.: Requirements for an HMI with focus on an adaptive recommendation service in the vehicle according to Walter et al. (2015c)

Controllability	The user should be able to control particular actions or states of the adaptive recommendation service.
Freedom of choice	The user should be able to choose to use or decline an adaptation.
Interruptibility	No uninterruptible sequences of visual-manual interactions should be required, and an interrupted sequence should be able to be resumed.
Speed	The ability to control the speed of interaction should be provided; no time-critical response should be necessary.
Reversibility	User input or configuration should be reversible.
User Experience	The adaptive recommendation service should have a high usability and positive user experience.
Efficiency	The user should be able to perform tasks quickly.
Effectiveness	The user should be able to finish tasks with high accuracy and completeness.
Satisfaction	The usage of the adaptive recommendation service should be without impairment and a positive attitude should be supported.
Joy-of-Use	The use of the adaptive recommendation service should be enjoyable.
Accessibility	All relevant information should easily be accessible.
Feedback	For every user action, there should be a system feedback that is timely and clearly perceptible.
Recognizability	The attention of the user should be directed to the needed information.
Simple error handling	The user should not be able to make serious errors. The system should also offer simple error handling.
Consistency	Consistent sequences of actions, identical terminology and consistent commands should be used.
Compactness	Only the information needed to complete the intended task should be shown.
Personalization & Adaptivity	The adaptive recommendation service must adapt its presentation to different users, devices and situations.
Changing User Behavior	The adaptive recommendation service must be able to handle a change in the user behavior over time.
Stability	The user interface should not be modified too much during usage.

Table 6-1.: Requirements for an HMI with focus on an adaptive recommendation service in the vehicle according to Walter et al. (2015c)

Speed of Adaptation	The phase of learning should be short even when only little usage data exists.
Breadth of Experience	The user should be able to operate the non-adapted system.
Data Privacy	The user should be able to control the data collection.
Recommendation	The user can be supported by giving recommendations.
Proactive	The recommendation should be proactive.
Scalable	A variety of functions should be supported, which should be extendable during run time.
Unobtrusiveness	The intelligent support should not distract the user from normal usage of the application.
Accuracy	Correct recommendations with a high accuracy are needed.

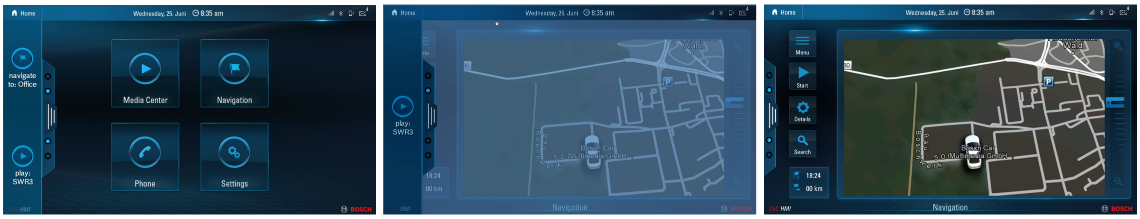
The collected requirements covering general requirements for in-vehicle systems as well as specific requirements for adaptive systems and the adaptive recommendation service. Depending on the context of application of the adaptive recommendation service, the requirements need to be modified and complemented.
The requirements need to be taken into account for different parts of the recommendation service as architecture, algorithms, and interaction concept. Within this chapter the interaction of the adaptive recommendation service with the user is in focus. Most of the requirements are used to develop a suitable concept while others are out of scope or have a more indirect influence. Requirements as the ones listed under user experience can directly be considered for the interaction concept. In comparison, requirements as "legal restrictions" and "accuracy" have no big impact on it on first glance.

6.3.2 Click-through Prototype

Based on the results of the first user interview, described in Section 6.2.2, and the requirements of the previous Section 6.3.1 the concept of the adaptive recommendation service is further developed. The focus is on the presentation form of the recommendation, addressing mainly the requirements associated with "driver distraction" and "recommendation". Requirements as "legal restrictions" or "accuracy" are not taken into account at this stage of development as they have more an indirect influence. The requirement "sound level" is out of scope as the focus is on a visual representation of the recommendations.
Moving into the direction of a more realistic prototype, the next prototype of the adaptive recommendation service is realized as a click-through prototype. For this, the tool Balsamiq[1] is used to create different mock-ups for the different levels of the adaptive recommendation service. Although it is not fully functional and the actions of the system must be triggered by a person, the users get a better impression of how an adaptive recommendation service can work. For the click-through prototypes, screens of an existing infotainment system, which is used for prototypes

[1] `https://balsamiq.com/`, last accessed on 29/09/2016

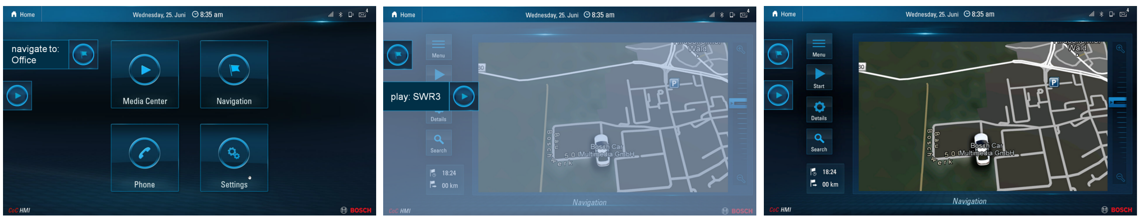
within the advanced development at Bosch, are taken as a basis. The underlying infotainment system is also realized as a click-through prototype, enabling the demonstration of a use case within the manual level.
The support level US is represented as a list of shortcuts, where one out of up to four recommendations can be chosen by the user. This shortcut list is realized in two different ways. The first variant is a list of shortcuts in an additional menu bar at the side of the screen (US1), as shown in Figure 6-6. The shortcuts consist of the same icon as the referenced application and a short text indicating the configuration of the shortcut. The configuration is represented by the name of the function and the configuration of the function. For example in case of a shortcut belonging to the navigation, the shortcut consists of the function "navigate to" and an abbreviation for the intended address. This content of a recommendation is generic to enable an easy extendability during run time.



(a) Shortcut bar with two active recommendations (b) Shortcut bar with one active recommendation (c) Minimized shortcut bar

Figure 6-6.: One variant to realize the support level US is a shortcut menu bar, which is shown at the left side of the screen. The menu bar can be minimized and maximized by an indicator shown in the middle of the bar. Up to four recommendations can be displayed. The number of displayed recommendations is indicated by four dots even when the menu bar is minimized.

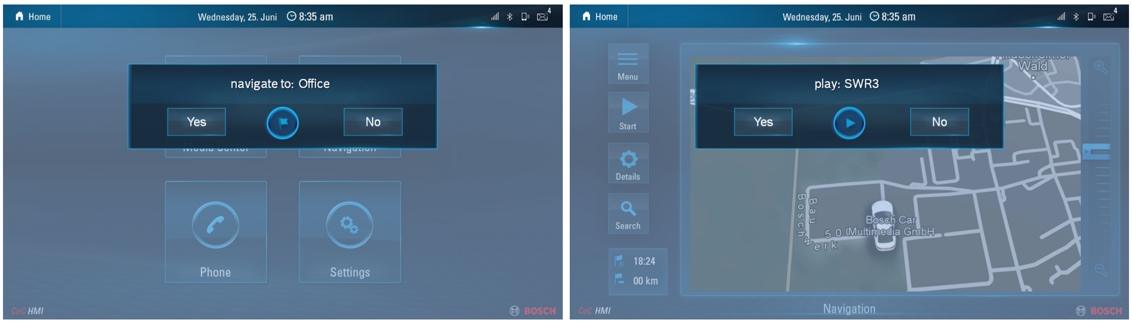
The shortcuts are evenly distributed depending on how many are shown at the same time (see Figure 6-6(a) and Figure 6-6(b)). The menu bar can be minimized and maximized by clicking on three stripes in the middle of the bar (see Figure 6-6(c)). On the home screen, the shortcut bar stays open because there is enough space available. Four dots show how many recommendations are offered even when the menu bar is minimized. They are activated from inside to outside and then from top down, starting with the dot directly above the three indicators, as shown in Figure 6-6(b), and continuing with the one directly below the indicators (see Figure 6-6(a)). To select a recommendation and start the preconfigured function, the user needs to click on the icon or text of the shortcut. Afterwards, the selected recommendation disappears from the list of shortcuts.



(a) Shortcut to start the navigation to the office (b) Shortcut to change the radio station (c) Minimized shortcuts

Figure 6-7.: A second variant of the support level US is realized by displaying the shortcuts in form of notifications. The notifications are moving into the screen from the left side. If the driver has recognized them but is looking away, they will be minimized automatically. In addition they can be minimized and maximized by clicking on the icon of the application.

The second concept (US2) belongs also to the support level US, but the recommendations are displayed in form of notifications as shown in Figure 6-7. The notifications are moved into the screen from the left side (see Figure 6-7(a)). They are minimized in case the user looks at the recommendation, but is not interested at the moment and looks away again for a certain time. In the minimized state, only the icon of the application is shown. If the user clicks on the icon, the notification is maximized again. The user can minimize it himself by clicking on the icon again (see Figure 6-7(b) and Figure 6-7(c)). To select a recommendation and start the preconfigured function, the user needs to click on the text. Afterwards, the selected notification disappears from the side of the screen.



(a) Recommendation to start navigation to the office

(b) Recommendation to change to the radio station "SWR3"

Figure 6-8.: In the support level UA, the user gets the recommendations in form of pop up messages, to accept or reject.

The third support level UA is realized as a pop-up message (see Figure 6-8), where the user needs to accept or reject the recommendation. The displayed content of the pop up is similar to the shortcuts. This includes the icon of the application, the name of the function, and the configuration of the function. Besides that a "Yes" and a "No" button is displayed at the bottom of the pop up message. Figure 6-8(a) shows the pop up with a recommendation to start the navigation to the office and Figure 6-8(b) a recommendation to start playing the radio station "SWR 3". If the user approves the recommendation, by clicking on the "Yes" button, the preconfigured function starts and the pop up disappears. If the user rejects the recommendation by clicking on the "No" button, the pop up disappears with no additional effect.

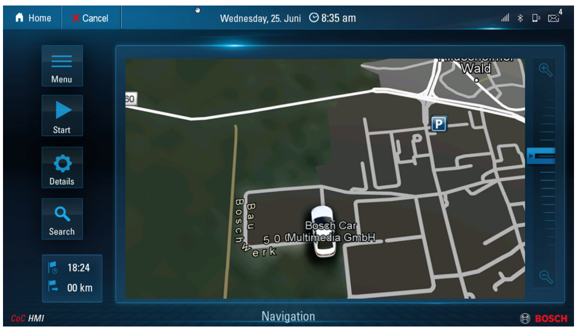


Figure 6-9.: In the level FA the preconfigured application starts fully automatically.

The last support level FA is the automatic execution of a preconfigured function, which can be canceled by a cancel button (see Figure 6-9) that is displayed only when the function is started automatically by the adaptive recommendation service.
In comparison to the first sketches, described in Section 6.2.1, the concept of the adaptive recommendation service has been developed further. Many of the findings of the user interview,

described in Section 6.2.2, have been included. The improved concept, realized as a further advanced click-through prototype, is ready to be evaluated by experts within a heuristic expert evaluation.

6.3.3 Heuristic Evaluation - Usability Evaluation

Another evaluation method, conducted at a very early stage within the user-centered design process, was the heuristic evaluation. This method, as described in Section 2.3.3, is useful to identify existing usability problems of a concept. For this, a group of experts from different but related fields including HMI software architects, designers and ergonomists discussed the given concepts according to provided heuristics from the perspective of the user (Nielsen, 1995a). The experimental design and results are described in the next sections.

6.3.3.1 Experimental Design

The heuristic expert evaluation was conducted with each expert individually. The procedure was the same for every expert. Nine heuristics; a mix of the heuristics of Nielsen (Nielsen, 1994) adapted for this evaluation and extended by other important heuristics for driver distraction, were introduced. The heuristics described desired characteristics of the interaction between the user and the system, to be used as an orientation and to evaluate the concepts from different perspectives, and are attached in Appendix B.
After this introduction, a storyline was presented from which the expert assumed the role of a user.

Use Case - Scenario description
"It is Monday morning 8am and as usual the driver is on his way to the office. Already driving, he should start the navigation to the address of his office and afterwards switch to the radio to listen to the news on the radio station SWR3."

The experts were requested to perform the use case with the click-through prototype of the basic infotainment system. After familiarisation with the underlying infotainment system, they were introduced to the idea of an adaptive recommendation service. They were told that they had been using the infotainment system now for a while and the adaptive recommendation service had learned that they would start the navigation to the office and change the radio station to SWR3 on Monday mornings at around 8am at a specific point on their route to the office. Next, the experts were requested to perform the tasks of the use case again, with the click-through prototypes of each level, and to evaluate each one. They were later asked to describe the identified usability problems so that the interviewer could construct a protocol.
All click-through prototypes ran on a 10inch tablet PC. The order in which the levels were presented to the experts was permuted.

6.3.3.2 Results

A total of six experts (N = 6) took part in this heuristic evaluation; as recommended by Nielsen (2012) as being the number of participants with the best cost-benefit ratio. The four different concepts US1, US2, UA and FA were evaluated by experts from the fields of Ergonomics, Software Development, Design and User Experience. Each finding was assigned to one of the heuristics and weighted with a severity rating from 0 to 4 depending on frequency, impact on the user and persistence of the problem (see Nielsen (1995b)). The total number of identified usability problems was different for each concept as the overview presented in Figure 6-10 shows.
For the concepts US1 and US2 more usability problems were identified than for the other two concepts. Several of those problems were rated with four. The concepts US1 and US2 included

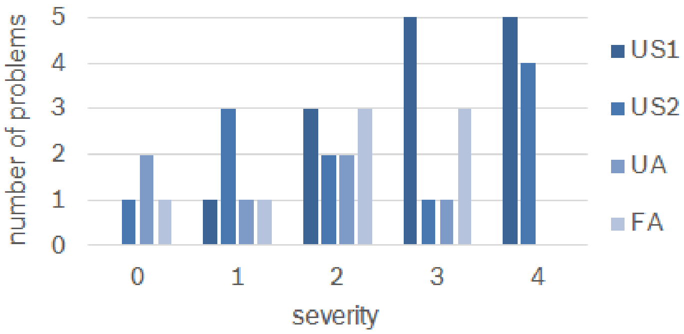


Figure 6-10.: The result of the heuristic evaluation for each concept is summarized according to the severity rating (Walter et al., 2015c)

more interaction with the user compared to the concepts UA and FA. This could be the reason why more usability problems and with a higher severity rating were identified for those concepts than for the others. Figure 6-10 shows the distribution of the number of problems according to the severity broken down to each concept.
All findings of the heuristic evaluation are listed in the Appendix C. Some of the findings are mentioned and discussed here. For the concepts US1 and US2 the main issues were the order of the shortcuts and displaying not enough information to understand the shortcuts especially when minimized as in concept US2. The concept of minimizing and maximizing the menu bar in US1 should be consistent and not change on the home screen. In the concept US2 it was difficult to understand the difference between how a recommendation could be selected and how a shortcut could be minimized. For the concepts UA and FA, an option to deactivate a recommendation directly was requested and the participants highlighted the loss of control and lack of transparency. Several issues that could be improved were addressed in this heuristic evaluation by the experts and some suggestions given.

6.3.3.3 Discussion

The goal of the heuristic expert evaluation was to identify usability problems of the developed concepts. The experts identified several problems and in addition brought in their ideas how to address them. This was very fruitful for the improvement of the concepts. The click-through prototypes were quickly created and supported the communication of the idea of the adaptive recommendation service enabling a hands-on experience for the experts.
In future, either US1 or US2 will be further developed. As the issues identified for concept US1 are more easily solved, this concept will be selected. For all concepts, more transparency to understand the system's behavior is needed. This will be addressed in the next iteration of the user-centered design process. In summary, the expert evaluation was very useful to compare different concepts and to identify possibilities for improvement. These findings fit the requirements described in Section 6.3.1.2. In this stage of development the focus is on the presentation form of the recommendation with the goal to address the reduction of driver distraction. The experts found the approach of the adaptive recommendation service suitable in general for this goal but some aspects regarding usability need to be improved. These aspects are reflected in the findings of this evaluation and match the remaining requirements in Section 6.3.1.2 as for example the ones under "user experience", "traceability" or "controllability". These requirements are in focus within the next iterations of the user-centered design process.

6.4 Third Iteration

Traceability is a very important aspect of adaptive systems, especially since the behavior of the adaptive system changes over time and is not easily predictable by the user. Traceability is one of the main requirements described in Section 6.3.1 for the adaptive recommendation service. However, the heuristic evaluation, described in Section 6.3.3, has shown that it is not yet sufficiently addressed. Therefore, the traceability of the adaptive recommendation service is in focus of the third iteration of the user-centered design process. An explanation menu should be developed to increase the transparency. First, a closer look is taken on the requirements regarding traceability, which are then the basis of the following developed prototypes. Afterward, they are evaluated by participants of a user interview.

The content of this section has been published in part in Walter et al. (2015b) and Kaplan (2015).

6.4.1 Requirements for an explanation menu

Transparency is the ability of the system to communicate knowledge about the system behavior and its triggers. Therefore, it must be determined which information needs to be presented to transfer the right level of information and how this information can be presented in an easily understandable manner. For the analysis of the requirements according to the explanation menu, the work of Lim and Dey (2009) is used. Lim and Dey (2009) have analyzed the information that is important for users to understand the system behavior. Therefore, they have conducted a user survey where different context-sensitive applications have been evaluated. The identified information has been mapped to characteristics of the applications. This is used to determine the necessary information to explain the system behavior according to the characteristics of the adaptive recommendation service. This information needs to be presented in the explanation menu. As the adaptive recommendation service supports the user reaching a certain goal, provides recommendations, and does this based on external data, Lim and Dey (2009) recommend to present the following information related to each recommendation: The possibility to change the presentation (Output); the information sources (Input); how a recommendation is determined (How); different behavior depending on the context (What if); and the relevance of a recommendation (Certainty). The work of Lim and Dey (2009) is focused on context-sensitive applications, therefore the information needs to be extended with regard to an adaptive application. An additional requirement is to show changes in the behavior, as adaptive systems adapt their behavior during run time to the behavior or characteristics of the user. Therefore, it is important to communicate this change of the behavior to the user.

In addition to the content there are requirements regarding the presentation and operation of this content. The presentation should be clear, to support quick understanding of the provided information. It also needs to be suitable for the vehicle and general as well as extendable to support all varieties of recommendations independent from the application and context. Furthermore, it is important that the operation of the explanation menu is intuitive to the users.

6.4.2 Click-through Prototype for Explanation menus

On the basis of the defined requirements in Section 6.4.1, the click-through prototypes introduced in Section 6.3.2 are extended by different concepts for an explanation menu. In order to find a suitable presentation form for this large amount of identified information, the principle "Overview first, zoom and filter, then details-on-demand" of Shneiderman (1996) is used. Shneiderman (1996) also describes seven different data types and possibilities for their presentation in his "Task by Data Type Taxonomy". The data of the recommendations of the adaptive recommendation service can be mapped to two-dimensional data or hierarchical data. Concept 1 presents the two-dimensional data in an abstract form with regard to the context parameters.

In this way, the user can filter the recommendations according to the context parameters. In Figure 6-11, the recommendations are shown depending on their mapped position as points on a map.

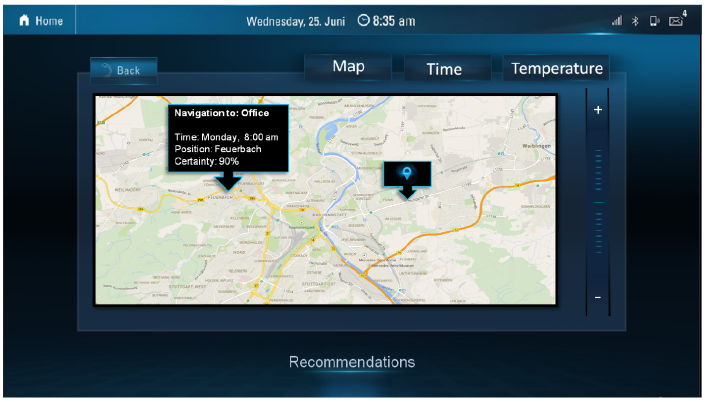


Figure 6-11.: Concept 1 shows the recommendations based on their context parameters in an abstract way. For example recommendations are shown depending on the value of the context parameter "position" as points on a map (Walter et al., 2015b).

In a hierarchical way, the data can be categorized in the first level based on the corresponding application (e.g. navigation or radio). The next level can be ordered according to additional characteristics of the applications, e.g. the recommendations of the navigation application can be ordered according to the intended destinations. On the last level the detailed information of each recommendation is shown. This can be visualized either as 2D-visualization as in Concept 2 (see Figure 6-12) in form of hierarchical tabs or as a 2,5D-visualization (see Figure 6-13) on different layers. In addition, all hierarchical layers can be seen the whole time in Concept 2 whereas in Concept 3 only the current layer is shown and a back button to navigate to the next higher layer.

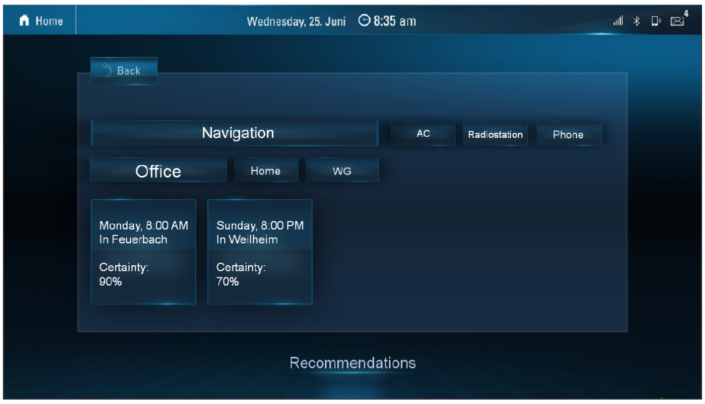


Figure 6-12.: Concept 2 shows the categorized recommendations in form of hierarchical tabs (Walter et al., 2015b).

The three concepts represent different presentation forms of the same data. Concept 2 and 3 are easily extendible in contrast to the first concept. One requirement is not yet addressed: The requirement to inform the user about changing behavior. This will be addressed in the next prototype as an extra feature, described in Section 6.5.
The prototypes of all three concepts have been realized as click-through prototypes with Balsamiq. Hence, the participants of the next user study have the option to explore the concepts by themselves on a tablet PC.

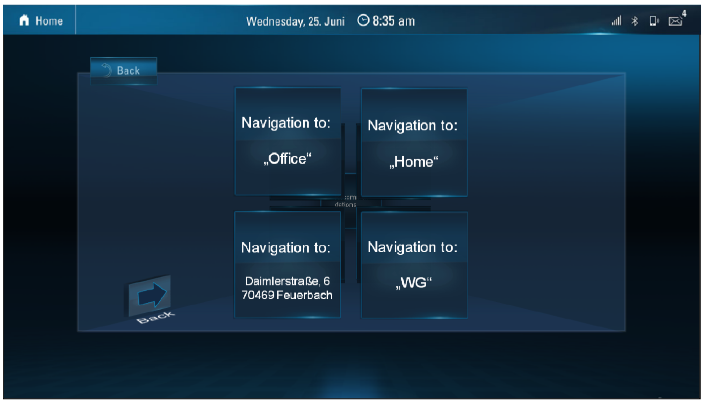


Figure 6-13.: Concept 3 presents the hierarchies of recommendations on different layers (Walter et al., 2015b).

6.4.3 User Interview - Evaluation of Transparency

The next study conducted within the user-centered design process is an additional user interview. The goal of this interview was to evaluate if the explanation menu provided enough information to understand the behavior of the adaptive recommendation service. In the next sections, the experimental design and the results of the user interview are described.

6.4.3.1 Experimental Design

The interview started with demographic questions, including an estimation of their own technical affinity. The adaptive recommendation service was then introduced with the help of the click-through prototype of one support level addressing the same use case as in the first iteration (see Section 6.2.1 - Use case: "start the navigation to the office as on every Monday morning"). The selection of the support level was randomly distributed over all participants. Afterwards, the participants were invited to ask any questions about the system. This procedure is oriented towards the procedure of the user study from Lim and Dey (2009). The questions asked correlated with the information that should be provided by the explanation menu. The user interview continued with the introduction of one of the concepts for the explanation menu. The participants could explore the click-through prototype on a tablet PC on their own, thereby experiencing the system behavior. After the exploration, the users were again asked for any questions about the system to verify that no information was missing, and also asked how well they felt they understood the system behavior on a scale from one to four (1 = "I totally understand the system behavior", 2 = "I understand the system behavior in the broadest sense", 3 = "Several points are still not clear to me", 4 = "I didn't understand the system behavior at all"). The participants were also asked about their user acceptance of the overall adaptive recommendation service, and whether they would implement such an adaptive recommendation service in their own vehicle. Each participant experienced just one of the concepts, to prevent transfer of background knowledge from a previous version. All participants were given the same information within the user interview but got to know different forms of presentation and different support levels (3 concepts x 3 support level). The interview guideline can be found in Appendix D.

6.4.3.2 Results

Twelve participants (N = 12; 8 male, 4 female) took part in the user interview. Prerequisites for participating were to hold a driver's license and own a vehicle with integrated infotainment system. The participants were aged between 26 and 54 (M = 36.7, SD = 10.6). They had driven between 4,500 km and 20,000 km (M = 12.042 km, SD = 4324 km). Two of the participants

estimated their technical affinity on a scale from 1 (not technical oriented) to 5 (highly technical oriented) with a 5, six participants with 4, three with 3, and two with 2.
As twelve participants took part in the user interview, each concept was introduced to four participants. This means that for each concept, one of the support levels was used twice to explain the use case. The summary of the results can be found in Appendix D and is described in the following: The participants were asked before and after the exploration of the concept of the explanation menu for questions they might have about the system. The questions before exploring the explanation menu could mainly be mapped to the categories of information identified in the requirements in Section 6.4.1. It can be concluded that all information supposed necessary for understanding the system behavior was also requested by the participants in this special case. In addition, questions that can be summarized under the term "configuration" were asked; for example "Can the system be reset?". And then there were questions that could not be categorized, for example "Does my car recognize me automatically?". Those questions do not refer directly to the behavior of the adaptive recommendation service and are therefore not relevant for the explanation menu. After exploring the explanation menu fewer questions were asked and the remaining questions were more specific. Only two questions could still be mapped to the categories of the requirements: "How does the algorithm work?" (How) and "How are the context parameters measured?" (Input). Both questions were very specific and exceeded the knowledge that should be created. All other questions didn't refer to the behavior of the adaptive recommendation service. From this result it can be concluded that all necessary information was available to understand the system behavior.
Regarding the questions, no difference between the concepts could be determined. The different forms did not have a positive or negative influence on understanding the recommendation service. The subjective perception of the system understanding could be improved by the explanation menu, as all participants mentioned that their understanding improved through the explanation menu. The participants rated their system understanding on a scale from one (high) to four (low) with an average of 1.75 for the first concept, 1.5 for the second concept and 2 for the third concept. This result shows that the participants perceived their understanding already as quite good but with room for improvement. As the participants experienced just one use case of the adaptive recommendation service, they might have the feeling of not knowing the system completely.
Regarding the question of whether the participants would implement such an adaptive recommendation service in their own vehicle before they had explored the explanation menu, three of them agreed, three disagreed and six said they would make their decision depending on the price. After they experienced the explanation menu they were asked the same question again and now seven agreed, two disagreed and three would still make it dependent on the price. As the intention to use a system is seen as an indicator for user acceptance, it can be said that the explanation menu has a positive influence on user acceptance. The presentation form did not made any difference to the result.

6.4.3.3 Discussion

One main challenge of an adaptive recommendation service is making the system behavior transparent to the user. This has been addressed in the third iteration of the user-centered design process with the development of an explanation menu. The explanation menu should be general and extendible; that it is flexible for the changing behavior of the adaptive recommendation service, applications installed during run time, and different context parameters. Nevertheless, all necessary information to explain the system behavior must be presented. The results of this user interview show that the concepts for the explanation menu meet those requirements. Some participants requested very specific knowledge about the system behavior, but including this would increase the complexity of the explanation menu, and could result in a negative effect on

the traceability. Regarding the different presentation forms, no influence could be recognized on the system understanding. Both, concept 2 and concept 3 meet the requirement for extendability, in comparison to concept 1 which does not meet this requirement. Therefore, one of those two concepts should be further developed.
As the experience of the adaptive recommendation service was very limited, the results of the user interview need to be handled with care, and a more realistic prototype is needed to evaluate the adaptive recommendation service regarding user acceptance. In the next iterations of the user-centered design process the concept of the adaptive recommendation service should be extended by measures to address the feeling of losing control. This need could be identified in some of the questions the participants asked regarding the ability to configure the system. In summary it can be said that only with an overall concept including for example an explanation menu and other measures, the adaptive recommendation service can be evaluated properly regarding usability issues. A prototype with increased functionality is pursued in the next iterations of the user-centered design process.

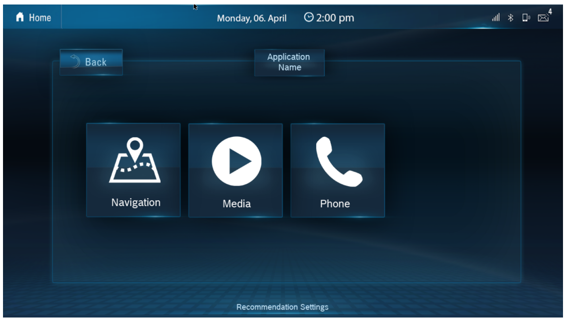
6.5 Fourth Iteration

In the fourth iteration, a higher priority was given to the experience of the adaptive recommendation service. The main contribution of this iteration was the Wizard of Oz experiment, where the participants used an adaptive recommendation service to use functions of the infotainment system while driving in a driving simulator environment. The goal was to further develop the overall concept of the adaptive recommendation service to include the requirements "configuration" and "controllability" described in Section 6.3.1.2, advance the prototype and develop a method for evaluation of the usability with a reasonable experience of the adaptive recommendation service.

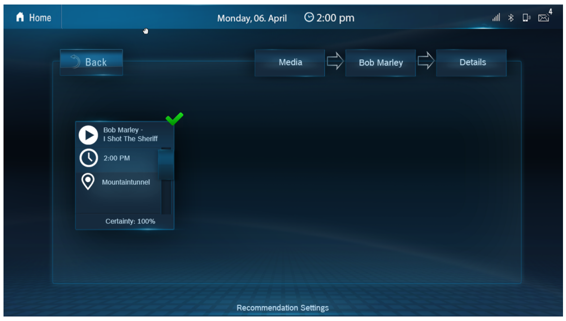
The content of this section has been published in part in Kaplan (2015).

6.5.1 Prototype for Wizard of Oz Study

In the previous iteration of the user-centered design process the explanation menu was in focus. Three concepts had been created (see Section 6.4.2) and evaluated (see Section 6.4.3). The findings of the user interview were taken up in this section to further develop the explanation menu for the adaptive recommendation service. The goal was to bring together all the benefits of each concept for the explanation menu into one joint concept. For example, according to extendability, the hierarchical view of Concept 2 or Concept 3 is more suitable than the two-dimensional abstract view of Concept 1. Therefore, the common concept will present the data in a hierarchical view. The advantage of Concept 2 is the easy way to navigate between the hierarchical layers. However, displaying all layers of hierarchy at the same time needs a lot of space, which means less space for the important content. This was solved in a different way in Concept 3. All these findings are incorporated into one common concept. In addition, the requirements associated with the categories "configuration" and "controllability" are in focus of this iteration and are taken into account in the resulting concept, shown in Figure 6-14.
Entering the explanation menu, an overview of all supported applications is presented (see Figure 6-14(a)). Selecting one application leads to the next layer of options, where the categories for each application are presented. The last view in the hierarchy is the one shown in Figure 6-14(b), where all available recommendations for this category are listed. The presentation of one recommendation includes the parameters for the configuration of the application and a list of parameters representing the context in which the recommendation is presented to the user. In addition, it is shown whether the recommendation is activated or not by an indicator on the right upper corner of the recommendation and the certainty of the recommendation service is displayed. A bar menu, displayed directly above this overview, enables the user to navigate between the



(a) Overview of the supported applications



(b) Overview of the learned recommendations for one subcategory of an application - in this case for the media application.

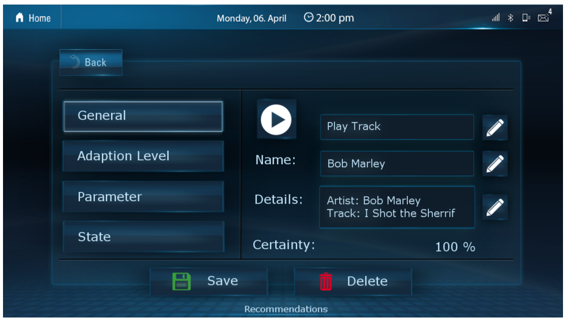
Figure 6-14.: The Explanation Menu of the adaptive recommendation service gives an overview of already learned recommendations. They are presented in a hierarchical structure. An option to navigate through the hierarchies is provided at the upper part of the screen.

layers of hierarchy.
In addition to this presentation of the available recommendations, the user can enter a detailed view of each recommendation by clicking on it. In this detailed view, shown in Figure 6-15, the user has the option to change parameters of the recommendation and therefore influence the behavior of the adaptive recommendation service.

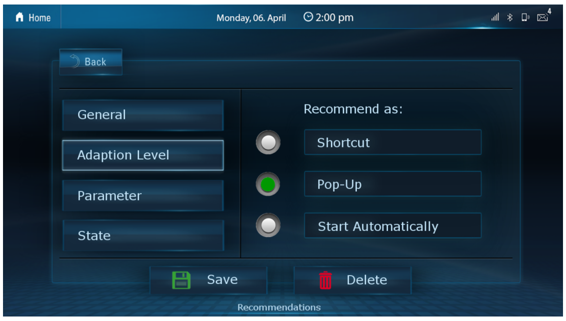
The first screen of the detail view is presented in Figure 6-15(a). The user has the option to change the application, the function and the values for the configuration of the function. In addition, the certainty of the underlying machine learning algorithm is indicated in percent. This refers to how confident the adaptive recommendation service is that the user wants to use this specific function with the given configuration in the determined context. The way the recommendation is presented can be selected in the second view shown in Figure 6-15(b). In the third view, see Figure 6-15(c), the values for the parameters defining the context can be changed. The last view covers the state of the recommendation. As shown in Figure 6-15(d) the user can activate or deactivate a recommendation. In addition, all changes can be saved by using the save button at the bottom of the screen or the recommendation can be deleted completely with the delete button.
One important requirement for making the behavior of an adaptive system transparent is to inform the user about changes of the system's behavior. Therefore, an extra dialog is used shown in Figure 6-16. This dialog will be shown after entering the vehicle, whenever the adaptive recommendation service has learned something new.

Before the adaptive recommendation service is going to be used by the driver, an introduction in form of a tutorial is shown, explaining the main features of the adaptive recommendation service before it can be experienced. This is important, since the adaptive recommendation service has a learning phase and is not directly perceptible. In addition, the driver might be less distracted if already prepared about what a recommendation will look like.

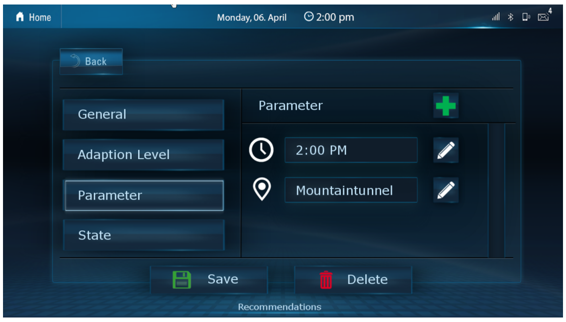
This prototype is used in a Wizard of Oz experiment, which is described in the next section. The functionality of the adaptive recommendation service is controlled by a person called the wizard. The prototype is a click-through prototype made with Balsamiq and can be controlled over a wireless presenter. Therefore, the wizard can change the screen to activate a recommendation and simulate the proactive behavior of the adaptive recommendation service. In order to achieve a smooth procedure, the screens of the prototype must be in the correct order according to a storyline that should be experienced within the experiment.



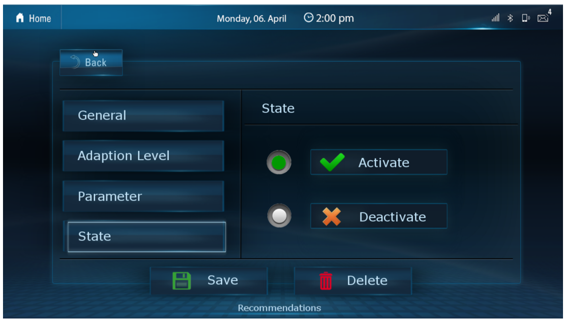
(a) Configuration of the recommendation according to application, function and configuration parameters.



(b) The presentation level is either Shortcut, Pop-up or Start Automatically.



(c) The section parameter includes all context parameters.



(d) The state represents whether a recommendation is activated or deactivated.

Figure 6-15.: The user has the option to display details of each recommendation the adaptive recommendation service has learned. In different views, the configuration of a recommendation, the presentation level, the context parameters, and the state of the recommendation are presented and can be changed by the user.

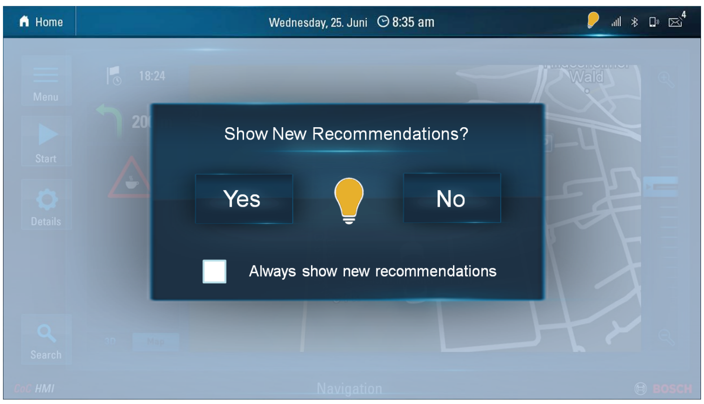


Figure 6-16.: A notification is shown to the user when the adaptive recommendation service has learned something new.

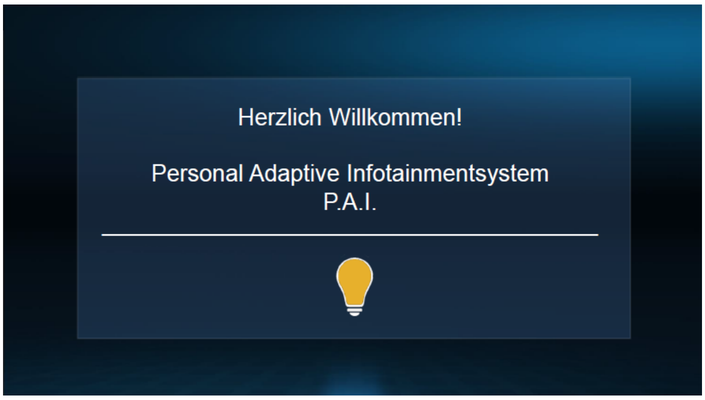


Figure 6-17.: The adaptive recommendation service is introduced by a tutorial to the user.

6.5.2 Wizard of Oz - Evaluation of Transparency and Usability

The next user study is a Wizard of Oz study with the focus on the requirements related to user experience; respectively usability and traceability. For a Wizard of Oz study, a more advanced prototype is needed than in the previous iterations. This prototype is controlled by a person, called the wizard, to simulate the functionality of a system. Within this study, the traceability of the recommendation service is evaluated in detail as well as the overall usability. In addition, the focus is on the method for evaluation. Prerequisite to get authentic feedback according to an adaptive system is experiencing the different phases of the system, as for example the learning phase or the phase of usage, as described in Section 3.4.2. On one hand the participants should use the adaptive system as freely as possible; on the other the experiment procedure needs to stay the same for all participants. This is difficult for a system that should adapt to individual preferences.

6.5.2.1 Preliminary considerations to the evaluation of adaptive systems

The adaptive recommendation service was developed with the intent to reduce driver distraction, which can be reached only if the driver uses it. Prerequisite for this to happen is a high usability. According to these goals, the adaptive recommendation service should be evaluated according to usability and driver distraction. In addition, weaknesses of the current concept should be revealed and possible solutions identified. This leads to the following challenges according to the evaluation. All the different aspects of an adaptive system need to be experienced by the participants, as for example adapting its behavior to individual preferences. Concurrently, the conditions and procedure need to be the same for all participants. Suitable methods to evaluate driver distraction and usability must be selected, which work together with the study procedure meeting the other requirements. The result is a study design with a high complexity due to many dependencies.
The main challenges for the study design are the prototype, experimental environment, a procedure that enables experiencing the adaptive system and methods to evaluate usability and driver distraction.
In the past, some studies with a similar goal were already conducted. One example is the study from Garzon (2013) whose main points according to the study design are described below. Garzon used a functional prototype based on the COMAND APS NTG4 from Mercedes-Benz. This functional prototype of the infotainment system was extended by an adaptive recommendation service, either presenting the recommendations in form of shortcuts or automatically executing the recommendations for the user. The functional prototype was presented on a PC monitor directly in front of the participants and could be controlled by a steering unit, which can usually be

found in the middle console of a car and a normal keyboard. A very simple driving simulator was used to provide an experimental environment consisting of a steering wheel, a PC monitor for presenting the driving simulation environment and pedals. The different support levels of the recommendation service were experienced by every participant of the study. The driver completed three rounds on a virtual copy of a recreated track in the driving simulation environment and had to change the frequency of the radio to a specific radio station. In each round the driver needed to solve the same task with another support level of the adaptive recommendation service, starting with a manual operation, then shortcuts and finally the automatic execution. In addition, the driver also experienced the error case of the recommendation service. This means that the recommendation service was trying to change the radio station once again in the third round, which had to be canceled by the participant. To evaluate usability, the questionnaire AttrakDiff was used and a specific questionnaire for adaptive systems. Driver distraction was evaluated with the questionnaire NASA-TLX and no additional driving behavior was considered. From this design of Garzon (2013) we were able derive best practices and lessons learned. A prototype with a high functionality to enable a broadly realistic experience needed to be kept. The realistic test track in the driving simulation environment supported this as well. Also definitely kept should be the experience of the error case complemented by the experiences of the learning phase. Both are important to get an overall picture of the adaptive recommendation service. Changing the radio station is a realistic task but not a task that happens too often and one which is very simple. The more complex or often a task occurs, the more beneficial is the adaptive recommendation service. Therefore, it is important that the participants could at least experience tasks with different difficulty levels.

For the assessment of driver distraction a subjective method, the NASA-TLX, was chosen by Garzon. But there are also a lot of objective methods available which are also standardized, as for example the Detection Response Task (ISO/DIS 17488, 2015). In this study an objective method is the preferred option.

In summary this means to have a functional prototype with a realistic range of functions. A driving simulator environment provides a safe environment and in addition enhances controllable and reproducible conditions. The learning phase and usage phase including the error case should both be included in the experimental procedure. An objective method to evaluate driver distraction compatible with the other requirements needs to be selected, and the focus of the usability evaluation needs to be on factors like traceability, controllability and obtrusiveness.

6.5.2.2 Experimental Design

Due to many dependencies and challenges, designing a driving simulator study to evaluate an adaptive system is quite complex. Therefore, developing a method to evaluate the recommendation service is done in two steps. The first step is the Wizard of Oz study, also conducted as a driving simulator study, which is described in the following, and the second step is the driving simulator study described in Section 8. Findings according to the study procedure from the first study will be incorporated in the second study. This approach provides the option to gain experience, reduce the complexity for each step and improve the method accordingly. The focus of the Wizard of Oz study is on the study procedure that enables the experience of the recommendation service. In addition, the current prototype should be evaluated according to its usability and especially traceability. The second point is followed up from the previous study, evaluating the explanation menu since the concept for the explanation menu has been reworked.

The two following hypotheses are evaluated within the Wizard of Oz study:

1. The user understands the behaviour of the adaptive recommendation service with help of the explanation menu.
2. The interaction concept of the adaptive recommendation service is resulting in a high usability and user experience.

The first hypothesis addresses the traceability and refers to the mental model a user develops when using a system. The mental model includes knowledge about possible user actions and understanding of the system's actions. When users have a complete mental model, they know at any time which actions can be taken and what the system does in this moment (Vollrath, 2015). According to Kulesza et al. (2013) the mental model of a user can be examined by requesting the essential information. In case of the recommendation service, the important facts a user should know are described through the requirements in Section 6.4.1. The user has a sufficient mental model if he/she can describe all relevant facts described in the requirements. If not, the explanation menu provides sufficient information and in a suitable form to build up such a mental model. A questionnaire is developed to ask for information the user should know about the adaptive recommendation service. The participants experience different recommendations during the experiment. For each recommendation they need to describe why the recommendation was given (How), in which context it was given (Input), the certainty of the system (Certainty), and whether there was the possibility to give this recommendation in different forms plus a description of these (Output). In the error case the participants were asked why they had not received a recommendation (What if - Part 1) and how the situation would have looked had they received one (What if - Part 2). In addition, they were asked how certain the system would have been about this recommendation (Certainty).
The second hypothesis addresses also (partially) the traceability but mainly the usability and user experience of the adaptive recommendation service. For these two points standardized questionnaires, the ISONorm and AttrakDiff, were used. Both questionnaires are described in Section 2.3.2. The ISONorm questionnaire refers to the dialogue principles described in ISO 9241-110 (2006). Due to the fact that the participants could not interact freely with the prototype of the adaptive recommendation service, the questionnaire was shortened. The principle "error tolerance" was not considered and therefore all corresponding questions were excluded.
The questionnaire addressing the mental model and a demographic questionnaire can be found in Appendix E.
For the Wizard of Oz study, the prototype as described in Section 6.5.1 was used. The prototype was run on a 10inch tablet PC mounted on a vehicle cockpit mock-up in the position of a central display. In addition, the cockpit mock-up included a cluster display displaying the current speed of the participant in the driving simulation. A gaming steering wheel and pedals were used to control the vehicle in the driving simulator environment; shown on a TV in front of the participant. Driving simulation software Silab[2] was used. The recommendation service was controlled via a wireless presenter by the Wizard. The participant used the infotainment system and recommendation service via touch.
On one hand the adaptive recommendation service should adapt to the individual behavior of each user; on the other, the procedure must be the same for all participants. Closing the gap between both sides, the user drove the same route multiple times and each time had the same three tasks. In this way repetitive behavior was simulated. The track within the driving simulation had three distinctive points; a parking lot, a tunnel and a traffic jam. The participant received the following scenario description as instruction. The scenario is shown in Figure 6-18.

[2] `https://wivw.de/en/silab`, last accessed on 09/09/2017

Use Case - Scenario description

"Before starting home (S1), you start the navigation to your home address (R1). You enjoy listening to music and start playing the song "I shot the Sheriff" (R2) when entering the tunnel (S2). Afterward, when reaching the traffic jam (S3) a person named John Black (R3) should be called from the contacts."

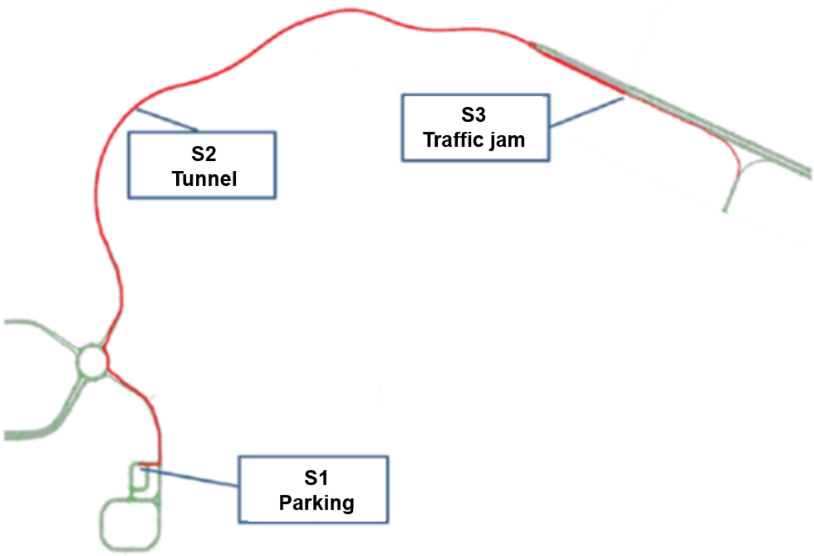


Figure 6-18.: The participants drive through a scenario starting on a parking lot, driving through a tunnel and reaching a traffic jam at the end of the route.

In Figure 6-19 the procedure using the Wizard of Oz study is shown. The study started with an introduction, the procedure and goal of the study were roughly outlined, and the participants filled out a short demographic questionnaire (e.g. age, driven kilometers per year, number of years owning a driver's license). Next, the participants got comfortable with the driving simulator before the infotainment system was explained to them. They were advised that the infotainment system was a very early prototype and its functionality, as for example the navigation, would be simulated via a static screen. Afterward, they would be able to explore the infotainment system on their own. The recommendation service was also introduced via a tutorial which they could go through at their own speed. Within this tutorial the functionality was explained, and the explanation menu and different support levels introduced. Next, two runs driving with the driving simulator and fulfilling the tasks of the scenario manually followed. It was explained to the participants that this was the learning phase of the recommendation service, which would memorize their operations according to the context as introduced in the tutorial. In the third run, they should use its support. Here, the adaptive recommendation service first notified the participants that it had learned new recommendations. The participants could then explore the explanation menu with the newly learned rules. Afterward, they were requested to drive through the scenario again, doing the same tasks but with the support of the adaptive recommendation service. The scenario was a bit different this time as there was no traffic jam at the end. Therefore, from the system's perspective the context was different and no recommendation was given for the last task, although the driver would want to do the same operation again. This simulated the error case. The participants were asked to stop and fill out a questionnaire directly after each given recommendation and at the end of the track to analyze their mental model. The questions and expected answers are shown in Table 6-2. At the end of the experiment, the participants filled out the questionnaires AttrakDiff and ISONorm.

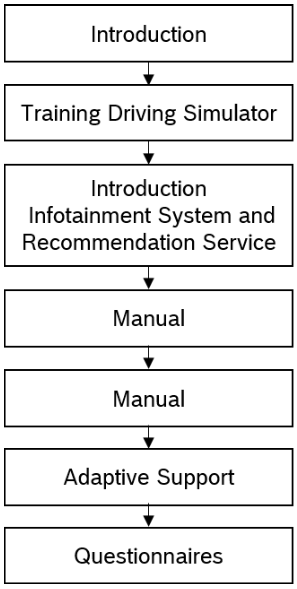


Figure 6-19.: Study Procedure of the Wizard of Oz Study, evaluating the adaptive recommendation service in a driving simulator environment. The step indicated with "Manual" describes manual operation of the infotainment system in comparison to the adaptive support.

Table 6-2.: Questions according to the mental model of the user and the corresponding expected answer.

Requirement	Question	Answer
How	Explain why the infotainment system has given this recommendation.	Individual recurrent usage behaviour the system has learned
Input	Describe the situation in which you have received a recommendation.	S1: Parking, 2:00pm S2: Tunnel, 2:00pm
Certainty	What is the degree of certainty of the system for this recommendation?	100%
Output	Is it possible to show the given recommendation in a different form?	Shortcut, Pop-up, Start Automatically
What if	Why have you not received a recommendation? Describe the situation in which you would have received a recommendation.	There was no traffic jam. S3: Traffic jam, 2:15pm

6.5.2.3 Results

Twenty participants (N = 20; 17 male, 3 female) took part in the Wizard of Oz study. The participants were aged between 22 and 63 (M = 31.25 years, SD = 9.4 years). Prerequisite for participating was to hold a driver's license, which they held on average for 13.8 years. Fourteen participants owned their own vehicle. Eleven of the participants estimated their technical affinity on a scale from 1 (not technical oriented) to 5 (highly technical oriented) with 5; five participants with 4, and four with 3. Seven of the participants experienced the recommendations of the recommendation service in form of shortcuts (Level: US), six in the form of pop-ups (Level: UA) and seven as automatic executions (Level: FA). The data of one person needed to be excluded

due to driving simulator sickness, reducing the number of participants experiencing the level FA to six.
Based on the data gathered, the results according to traceability and respectively the mental model of the participants were analyzed. After presenting a recommendation to the participants, they stopped at the side of the road and were asked questions about their current mental model. The answers were analyzed. Table 6-3 contains the number of correct, partially correct and wrong answers according to the first and second recommendation. Table 6-3 includes the same information for the error case.

Table 6-3.: Number of correct (c), partially correct (p) and wrong (w) answers according to the behavior of the adaptive recommendation service within the Wizard of Oz study for Recommendation 1 (Navi) and Recommendation 2 (Media) (N = 20).

Recommendation	How			Input			Certainty			Output		
	c	p	w	c	p	w	c	p	w	c	p	w
Recommendation R1	19	0	0	18	1	0	11	0	8	16	2	1
Recommendation R2	19	0	0	13	6	0	12	0	7	16	2	1

Table 6-4.: Number of correct (c), partially correct (p) and wrong (w) answers according to the behavior of the adaptive recommendation service within the Wizard of Oz study for Recommendation 3 (Call) (N = 20)

Recommendation	What if - Part 1			What if - Part 2			Certainty		
	c	p	w	c	p	w	c	p	w
Recommendation R3	19	0	0	14	5	0	12	0	7

In the following, the results regarding traceability are described in more detail. The answers of the participants are summarized and analyzed according to the corresponding questions respectively requirements listed in Table 6-2. The results are referred to the mental model of the participants.

- **How**: All of the participants answered that the recommendation service gives recommendations according to learned and identified user needs based on observed usage behavior. Therefore, the mental model for this requirement is correct for all participants.
- **Input**: This answer is answered correctly or partially correctly by most of the participants. They mentioned the position and time to describe the context in which a recommendation has been triggered. Some answered it only partially correctly because they forgot either time or position.
- **Certainty**: According to the certainty, many participants had a gap in their mental model and could not answer this question at all and not even partially. Here, the concept of the recommendation service needs to be improved.
- **Output**: All participants except of one person answered this question correctly or partially correctly. They could name one or both alternative output options.

- **What if**: It was recognized by all participants that no recommendation was given because of the missing traffic jam. But only 12 of them mentioned the time when they were asked to describe how the context needed to be for a recommendation to be triggered.
  Some parameters seemed to be recognized more than others even though the participants had explored all parameters before in the explanation menu.

In summary, the participants understood the actions of the adaptive recommendation service. The mental models of the participants which were evaluated, were in 4 of 5 cases correct or partially correct. Therefore, the first hypothesis can be confirmed in general but with some restrictions. Two points stood out negatively: The listed context parameters for each recommendation were only partially perceived by the participants. In the scenarios, the context was described through position and time but the time was not recognized. A reason could be that the sense of time in the driving simulator differs from the reality. The second point is the presentation of the certainty. Some participants could not remember that this information had been presented at all. A reason for this could be that this information was not seen as important for them because it is a very artificial value. In other words it doesn't makes sense if the recommendation service is not trained in reality. The participants had in general a good understanding of the system behavior. It can be concluded, that the explanation menu supports the transparency of the adaptive recommendation service and therefore the traceability of the system understanding, but needs to be further improved.

The second hypothesis evaluated in the Wizard of Oz study is related to the usability and user experience of the prototype. These were analyzed with help of the ISONorm and AttrakDiff questionnaire. First, the results of the ISONorm questionnaire are analyzed. This questionnaire refers to the dialogue principles described in ISO 9241-110 (2006). For each dialogue principle five statements were rated on a 7-point Likert scale. In order to make a conclusion about the usability, the ratings of the principles were compared with values collected and analyzed by Prümper (1997). Prümper has summarized the results of 41 studies where the ISONorm questionnaire has been used to provide comparison values for future studies. The values for each principle can be found in Table 6-5. The mean value for the ISONorm overall value is 4.64. With help of these values, it can be determined how a system is rated in comparison to other systems.

Table 6-5.: Mean values of the rated principles based on 41 studies, where the ISONorm has been used to rate applications collected and analyzed by Prümper (1997).

Principle	Mean	Min	Max	SD
Suitability of the task	4.87	2.60	5.76	.70
Self descriptiveness	4.55	2.50	5.7	.65
Controllability	5.01	3.20	6.13	.75
Conformity with user expectations	4.94	2.97	6.09	.72
Error tolerance	4.29	2.59	5.75	.79
Suitability for individualization	4.28	2.41	5.92	.92
Suitability for learning	4.52	2.56	5.83	.70

The mean values of the rating for each principle within the Wizard of Oz study can be found in Figure 6-20. The overall ISONorm mean value is 5.8 and is therefore 1.16 higher than the value determined by Prümper. The same applies to the single ratings of each principle. The usability of the infotainment system and adaptive recommendation service is rated above average in comparison to the ratings collected by Prümper. A reason for this could be the high technical orientation of the participants. It is possible that the operation of the infotainment system and adaptive recommendation service is more intuitive for highly technical oriented people than for others. In order to make this conclusion in general, the Wizard of Oz study must be repeated with more participants with a greater distribution according to the level of technical orientation. For the participants who took part, it could be said that the usability of the infotainment system and adaptive recommendation service was already acceptable. The second hypothesis was confirmed for the participants of this study according to the results collected with the ISONorm questionnaire.

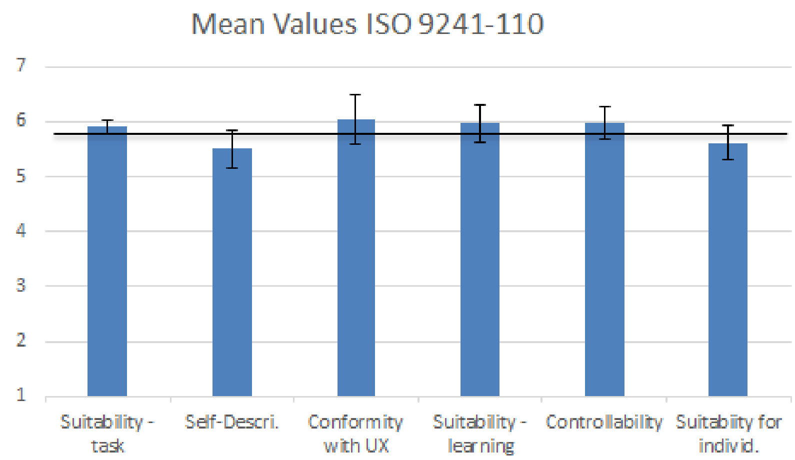


Figure 6-20.: Result of the ISONorm questionnaire analysis in the Wizard of Oz experiment to evaluate the usability of the infotainment system and adaptive recommendation service according to the dialogue principles of the ISO 9241-110 (2006) for N = 20 participants.

In addition to the ISONorm questionnaire the AttrakDiff questionnaire is used to analyze the usability and user experience of the adaptive recommendation service. The general mean values of the AttrakDiff for pragmatic quality, hedonic quality - stimulation (S), hedonic quality - identification (I), and attraction are within a range between -1.0 and 1.0 according to Hassenzahl et al. (2003). Values under -1.0 are below average and values above 1.0 are above average. The mean values of the ratings in the Wizard of Oz study show that the infotainment system and adaptive recommendation service were rated above average. The high rating of the hedonic quality means that the participants could identify themselves with the application and see the possibility to develop themselves with it. In addition, the participants had the feeling that they could reach their goals with the system, which can be seen by the high rating of the pragmatic quality. Also the attraction was rated positively above average. Therefore, the second hypothesis was also confirmed according to the results collected with the AttrakDiff questionnaire.

The evaluation of the adaptive recommendation service within a Wizard of Oz study was successful. New findings were made according to the current concept and the design of a study to evaluate an adaptive system. The results and their impact for the next steps will be discussed in detail in the next section. The detailed results of each questionnaire can be found in Appendix E.

6.5.2.4 Discussion

The Wizard of Oz study was the first step towards developing a method for the evaluation of the adaptive recommendation service in a driving simulator environment. The main points for the study design are the prototype, experimental environment, procedure that enables experiencing

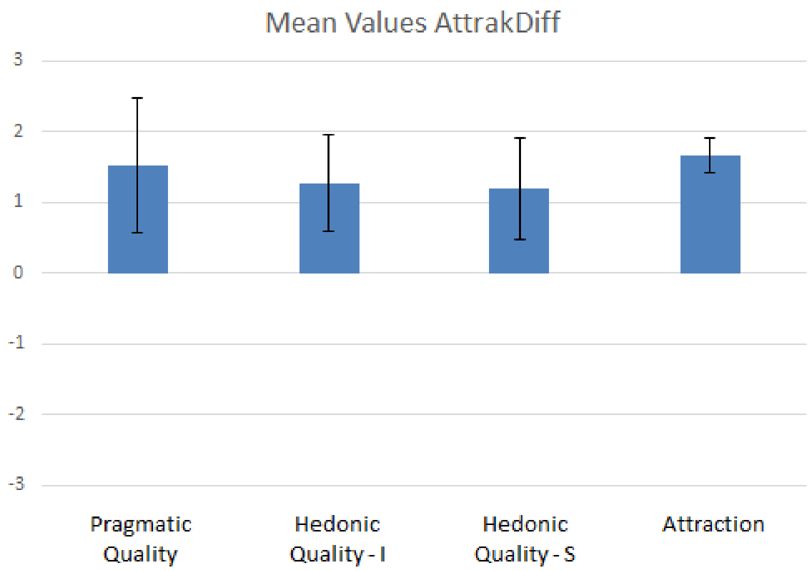


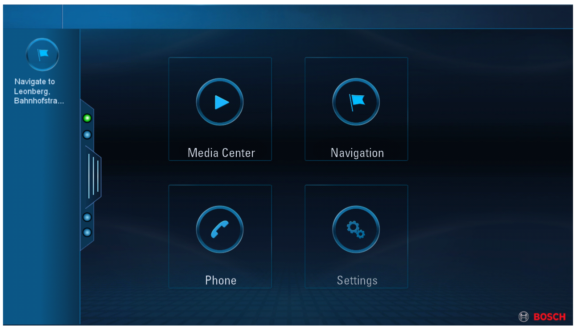
Figure 6-21.: Result of the AttrakDiff questionnaire analysis from the Wizard of Oz study showing the mean values of the pragmatic quality, hedonic quality - stimulation (S), hedonic quality - identification (I), and attraction (N = 20).

the adaptive system and methods to evaluate usability and driver distraction. Starting with the prototype, it enabled the participants to understand the concept of the adaptive recommendation service and was made without much effort. However, it was difficult to operate it by the Wizard and due to low functionality, many functions were substituted by a static screen, which can be improved. A prototype with more functionality, that does not need to be controlled by a Wizard, would be more realistic. The driving simulator provides a safe environment and in addition enhances controllable and reproducible conditions. It supported the experience of the adaptive recommendation service in an environment closer to reality than just describing it, as had been done in previous studies. The user story enabled experiencing the behavior of the adaptive recommendation service. Both, learning phase and usage phase were integrated in the user story as well as the error case. However, the error case does not comply with the worst case. In the worst case the user needs to cancel the action of the adaptive recommendation service and use the infotainment system afterwards manually for the intended task. This means that the user has more operation steps than without the recommendation service. This worst case scenario should be included in a future study design. Besides the error case, it was also not beneficial to interrupt the procedure several times. After a recommendation was given to the participants, they had to fill out a short questionnaire. This disturbed the overall impression. Other than for the traceability, standardized questionnaires were used to rate the usability and how appealing the infotainment system and adaptive recommendation service were to the user. The results of the AttrakDiff questionnaire were not very informative to improve the concept in this stage of development. In addition, these questionnaires do not cover usability challenges of adaptive systems in sufficient detail. The infotainment system can be rated with these questionnaires, but for the adaptive recommendation service an additional questionnaire is needed. The results according to the traceability show that the explanation menu is very beneficial for the system understanding of the user. Some points need to be improved and should be taken up in one of the next iterations within the user-centered design process. For the next step, the effect of the adaptive recommendation service on driver distraction should also be evaluated. An objective method to evaluate driver distraction, which is compatible with the other requirements and fits into the study procedure, needs to be selected. These findings are taken up in the next sections.

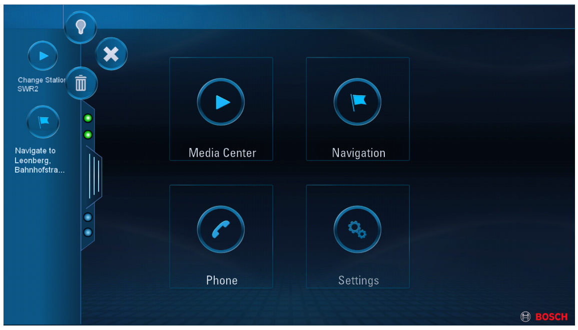
Section 6.6 describes the reworked overall concept of the adaptive recommendation service, which is the basis for the described high-fidelity prototype in Chapter 7. This prototype is part of the next iteration, where the evaluation part is described in Chapter 8. This is the second step towards developing a method evaluating the recommendation service in a driving simulator environment.

6.6 User Interface for an Adaptive Recommendation Service

After four iterations of the user-centered design process an interim result is available, and a concept for the adaptive recommendation service has been developed and evaluated from different perspectives based on the defined requirements in Section 6.3.1.2. The various elements of the interaction concept are described in the following:
The starting point was the three different levels to present a recommendation with increasing level of automation. In the first level, User Selection, the user gets a choice of options via shortcuts (see Figure 6-22(a)). Figure 6-23(a) shows the second level, User Approval, where the user gets a recommendation with one option and is asked for approval to execute it via a pop up message. In the last level, Fully Adaptive, the preconfigured function is executed automatically and the user has the option to cancel it via a button at the top of the screen, as shown in Figure 6-24.



(a) Recommendations are presented as shortcuts in a menu on the left side of the screen, which can be minimized. Four dots indicate the number of active recommendations.

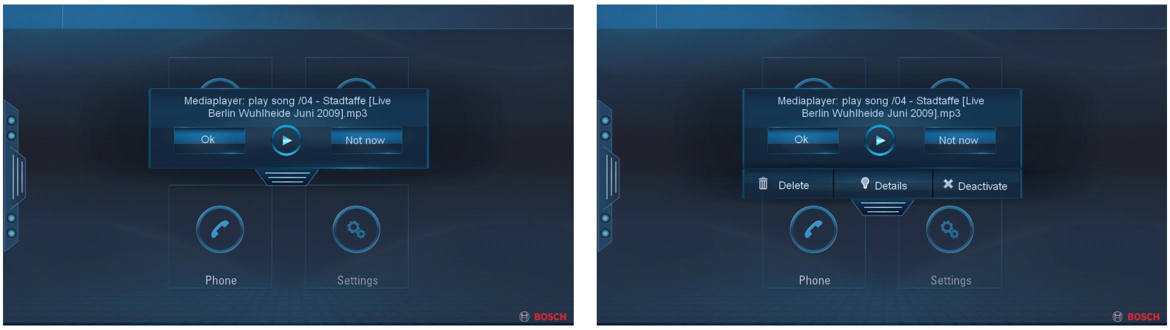


(b) Extra menu opens with a long button press. A click on the button with the symbol of a bulb opens the detail view of the explanation menu, the button with the cross deactivates the recommendation and the button with the bin deletes the recommendation.

Figure 6-22.: A list of shortcuts representing recommendations of preconfigured functions is provided to the user (User Selection (US)) with an option to quickly access details of a recommendation, deactivate the recommendation or delete it by a long button press on the shortcut.

In addition, the interaction concept includes further elements addressing the ability to control or understand the behavior of the adaptive recommendation service:

- Tutorial: The user gets an introduction about the functionality of the adaptive recommendation service before using it for the first time. The first screen of the tutorial is presented in Figure 6-25 and the whole tutorial can be found in Appendix F.
- Notification of new recommendations: If the adaptive recommendation service has learned new potential recommendations, the driver receives a notification over a pop-up message when he enters the car again (see Figure 6-26).
- Explanation menu: The explanation menu shows all potential recommendations the adaptive recommendation service has learned. They are categorized according to the application they refer to. The explanation menu is shown in Figure 6-27.



(a) Pop up showing the recommendation the user can accept or reject.

(b) In addition, buttons are available to delete or deactivate the recommendation or to switch to details in the explanation menu. This extra menu can be minimized and maximized by a little indicator at the bottom of the screen.

Figure 6-23.: Recommendations are given in form of a pop up messages, which need to be accepted or rejected by the user (User Approval (UA)). The user can open an extra menu by an indicator at the bottom of the pop up message, to delete a recommendation, quickly access details of a recommendation or deactivate it.

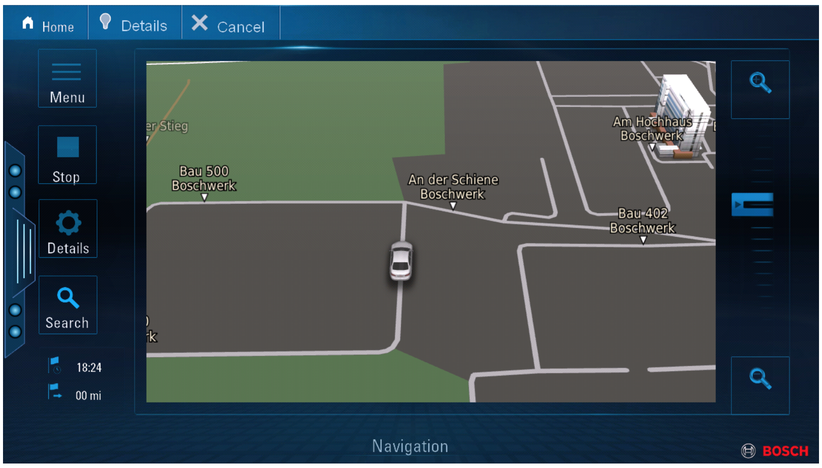


Figure 6-24.: In the level Fully Adaptive (FA), the preconfigured functions are executed automatically. In addition, buttons are shown to quickly access the details of the recommendation or cancel it.

- Parameter and State: The user can change the different parameters of a recommendation within the explanation menu, the configuration of the recommendation according to application, function and parameters of the function, the presentation form equivalent to the adaptation level, context parameters, and the state of the recommendation (see Figure 6-28). In addition, the user has the option to delete the recommendation completely by a delete button and the bottom of the screen.

- Quick access to functions of the explanation menu: For each given recommendation the details of the recommendation can be accessed directly when the recommendation is displayed to the user (see Figure 6-22(b), Figure 6-23(b) and Figure 6-24). In addition, at levels US and UA, the user has the option to directly deactivate or delete the recommendation. In Figure 6-22(b) the menu can be seen, which appears with a long button press on the shortcut. A click on the button with the symbol of a bulb opens the detail view of the explanation menu, the button with the cross deactivates the recommendation and the button with the bin deletes the recommendation. In level UA, the user can open an extra menu by an indicator at the bottom of the pop up message, as shown in Figure 6-23(b).

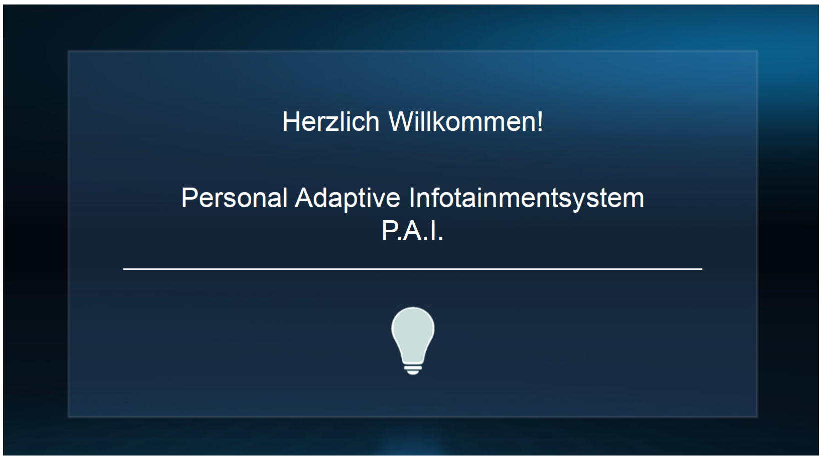


Figure 6-25.: Before using the adaptive recommendation service, the user gets an introduction in form of a tutorial. This is the first screen of the tutorial.

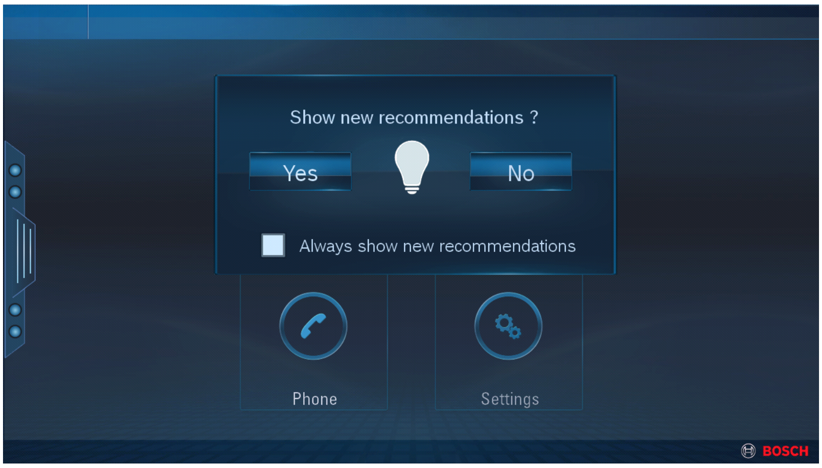


Figure 6-26.: This pop-up message is shown as notification when the adaptive recommendation service has learned new potential recommendations. It is shown when the driver re-enters the car.

Figure 6-27.: The explanation menu shows all learned rules of the adaptive recommendation service categorized according to the corresponding applications.

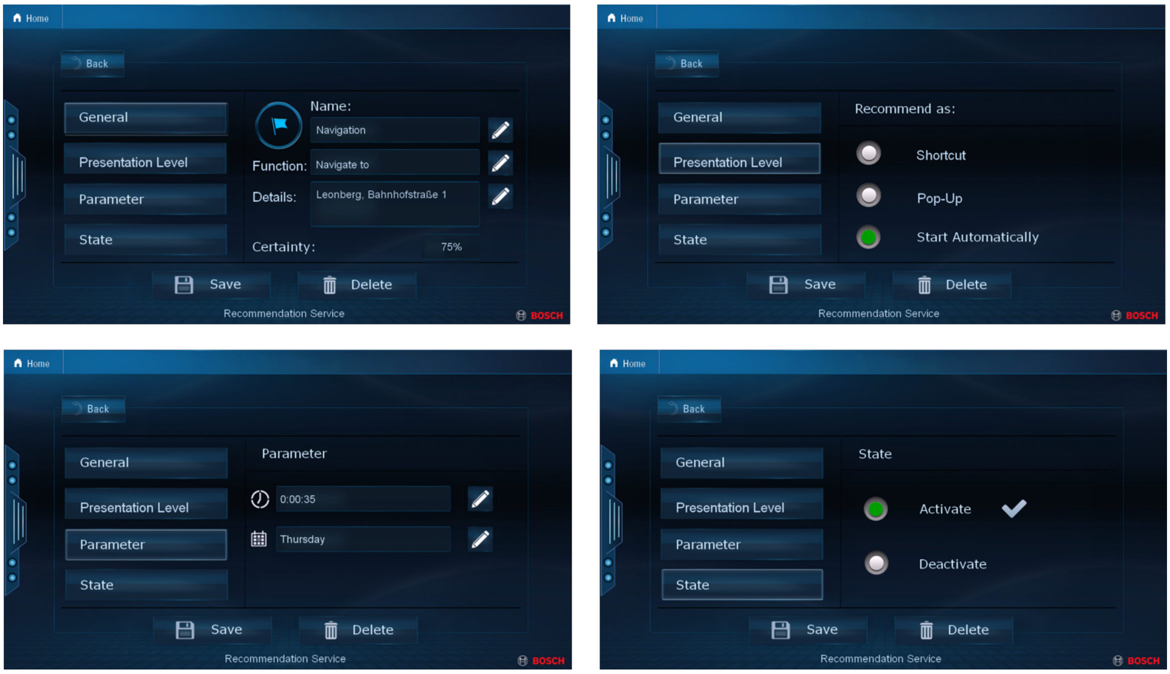


Figure 6-28.: The user has the possibility to change the values of certain parameters of the adaptive recommendation service, the configuration of the recommendation according to application, function and parameters of the function, the presentation form equivalent to the adaptation level, context parameters, and the state of the recommendation. It is also possible to delete the recommendation with the button at the bottom of the screen.

6.7 Conclusion of the User-centered Design Process

To sum up after four iterations of the user-centered design process, described in Section 6.1, it was very beneficial to develop an interaction concept for the adaptive recommendation service as well as methods for the evaluation in multiple steps. There exist many challenges according to the methods used to develop such an adaptive recommendation service as well as for the adaptive interaction concept itself. Therefore, a high complexity needs to be handled during development. The complexity was reduced by concentrating on different aspects and requirements in each iteration.

Incorporating the user from the beginning helped to understand their needs at a very early stage and to develop a suitable interaction concept in this not yet widely researched field. The applied methods for evaluation, supported by suitable prototypes, resulted in important findings.

The order in which the interaction concept was developed can be recommended for future developments. It was beneficial to start with the main interaction element between user and system, the recommendation itself and extent the interaction concept to satisfy further requirements. The order of the user studies was chosen based on the stage of development of the prototype and the suitability for the goal of the study. At the beginning, user and expert interviews with open questions were conducted to open up a dialogue and not limit the participants in their feedback. With further progress in development, the user studies became more focused on certain aspects such as traceability or usability. Standardized methods were used which delivered comparable results but were limited to specific issues; however, overall the order of the different studies can also be recommended for future approaches.

One important fact to evaluate an adaptive system is the experience of the system by the user. This has been addressed, especially in the Wizard of Oz study (see Section 6.5.2), but needs to be taken up in following evaluations such as the one described in Chapter 8. Experiencing the adaptive recommendation service is a precondition to get authentic feedback from potential users. In addition, a prototype supporting this is needed. A prototype with a high functionality is very beneficial for the experience of the user but at the same time a lot of effort is needed to develop it. Within the described user-centered design process different prototypes have been developed and applied, which is an efficient approach to balance the trade-off between costs and benefits. The next step towards a higher functionality will be made for the next prototype, described in Chapter 7.

7 High-fidelity Prototype

Within the user-centered design process and especially the Wizard of Oz study (see Section 6.5.2), it has been shown that the possibility of the user to experience the adaptive recommendation service is beneficial to get authentic feedback. Therefore, a certain degree of functionality needs to be available. The objectives of developing a high-fidelity prototype of the adaptive recommendation service, as the one described in this section, are on one hand to enable the user to use the adaptive recommendation service and experience the interaction concept described in Section 6.6 as realistic as possible, and on the other to provide a proof of concept for the reference architecture described in Chapter 5.2.
The high-fidelity prototype includes two different interaction concepts, between which can be switched easily, to compare the state-of-the-art with the further developed interaction concept described in Section 6.6. The prototype is used in an evaluation conducted in a driving simulator environment, described in Chapter 8. As a starting point for the implementation the pre-development platform of the division Car Multimedia at Bosch is used, which is based on hardware and software used for series products. Therefore, it can be shown that the approach of the adaptive recommendation service is also feasible for technological requirements of the market even though more work has to be done.

7.1 Framework

The adaptive recommendation service is implemented on the pre-development platform of the division Car Multimedia at Bosch. This pre-development platform is used to implement features directly on target hardware and software, enabling a fast transfer into series development.
The platform is modular and includes different target hardware and displays. The setup used for the high-fidelity prototype includes an infotainment system running on the target hardware, a 10-inch touch display and a cluster running on the target hardware, and a 12.3-inch display without touch.
The adaptive recommendation service is integrated into the infotainment system as an application. The architecture of the infotainment system is similar to the one described in Section 3.2.2. Three layers are required; operating system, middleware layer and HMI layer. Each application consists of an HMI logic located in the HMI layer and an application logic located in the middleware layer. In the architecture of the pre-development platform there is no extra application layer; this layer is combined with the middleware layer. The adaptive recommendation service will be structured in the same way.
The infotainment system of the pre-development platform includes a media application consisting of a tuner and a media player that can play songs from different sources; for example USB. In addition, a phone application and navigation application, as well as a settings application, are running on the platform. The user interfaces and interaction steps needed to operate each of the applications are described in Section 7.2.1 (Robert Bosch GmbH - Car Multimedia - Center of Competence for HMI, 2013).

7.2 Interaction Concept

The infotainment system of the pre-development platform includes an application for home screen, media, navigation, phone, and settings. In the user study, described in Chapter 8, the media application and navigation application are used to solve secondary tasks during the evaluation. The interaction steps to start a navigation, play a song or change the radio station are described in Section 7.2.1.
The adaptive recommendation service is integrated as an additional application, which can be enabled or disabled. Furthermore, it can be switched between two different interaction concepts for the adaptive recommendation service over the settings application. This is described in Section 7.2.2.

7.2.1 Infotainment System

The infotainment system provides applications for navigation, media player, and radio. For all those applications and their functions, recommendations can be given. In the following the interaction steps, which are needed to start the navigation, choose a song, or change the radio station are shown. This is part of the HMI logic of the applications.
Using the navigation application to start a route guide involves many operation steps, as shown in Figure 7-1. First, the navigation application is selected on the home screen of the infotainment system. In the main screen of the navigation application, the menu button on the left needs to be selected to get to the next screen, where the type of input is selected. If the user wants to enter an address directly, "destination input" needs to be chosen. Afterward, the address needs to be entered. An address consists of country, which is preselected, city, road, and house number. For each of them the user selects the text field whereby a keyboard appears on the right side of the screen. Entering the first letters is enough; with the enter key a list of choices appears, and the user can scroll and select the intended entry. After entering all details of the address, the user can start the route guidance by clicking on the button "start guidance" at the bottom. The screen changes to the main screen of the navigation application and shows the route guidance to the entered address.
To play a song from the song list, the user selects the media application on the home screen, which includes the radio as well as the media player application (see Figure 7-2). Depending on which of the two applications is in the foreground, the user can start directly choosing a song or change the application by using the source button on the upper right corner. If the source is set to USB, the media player application is in foreground and the user can select a song from the list over the button "Songs". The user navigates the list using the arrow buttons on both sides of the screen. By clicking on the wanted song, the main screen of the media player application appears and the song is played.
As already mentioned, it is also possible to listen to a radio station over the media application, as shown in Figure 7-3. Here, the source needs to be changed to radio, and the user can choose the station by clicking on the arrow buttons on the left and right side of the screen, or use the preselect buttons on the bottom of the screen, where preferred stations are stored.

7.2.2 Recommendation Service

The adaptive recommendation service is implemented as an additional application for the infotainment system. The infotainment system includes a menu, which is called playground, to activate or deactivate certain applications. Over the Home screen the Settings application can be chosen. The menu entry "Profile Settings" is then selected to get to a view where the playground can be entered, as shown in Figure 7-4. The infotainment system is extended by two

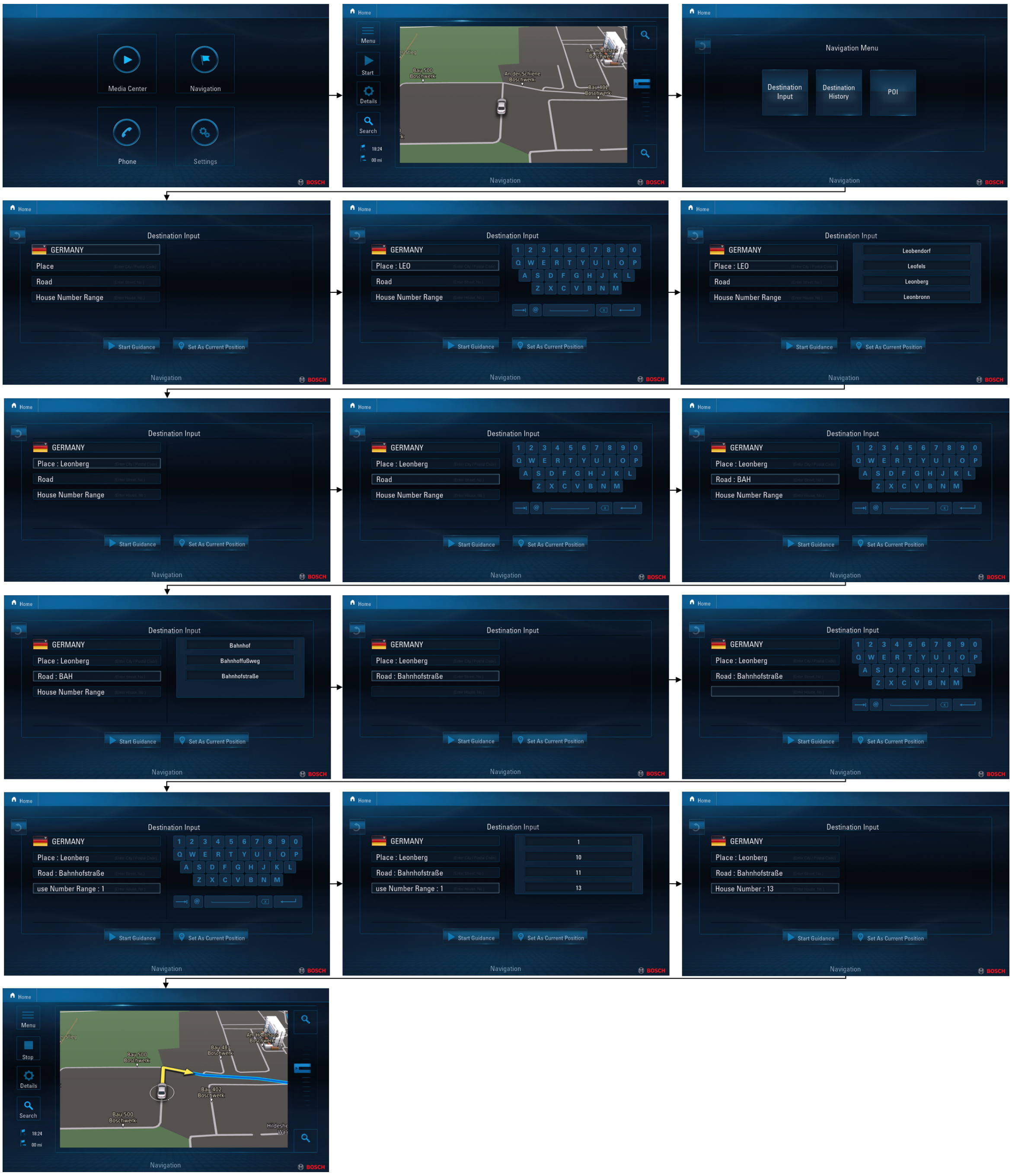


Figure 7-1.: The necessary interaction steps are shown to start the navigation, enter an address and start route guidance.

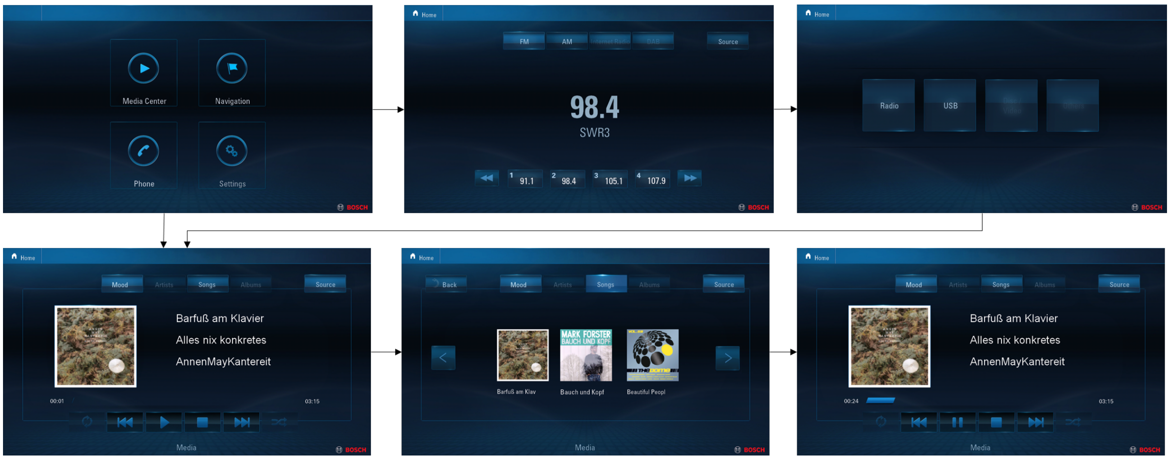


Figure 7-2.: To choose a song and start playing it different interaction steps need to be executed.

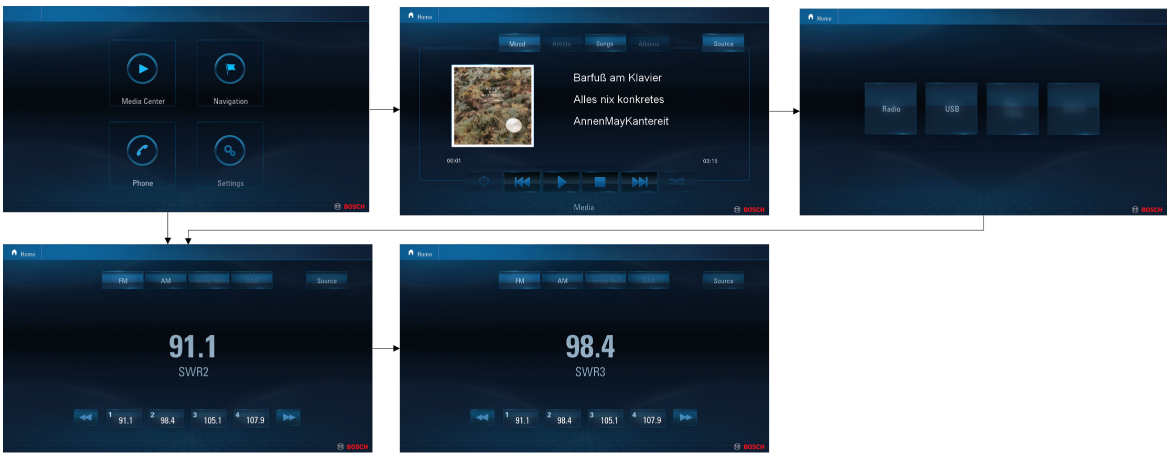


Figure 7-3.: The interaction steps to change the radio station within the infotainment system of the pre-development platform.

different variants of the adaptive recommendation service, called variant A and variant B, which can be activated over the playground menu.

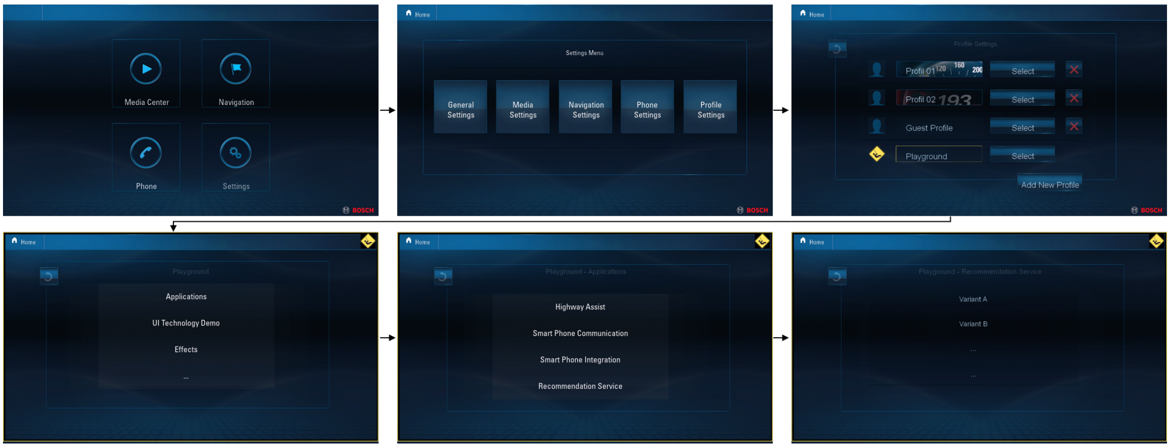


Figure 7-4.: The infotainment system includes a playground section where applications can be additionally activated, as for example the adaptive recommendation service in both variant A or variant B.

Variant A represents the basis variant of an adaptive recommendation service. Comparable variants have been evaluated by Lavie (2007) and Garzon (2013), whose recommendations are given in the already described three different levels, US (see Figure 7-5), UA (see Figure 7-6) and FA (see Figure 7-7).

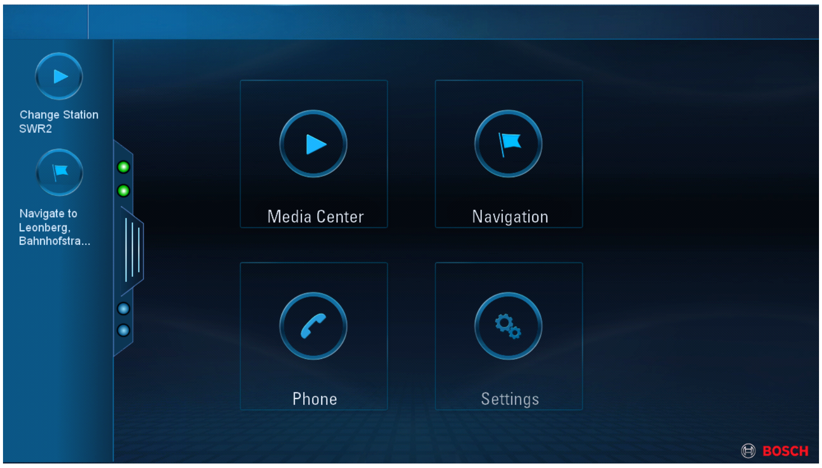


Figure 7-5.: Variant A - A list of shortcuts representing recommendations of preconfigured functions is provided to the user (User Selection).

Variant A represents the basic variant of an adaptive recommendation service. It comes without the additional measures addressing controllability, traceability, and obtrusiveness, and consists only of the mentioned possibilities to give recommendations. The second variant of the adaptive recommendation service, variant B is based on variant A but extended by additional measures to improve usability. Its interaction concept and included user interfaces are described in Section 6.6. The flow charts of variant A and variant B can be found in Appendix G.

7.2.3 Analysis of Interaction Steps

The adaptive recommendation service has the goal to reduce the number of operation steps needed to accomplish a task in comparison to the manual usage of the infotainment system. This can already be evaluated theoretically without a user study. A keystroke level model is used

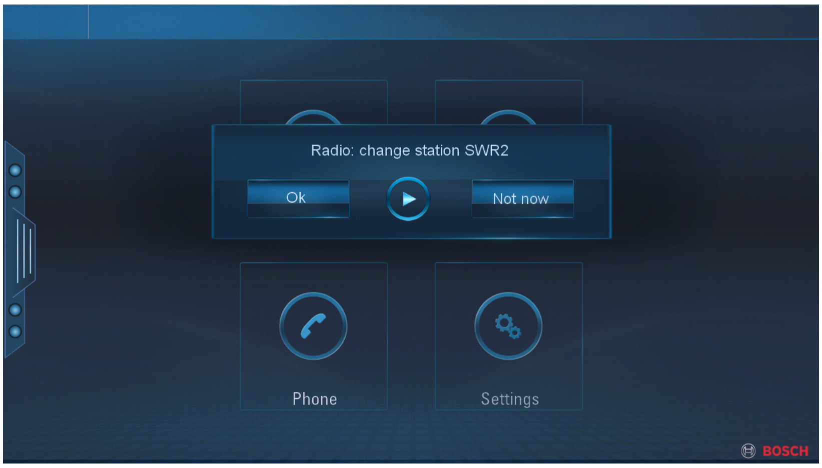


Figure 7-6.: Variant A - Recommendations are given in form of pop up messages, which need to be accepted or rejected by the user (User Approval).

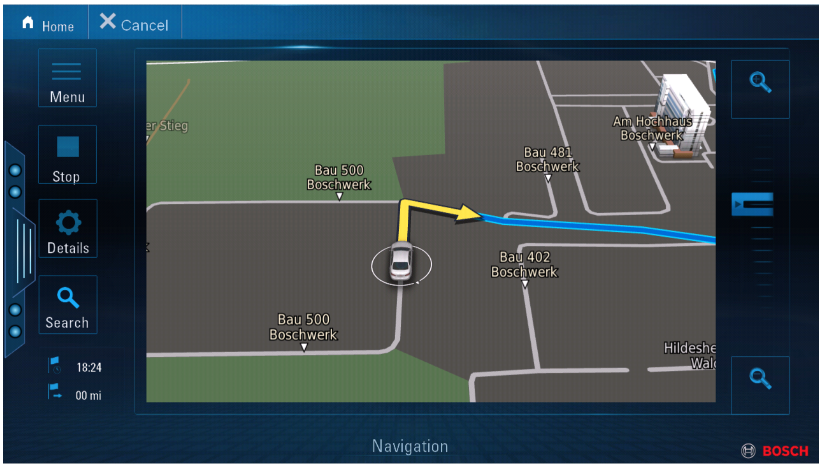


Figure 7-7.: Variant A - In the level Fully Adaptive, the preconfigured functions are executed automatically.

to analyze the reduction and additional effort in an error case for the high-fidelity prototype.

A keystroke level model as introduced by Card et al. (1980) is used to split an operation in single operators in order to estimate the time needed to accomplish a task by an expert. This method has been developed for the analysis of desktop applications but is not sufficient for applications on mobile devices or devices with touch screens such as the infotainment system of the high-fidelity prototype. Rice and Lartigue (2014) have evolved the keystroke level model for touch screens and mobile devices. The adapted model is called Touch-Level Model and is used in the following to analyze the interaction to start the navigation to a destination, choose a song from a list, and select a radio station. These are the tasks described in Section 7.2.1 for the manual usage. The interaction steps needed to accomplish a task with the three different support levels of the recommendation service are compared with the manual usage. It must not be distinguished between variant A and variant B of the recommendation service since both are equal regarding the interaction steps when accomplishing a task. Rice and Lartigue (2014) describe different operators that can be used to split an operation. The subset used to analyze the operation steps when using the high-fidelity prototype are described in Table 7-1.

Table 7-1.: Operators of the Touch-Level Model according to Rice and Lartigue (2014)

Operators	Description
Keystroke/Button Press (K)	A button press on a purely virtual keyboard.
Homing (H)	The act of positioning fingers or the hand over various parts of the interface in preparation for touch screen operations.
Mental Act (M)	The mental preparation needed to perform another action.
Response Time (R(t))	The time spent waiting on the interface of the system to respond.
Distraction (X)	A multiplicative operator that adds time to other operators. It models the distractions that naturally take place in real-world usage of a mobile device.
Tap (T)	Tapping some area of the screen to effect a change or initiate an action.
Swipe (S)	A 1+ finger gesture in which a finger or fingers are placed on the screen and subsequently moved in a single direction for a specified amount of time.

First, the described operators are used to analyze the operation steps to accomplish the tasks described in Section 7.2.1 with the infotainment system without the adaptive recommendation service. The analysis is shown in Table 7-2. The following tables, Table 7-3, Table 7-4, and Table 7-5, contain the analysis of the same tasks but executed with the adaptive recommendation service in one of each support level.

Comparing the summary of operators, number and type needed for the manual usage and the adaptive recommendation service, it can be seen that many operators are not needed while using the adaptive recommendation service. This shows already that the number of operation steps is reduced through the adaptive recommendation service. With the TLM a total time needed to accomplish a task can be calculated but here the total number is not needed for the comparison.

Table 7-2.: Manual: The Touch-Level Model is used for an analysis of the interaction steps needed to accomplish tasks with the infotainment system without the recommendation service.

Task	Operators	Description
Navigation	1. H + T + R(t) + M	Select "Navigation"
	2. H + T + R(t) + M	Select "Menu"
	3. H + T + R(t) + M	"Destination Input"
	4. H + T + R(t) + M	Select "Place"
	5. H + 4*K + R(t) + M	Enter first three letters of city and press enter
	6. H + x*(S + R(t)) + T + R(t) + M	Select city in a list, scroll x times
	7. H + T + R(t) + M	Select "Road"
	8. H + 4*K + R(t) + M	Enter first three letters of road and press enter
	9. H + T + R(t) + M	Select "House number"
	10. H + (z+1)*K + R(t) + M	Enter house number with z numbers and press enter
	11. H + y*(S + R(t)) + T + R(t) + M	Select house number in a list, scroll y times
	12. H + T + R(t)	Select "Start Guidance"
	12*H + 9*T + (z+9)*K + (x+y)*S + (12+x+y)*R(t) + 11*M	Summary
Media	1. H + T + R(t) + M	Select "Media"
	2. H + T + R(t) + M	Select "Source"(optional)
	3. H + T + R(t) + M	Select "USB"(optional)
	4. H + T + R(t) + M	Select "Songs"
	5. H + x*(T + R(t)) + M	Scroll through list x times
	6. H + T + R(t)	Select song
	6*H + (x+5)*T + (x+5)*R(t) + 5*M	Summary
Radio	1. H + T + R(t) + M	Select "Media"
	2. H + T + R(t) + M	Select "Source"(optional)
	3. H + T + R(t) + M	Select "Radio"(optional)
	4. H + T + R(t)	Select preselect button
	4*H + 4*T + 4*R(t) + 3*M	Summary

Table 7-3.: User Selection: The Touch-Level Model is used for an analysis of the interaction steps needed to accomplish tasks with the infotainment system with the recommendation service. The recommendations are given as shortcuts in the support level "User Selection" for the case of success (recommendation meets user need) and error case.

Task	Operators	Description
Navigation	1. H + T + R(t) + M	Open shortcut bar
	2. H + T + R(t)	Select shortcut
	2*H + 2*T + 2*R(t) + M	Summary
Media	1. H + T + R(t) + M	Open shortcut bar
	2. H + T + R(t)	Select shortcut
	2*H + 2*T + 2*R(t) + M	Summary
Radio	1. H + T + R(t) + M	Open shortcut bar
	2. H + T + R(t)	Select shortcut
	2*H + 2*T + 2*R(t) + M	Summary
Error Case	1. H + T + R(t) + M	Open shortcut bar
	2.-x. see Manual	Manual operation of the task
	H + T + R(t) + M + operation steps of manual operation	Summary

Table 7-4.: User Approval: The Touch-Level Model is used for an analysis of the interaction steps needed to accomplish tasks with the infotainment system with the recommendation service. The recommendations are given as shortcuts in the support level "User Approval" for the case of success (recommendation meets user need) and error case.

Task	Operators	Description
Navigation	1. M + H + T + R(t)	Select "Ok" on Pop up
	M + H + T + R(t)	Summary
Media	1. M + H + T + R(t)	Select "Ok" on Pop up
	M + H + T + R(t)	Summary
Radio	1. M + H + T + R(t)	Select "Ok" on Pop up
	M + H + T + R(t)	Summary
Error Case	1. M + H + T + R(t)	Select "Not now" on Pop up
	2.-x. see Manual	Manual operation of the task
	M + H + T + R(t) + operation steps of manual operation	Summary

Table 7-5.: Fully Adaptive: The Touch-Level Model is used for an analysis of the interaction steps needed to accomplish tasks with the infotainment system with the recommendation service. The recommendations are given as shortcuts in the support level "Fully Adaptive" for the case of success (recommendation meets user need) and error case.

Task	Operators	Description
Navigation	M	Grasp automatic execution
	M	Summary
Media	M	Grasp automatic execution
	M	Summary
Radio	M	Grasp automatic execution
	M	Summary
Error Case	1. M + H + T + R(t)	Select "Cancel"
	2.-x. see Manual	Manual operation of the task
	M + H + T + R(t) + operation steps of manual operation	Summary

In the error case more operators are needed while using the adaptive recommendation service because the action of it must be overwritten by the user. But the percentage of these additional operators is low in comparison to the total number of operators needed for the manual usage. It must be further evaluated how big this effect is and if it causes more damage than is beneficial for the user.
One operator, Distraction (X), has not been used within the analysis. There are different types of driver distraction as described in Section 2.2.2. Operating the infotainment system and driving are competing tasks regarding the available resources of the driver. The influence of the operator Distraction while driving is not known and must be further analyzed. Driver distraction is the focus of the next evaluation described in Chapter 8.

7.3 Implementation of the Adaptive Recommendation Service

The adaptive recommendation service is implemented as an application running on the infotainment system of the pre-development platform of the division Car Multimedia at Bosch. For this, the reference architecture described in Section 5.2, is used. Figure 7-8 shows the components and interfaces of the adaptive recommendation service integrated in the infotainment system. The reference architecture is integrated in the framework described in Section 7.1.
The HMI logic is part of the HMI component called "Recommendation HMI", including a state machine and the assets to show the screens described in Section 7.2.2. The application logic is part of the IC, IUN and DVE. All persistent data, as for example the determined rules for recommendations, are stored in a data pool consisting of several databases defined with SQLite[1]. This ensures an encapsulation of the data and a persistent storage.
In the reference architecture, described in Section 5.2, the applications communicate directly with the recommendation service. It would be a high effort to change every application that it is able to communicate with the recommendation service. Therefore, an additional component, the

[1] `www.sqlite.org`, last accessed 25/05/2017

infotainment abstraction layer, has been created taking over this communication. The infotainment abstraction layer communicates directly with the applications through already existing interfaces and uses the interfaces provided by the recommendation service to communicate with it. The applications don't need to be changed and the reference architecture can be implemented as intended. Whenever a function of one of the applications; tuner, media, or navigation, is used, the infotainment abstraction layer is notified and sends a message to the recommendation service. The reverse also applies; executing a preconfigured function is done via the infotainment abstraction layer, triggered by a request from the recommendation service. For the communication between the different components a D-Bus[2] connection is used. In addition, an internal Bosch framework, called CCA, is used for the communication with some of the applications.
Normally, the DVE receives context parameters directly from sensors or other applications. In this case the context parameters are sent from the driving simulator software Silab[3] over a tool called XVHMI socket layer. The XVHMI socket layer runs on the same PC as the driving simulation and receives messages directly from Silab. This tool provides a socket to communicate with Silab and builds up a connection with the DVE to send parameters like the position on a track to the recommendation service.
The adaptive recommendation service can run in two different modes; a demo mode and non-demo mode. In the non-demo mode the learning algorithms of the IUN are activated and the recommendation service creates new recommendations based on the tracked usage behavior. In the demo mode no new rules are created. This mode is used for the next evaluation, described in Chapter 8, where the behavior of the recommendation service is predetermined according to a user story. Therefore, a database file with preconfigured rules can be loaded into the data pool. In this mode it is also possible to trigger recommendations from the driving simulator directly. A message is sent to the recommendation service including the ID of an existing rule in the data base over the socket connection whereupon the corresponding rule gets active and a recommendation is shown on the screen.
The high-fidelity prototype has been implemented according to the described architecture in Figure 7-8 by interns and the team of the department RBEI/ECG1 of Bosch.

[2] https://www.freedesktop.org/wiki/Software/dbus/, last accessed 25/05/2017
[3] https://wivw.de/en/silab, last accessed 25/05/2017

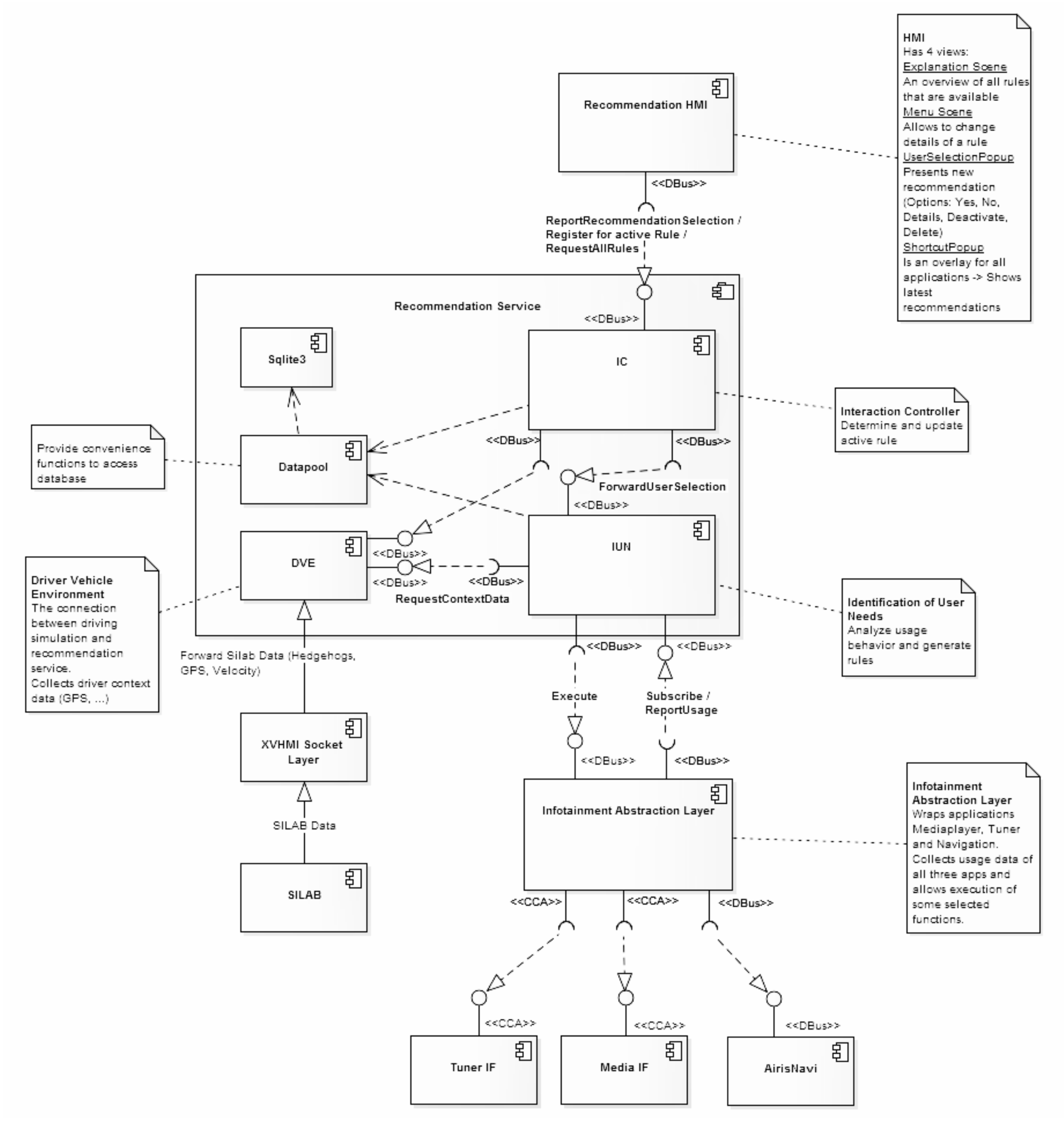


Figure 7-8.: Components and interfaces of the adaptive recommendation service integrated in the infotainment system of the pre-development platform of Bosch.

8 Evaluation of Driver Distraction and User Acceptance

This chapter addresses the last step of the described user-centered design process in Section 6.1. A driving simulator study is conducted to evaluate whether driver distraction can be reduced with the adaptive recommendation service, even in a worst case scenario, and to determine whether the measures taken to improve usability have a positive effect. A high-fidelity prototype, described in Chapter 7, is used and the method of the Wizard of Oz study, described in Section 6.5.2, is further developed and applied here. In focus for the evaluation are the requirements described in Section 6.3.1.2, applicable for an interaction concept. In this case, usability refers to the requirements listed below "traceability", "configuration", "controllability", "user experience", and "recommendation".

8.1 Objectives and main assumptions of the Driving Simulator Study

The goal of the user study is to compare two different interaction concepts of the adaptive recommendation service (see Section 7.2.2), the state-of-the-art and the further developed version of this work, with the focus exclusively on one support level to reduce the complexity of the study. All recommendations in the user study are given in form of pop up messages (level UA).

The focus of this study is on usability and driver distraction, comparing the degree of driver distraction of users of the adaptive recommendation service with the distraction level of those employing manual usage. The degree of driver distraction is evaluated for both versions of the adaptive recommendation service in comparison to the manual usage.

Some main assumptions are made for evaluating the adaptive recommendation service regarding usability and driver distraction. The usage of the infotainment system during driving can result in an increasing visual, manual or cognitive distraction of the driver or the distractions can all occur simultaneously. The adaptive recommendation service intends to reduce the distraction of the driver. A reduction of the manual distraction is obvious because the number of interaction steps is reduced. But the effect on visual distraction and especially cognitive distraction is not as obvious, and the usability problems and distraction could influence each other. This means that on one hand the distraction caused by choosing a function is decreased by using the adaptive recommendation service, but on the other hand the adaptive recommendation service could have a negative influence on the distraction of the driver, for example because of lacking traceability.

In addition, drivers tend to compensational effects, which is described by Schwalm et al. (2015) and in ISO/DIS 17488 (2015). Therefore, it is important to observe parameters for all different forms of distraction.

Both Lavie (2007) and Garzon (2013) have evaluated driver distraction of an adaptive recommendation service in previous studies. One result in both studies was the reduction of the driver distraction due to the usage of the adaptive recommendation service, although Lavie used driving performance (standard deviation of lane position (SDLP)) and task performance as measures, and Garzon used the subjective workload to prove this result. There was one exception; within the study of Lavie (2007), driver distraction increased in non-routine situations while using the adaptation level FA in comparison to the manual usage. In a non-routine situation a driver has a user need which is unknown to the adaptive recommendation service because it has not been observed before. Therefore, this can be handled as an error case as the driver receives no useful recommendation and needs to override the actions of the adaptive recommendation service. Lavie has evaluated the effect of the adaptive recommendation service on driver distraction related to tasks with different difficulty levels. Functions with a high complexity include for example reading and replying to a text message. In non-routine situations there isn't a big difference for complex and simple tasks but in routine situations, Lavie found that the adaptive recommendation service is beneficial for both but with a greater effect in the case of complex tasks, so it is important to evaluate tasks with different difficulty levels and the error case. Garzon (2013) identified a decreasing subjective workload with increasing adaptation level, but only for a very simple task, which was changing the radio station. The results of both studies cannot be compared due to very different conditions within the user studies. In addition, Garzon used exclusively subjective measures like questionnaires and Lavie used objective measures like the SDLP and task performance.

Therefore, the following points are important for the design of the user study described in this chapter:

- Considering tasks with different difficulty level
- Observing the degree of driver distraction in a worst case scenario
- Using objective measurements to evaluate driver distraction and subjective measurements for usability
- Evaluate driving performance, task performance and workload at the same time

In the following, the design of the study is described according to the used methods and applied procedure.

8.2 Methods

The user study has the goal of evaluating the interaction concept of the adaptive recommendation service regarding driver distraction and usability. Especially for assessing usability, it is important that the participants of the user study can experience the adaptive recommendation service. A method to enable this must be developed, so the findings of the previously conducted Wizard of Oz study are taken into account in developing this method. The main focus is on the experience of the different phases of the adaptive system with the help of a storyline while keeping the conditions equal for every participant. An environment needs to be created where the storyline can be presented in a reasonable way. In addition, a method to evaluate driver distraction which works together with the rest of the study design needs to be selected, and the methods to evaluate usability to be further improved. This is described in the following.

8.2.1 Storyline and Tasks

A key element of the user study, enabling the user to experience the adaptive recommendation service, is the storyline. The storyline describes a regular trip of a person. During this trip the driver receives tasks with different difficulty levels consistent to the storyline. The difficulty level of a task depends on the needed interaction steps to fulfill the task manually. Those interaction steps have been described in Section 7.2.1. With increasing complexity the needed biomechanical, cognitive, and visual resources rise to solve a task successfully.

Tasks:

- Changing the radio station (difficulty level: low)
- Choosing and playing a song from the song list (difficulty level: middle)
- Starting route guidance to an address (difficulty level: high)

The storyline is explained to the participants according to the picture shown in Figure 8-1 and the following text:

"You want to meet your friend in a cafe on a Tuesday afternoon as you do every Tuesday. You begin from home and first start the route guidance to the address of the cafe, which is "Leonberg, Bahnhofstrasse 10". On your route you drive through a forest where the reception of the current radio signal is very bad, so you switch the station to radio channel SWR 2 on the frequency 91.1. After driving through the forest, you go through a tunnel where there is no radio signal at all. You open the media player and select the song "Stadtaffe" from the song list. Before reaching the city, you decide to navigate directly to a parking lot near the cafe at "Leonberg, Karlstrasse 12"."

The storyline puts the participant in a routine situation, where he/she can benefit from the adaptive recommendation service. The participants are instructed to drive this route twice, using the infotainment system to fulfil the tasks manually, for training the adaptive recommendation service. Afterward, the participants drive the route once again, experiencing the support of the adaptive recommendation service. Through this, they experience the learning phase of the adaptive recommendation service, as well as the support phase. In addition, the worst case scenario is simulated by giving a further instruction than expected in the third round for the last task. A false recommendation is given to the participant, which needs to be overridden. The whole procedure of the user study is described in Section 8.3.

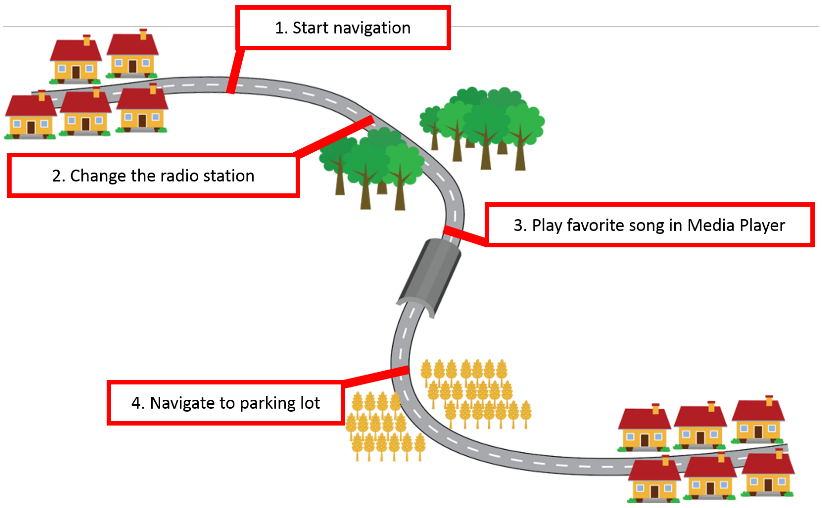


Figure 8-1.: The storyline is explained to the participants by showing this picture to them. This supports the participants to memorize the details of the storyline.

8.2.2 Driving Simulator and Silab

The route of the storyline is created within the driving simulation environment. For this, the driving simulation software Silab is used. The tasks are given to the participants with the help of audio files, which are played automatically when the driver passes certain points on the route. The route is divided into six parts with different lengths for start, end, and all four tasks.

The length is adjusted to the difficulty of the task, in order to give the participants enough time to fulfil the task before the next turn starts. The street of the route consists of two lanes, no other traffic appears, the street has moderate curves and hills to make it realistic, and a recognizable environment represents the storyline. The participants are asked to hold a constant speed of 30mph.
Figure 8-2 shows the driving simulator mock-up and Figure 8-3 the schematic structure of the involved components. The prototype consists of an infotainment system with the possibility to activate the adaptive recommendation service in variant A (variant representing the state-of-the-art) or variant B (further developed version). The infotainment system is displayed on a screen integrated in the driving simulator mock-up in the middle of the dashboard and can be operated via touch. The infotainment system is connected to the driving simulator software Silab to receive context parameters and other information. The prototype of the adaptive recommendation service runs in the demo mode. This means that the recommendations need to be triggered manually from outside, in this case by the driving simulator. By driving over certain points on the route, a message is send from Silab to the adaptive recommendation service to trigger the recommendations. Thereby, a defined behavior, which is exactly the same for each participant, can be guaranteed.

Figure 8-2.: The driving simulator mock-up used in this user study.

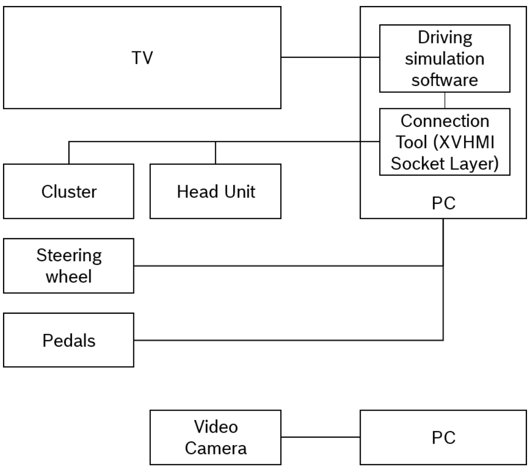


Figure 8-3.: Involved technical components: driving simulator with pedals and steering wheel, head unit and cluster, connection tool and driving simulation software running on a PC, and TV presenting the driving simulation.

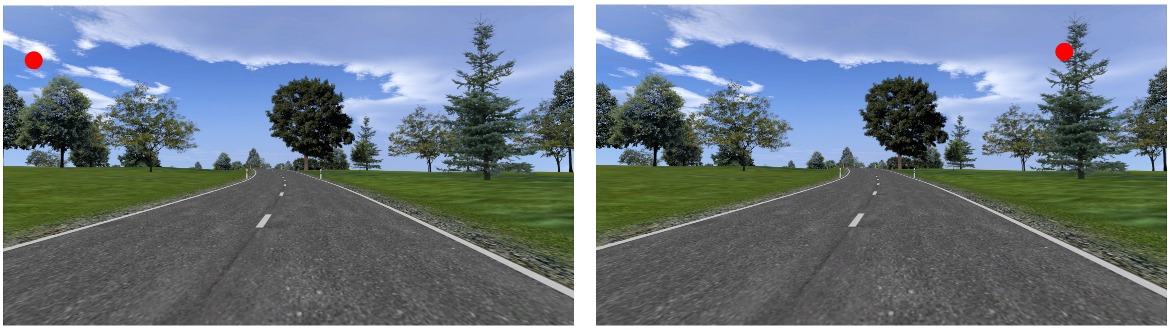
The same connection as the one to trigger recommendations is used to send the speed of the vehicle in the driving simulation continuously to the cluster. The driving simulator consists of a mock-up and a PC where the driving simulation software is running on. The pedals of the mock-up for acceleration and braking are connected to the PC via USB and the steering wheel over CAN. The steering wheel has one button which is used for the Detection Response Task (DRT) described in the next section. In addition, the study is recorded on video.

8.2.3 Driver Distraction and DRT

In the study of Lavie (2007) objective measures were used, whereas in the study of Garzon (2013) subjective measures were selected. In this study, both are combined. Objective measures are used to evaluate driver distraction and subjective measures to evaluate usability.
For the evaluation of driver distraction a suitable method must be selected. This method must be appropriate for using it along with a storyline and within a driving simulation. The Detection Response Task (DRT) is a method to assess the effect of a task on the attention of the driver. Different forms are described in the ISO/DIS 17488 (2015). Participants are requested to react to a frequently presented stimulus. The reaction time as well as the missed stimuli are tracked and interpreted. It can be used in parallel to driving in a driving simulator and operating the infotainment system as intended in the storyline.
In this study a remote DRT is realized. The stimulus is presented frequently in form of a red dot within the driving simulation on the screen in front of the participant. A stimulus is presented (S_{on}) for a maximum (SD_{max}) of one second and is then hidden (S_{off}) again, except when the participant is pressing a button on the steering wheel (R), in which case the stimulus is hidden immediately. The stimulus is presented randomly every three to five seconds. This procedure is described in Figure 8-4.

Figure 8-4.: The stimuli are presented for one second, except when the participant presses a button on the steering wheel before the time is over. In this case the stimulus is hidden immediately. The stimuli are presented again every three to five seconds randomly (ISO/DIS 17488, 2015).

The position of the stimulus on the screen changes randomly but is limited to a certain area. This area is on the left and right side of the road above the horizon. Two examples can be seen in Figure 8-5. As shown in Figure 8-6 the screen has a resolution of 1920 x 1080 pixels. The area on the left is a rectangle between (50px, 150px) as the upper left corner and (710px, 250px) as position of the lower right corner. The rectangle on the right side has the same size as the area on the left, with the coordinates (1210px, 150px) for the left upper corner and (1870px, 250px) for the lower right corner. The distance between participant and the screen of the driving simulator is approx. 2m. The diameter size of the stimulus is 3.8cm.
For driver distraction it is important to observe different parameters. Drivers tend towards compensational effects, described by Schwalm et al. (2015) and in ISO/DIS 17488 (2015).



(a) (b)

Figure 8-5.: Screenshots of the driving simulation showing a stimulus of the DRT on the left (a) and right side (b) of the road. Both pictures are examples for possible positions of the DRT stimuli.

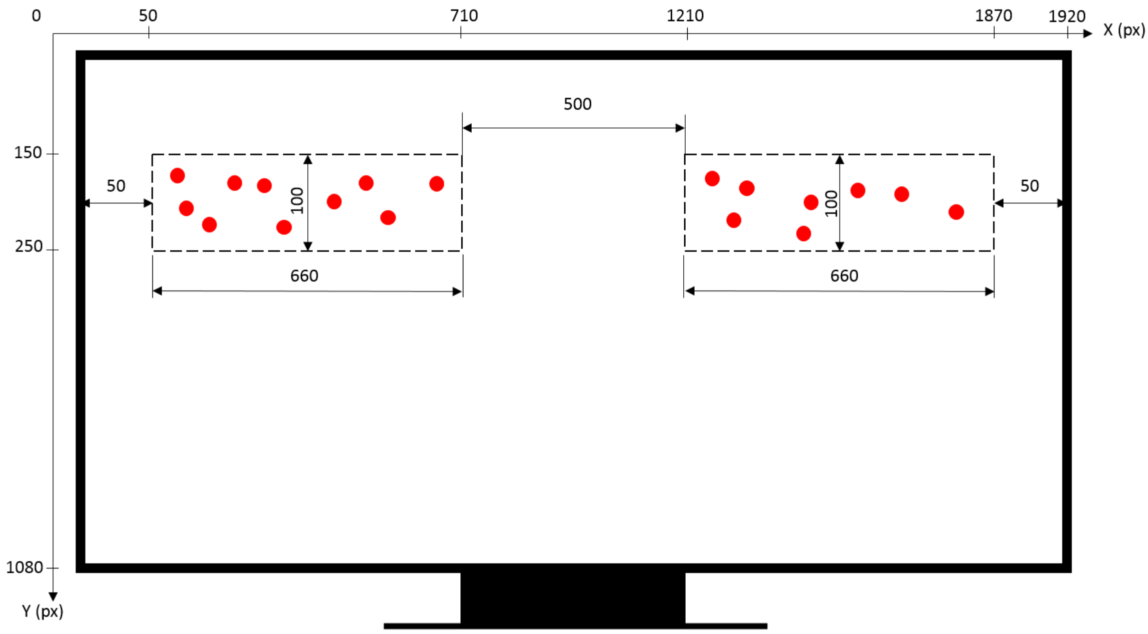
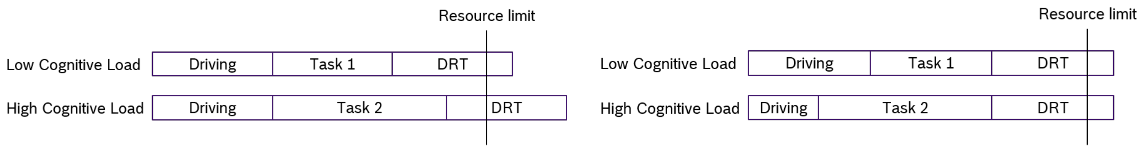


Figure 8-6.: The stimuli are presented within defined areas on the left and right side of the road over the horizon of the driving simulation environment.

Although the participants are instructed to focus first on driving, second on operating the infotainment system and last on the DRT, they cannot fully control this. Therefore, the conflict of attention resources can be observed as a reduced driving performance, as well as a reduced task performance or DRT performance, as shown in Figure 8-7. It is important to observe all three parameters: driving performance, task performance, and DRT performance.



(a) Task 2 allocates more resources than task 1; as the driver focuses on driving, the effect can be seen within the DRT performance.

(b) Task 2 allocates more resources than task 1; as the driver focuses on the DRT, the effect can be seen within the driving performance

Figure 8-7.: Drivers tend to compensational effects when a task leads to a high cognitive load. This can have an effect on different parameters: driving performance, task performance or DRT performance (according to (ISO/DIS 17488, 2015)).

Driving performance is represented by the standard deviation of the lane position (SDLP) (Knappe et al., 2006), the task performance by the task duration, and the DRT performance by hit rate and number of misses (ISO/DIS 17488, 2015).

8.2.4 Usability questionnaires

For the evaluation of usability different questionnaires are used. A standardized questionnaire to evaluate the seven design principles described in ISO 9241-110 (2006) is the ISONorm questionnaire (abbr. ISONorm) developed by Prümper and Anft (1993). It consists of 35 questions, five questions for each of the principles. The questionnaire provides indications for deficits regarding usability.
The ISONorm already covers a lot of usability criteria and also partially those especially important for adaptive systems such as self-descriptiveness or controllability. But the questions of the ISONorm are not specialized for adaptive systems. It makes a difference to ask in general whether the system provides beneficial situation specific explanations or more specific ones, as for example whether it is transparent to the user what recommendations can be provided to them. The goal is to identify deficits regarding usability of the adaptive system. It is important to ask the participants about these more specifically; therefore, the ISONorm questionnaire has been extended by another 13 questions. These questions address usability challenges of adaptive systems, like traceability, controllability, and obtrusiveness, which are not covered to this degree within the ISONorm questionnaire. This questionnaire and the demographic questionnaire, which the participants also need to fill out, are in Appendix H.

8.3 Experimental Design

The procedure of the user study includes many steps as the introduction, training phase of participants and running through the storyline multiple times. The procedure can be divided into seven phases, described in the following:

- Phase 1: Introduction - The goal of the study and the storyline are introduced to the participant. In addition, the participant needs to sign a declaration of agreement and fill out a demographic questionnaire.

- Phase 2: Training - In the second phase the functions and operation of the infotainment system are explained to the participant. The participant gets familiar with driving in the driving simulator and operation of the DRT, as well as managing the operations simultaneously, as shown in Figure 8-8.
- Phase 3: Baseline - After the training phase, the actual study starts. The participant drives the route which represents the storyline for the first time. In addition, the DRT must be accomplished but no additional task is given to the participant.
- Phase 4: Learning of the adaptive recommendation service (Manual) - The participant drives the same route twice, accomplishes the DRT and gets tasks which need to be fulfilled by operating the infotainment system. Afterwards the participant fills out the ISONorm questionnaire to evaluate the infotainment system without the adaptive recommendation service.
- Phase 5: Support (Variant A or Variant B) - After the learning phase of the adaptive recommendation service, the driver drives the route once again but completes the tasks this time with the support of the adaptive recommendation service. Contrary to the first two rounds, the last task of the storyline will be different to simulate the worst case. After driving, the participant fills out the extended ISONorm questionnaire to evaluate the infotainment system with the adaptive recommendation service.
- Phase 6: Baseline - The last drive in the user study is the same as in phase 3. This enables the evaluation of the learning effect regarding driving.
- Phase 7: Conclusion - At the end of the user study, the participant gets a compensation of expenses in form of a voucher.

Figure 8-8.: The participants need to fulfil all three tasks at the same time: driving, operating the infotainment system and DRT.

In this user study, two variants of the adaptive recommendation service are compared. All variants: manual usage, variant A and variant B, must be experienced by the participants. This cannot be part of one single user study due to dependencies regarding the order of introduction. The manual usage represents at the same time the learning phase of the adaptive recommendation service and therefore needs to happen before the usage of the adaptive recommendation service. In addition, variant A must be experienced independently or at least before variant B, because in variant B the participant gets a lot more information by the tutorial and explanation menu. The participants would not forget this information afterwards and would be already influenced.

To compensate a learning effect, the order of all variants must be permuted or each variant be evaluated in a single user study. The first option is not possible, therefore the user study is divided into three sub-studies with different groups of participants, as shown in Figure 8-9. In the first study, the participants experience only the infotainment system without the adaptive recommendation service. In the second study, they experience variant A and in the third study variant B. All three studies include the phases described before with one exception. Phase 5 is in study 1 not necessary, therefore this phase is the same as phase 4 but with the worst case scenario.

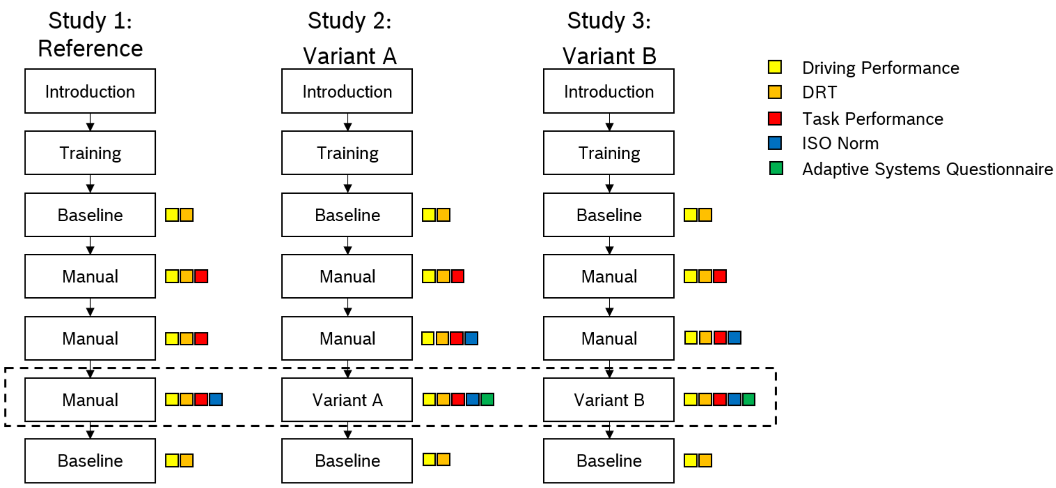


Figure 8-9.: The user study is conducted as an in-between subject design and divided into three sub-studies. Each of them include the same phases.

8.4 Hypothesis and Data Analysis

Driver distraction will be evaluated by analysis of SDLP, DRT performance and task duration. Usability is measured according to the ratings of the ISONorm and additional questionnaire with regard to adaptive systems. In addition to the collected data, the whole procedure is recorded by a video camera as a study protocol. The hypothesis and analysis of each parameter is described in the following.

8.4.1 Hypothesis

The following hypothesis are derived from the research question mentioned in Section 8.1 and Section 4.2 and are evaluated in this driving simulator study according to the collected data.

Is usability improved through the applied measures?:

- H_1: Users rate variant B better than variant A according to the usability.
  - The rating of the ISONorm is in total higher for variant B than for variant A.
  - The rating of the usability criteria of adaptive systems is in general and for each single criteria higher for variant B than for variant A.
- H_2: The usage of an adaptive system is beneficial for the usability. Users rate the usability of an infotainment system with recommendation service higher than without recommendation service.
  - The rating of the ISONorm is higher for variant A or variant B than for the infotainment system without adaptive recommendation service.

Is driver distraction reduced through the adaptive recommendation service?:

- H_3: Users solve the secondary tasks successfully faster using the adaptive recommendation service (variant A and variant B) in comparison to the manual operation of the infotainment system (per task).
  - Task duration is lower while using variant A or variant B in comparison to the manual operation of the infotainment system.
- H_4: Users are less distracted while using the adaptive recommendation service (variant A and variant B) in comparison to the manual operation of the infotainment system when receiving a fitting or false recommendation (per task).
  - SDLP is lower while using variant A or variant B in comparison to the manual operation.
  - DRT Hit rate is higher for variant A or variant B in comparison to the manual operation.
  - DRT Response Time is lower for variant A or variant B in comparison to the manual operation.

The calculation of each parameter is described in the following sections.

8.4.2 ISO Norm and questionnaire for adaptive systems

The ISONorm consists of 35 questions; five questions for each of the principles described in ISO 9241-110 (2006). Each question is rated on a 7-point Likert scale. For the analysis, the mean value of all answers for each question is calculated and summarized for each principle. In addition, a total value is determined for the ISONorm questionnaire.
The same is valid for the extension of the ISONorm for adaptive systems. This questionnaire consists of 13 questions addressing traceability (7 questions), obtrusiveness (2 questions), and controllability (5 questions) of the adaptive system. The questions related to traceability are derived from the questions used in the Wizard of Oz study, described in Section 6.5.2.

8.4.3 Standard Deviation of Lane Position (SDLP)

The SDLP is calculated as the standard deviation of all recorded distances between a specified point at the vehicle and the left or right lane boundary (Knappe et al., 2007).

- n the number of recorded distances
- d_i is a measured distance between the vehicle and the left or right lane boundary
- d_{avg} is the average of all recorded distances, $d_{avg} = \frac{\sum_{i=1}^{n} d_i}{n}$
- $SDLP = \sqrt{\frac{\sum_{i=1}^{n}(d_i - d_{avg})^2}{n}}$

The SDLP is calculated for each task per participant.

8.4.4 Task Duration

The duration of each task is defined as the time the participant needs to fulfil a task successfully. The measurement starts when the audio file telling the participant to solve a certain task starts playing and ends when the investigator presses a key on the keyboard directly after the participant has fulfilled the task successfully. It is measured in milliseconds.

8.4.5 DRT Performance

For calculating the DRT performance valid and invalid responses must be distinguished. Valid responses are all responses between 100ms and 2500ms, which are not followed by another response, as well as no other response appearing previous to it in this interval. Invalid responses are responses before 100ms (premature responses), after 2500ms (unrequested responses) and responses between 100ms and 2500ms which are followed by another response or with another previous response in the same interval (ISO/DIS 17488, 2015).

- HR (hit rate) is the number of valid responses divided by the total number of stimuli presented in a data segment
- RT_i (response time) is the time from stimulus onset until the response for a valid response
- MRT (mean response time) is the mean response time of all response times

All values are calculated for each task per participant.

8.5 Results

The statistical test of the analysis is done with Minitab[1] and a significance level of 5%. Significant differences are marked by a star in the following diagrams. The results of the analysis for the data of the two manual rounds before testing the recommendation service are referred to as "AM" or "BM". AM is related to the group of participants experiencing variant A of the adaptive recommendation service later in the experiment and BM is related to the data of the group experiencing variant B. M refers to the reference group, experiencing only the manual infotainment system. The DRT Response Time considers the mean response time of the participants.

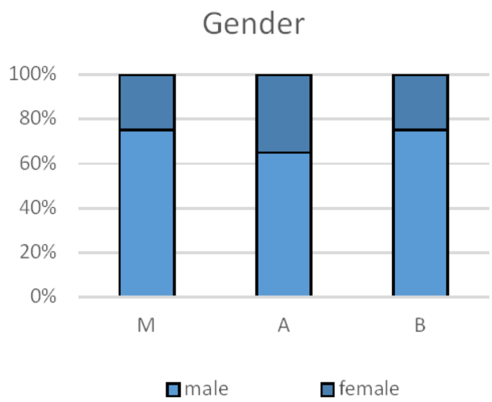
8.5.1 Participants

Sixty-five participants took part in this study. The data of five participants had to be excluded from the analysis as the participants could not complete the procedure due to a system error. The remaining sixty participants (N = 60; 43 male, 17 female) are aged between 22 and 54 (M = 30.2, SD = 7.49) and have all a drivers license. All of them are smartphone or tablet users. During the recruitment phase, the participants were asked to answer preliminary questions according to their gender, age and average driving distance per year. The participants were then distributed to the three different experimental groups with first priority on gender, then age and driving distance. The distribution according to the mentioned parameters and additionally the self-estimation of the technical affinity of the participants is shown in Figure 8-10.

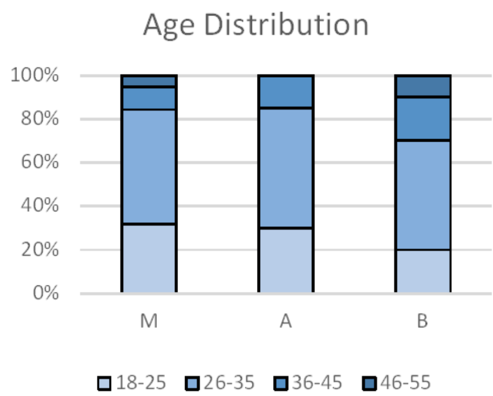
8.5.2 Preconditions

In order to compare results between the three sub-studies, two control conditions are defined to validate similar basic behavior of each sub-group. The first condition is, that the participants of the three sub-studies rate the manual infotainment system not significantly different referred to the ISONorm questionnaire. As a consequence it can be assumed that the three groups don't differ in their ratings and a difference between the rating of variant A and variant B can be explained by the different conditions. Figure 8-11 shows the results of the ISONorm ratings in total and for all sub-categories. A One-way ANOVA is conducted to compare the effect of the three different groups on the rating of the ISONorm questionnaire for the total rating and every sub-category. An analysis of variance shows that the effect of the three different groups on the ISONorm rating in total is not significant, $F(2, 57) = 1.63$, $p = 0.205$. This is also the case for

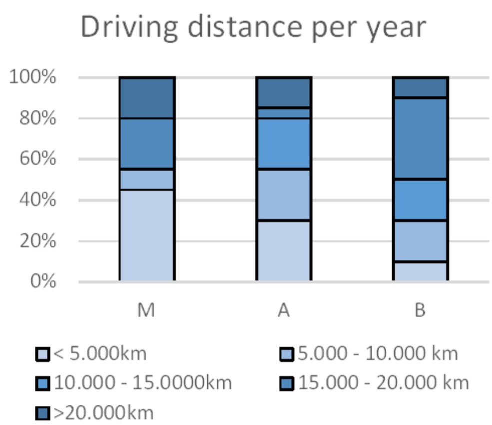
[1] `http://www.minitab.com`, last accessed 25/05/2017



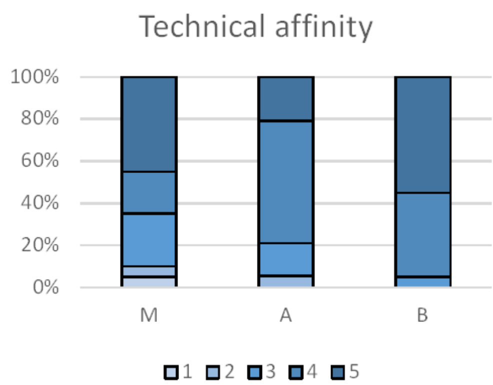
(a) Gender



(b) Age



(c) Driving Distance



(d) Technical affinity

Figure 8-10.: The sixty participants were distributed to three experimental groups considering their gender, age and average driving distance per year. In addition, the distribution according to the self-estimated technical affinity is shown.

suitability for the task (F(2, 57) = 1.35, p = 0.266), self-descriptiveness (F(2, 57) = 0.60, p = 0.553), conformity with user expectations (F(2, 57) = 0.76, p = 0.475), suitability for learning (F(2, 57) = 0.42, p = 0.659), controllability (F(2, 57) = 0.87, p = 0.426), and error tolerance (F(2, 57) = 2.12, p = 0.129). The analysis of variance shows that the effect of the three different groups on the ISONorm rating for the suitability of individualization is significant, F(2, 57) = 4.97, p = 0.010.

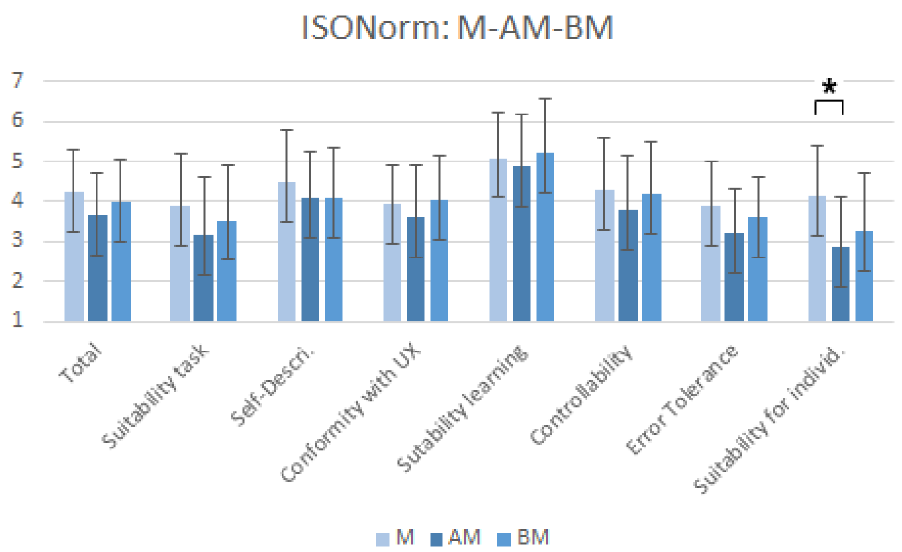
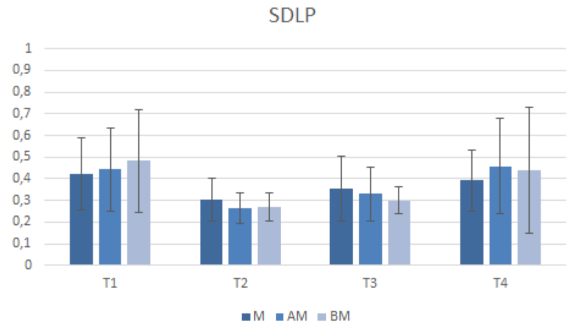
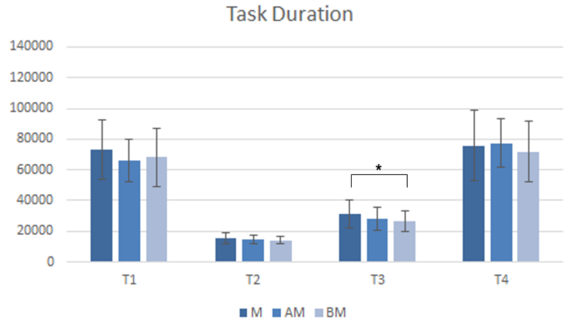


Figure 8-11.: All participants of the three different sub-studies rate the manual infotainment system with the ISONorm questionnaire. There is no significant difference between the three groups except for the sub-category "suitability of individualization".

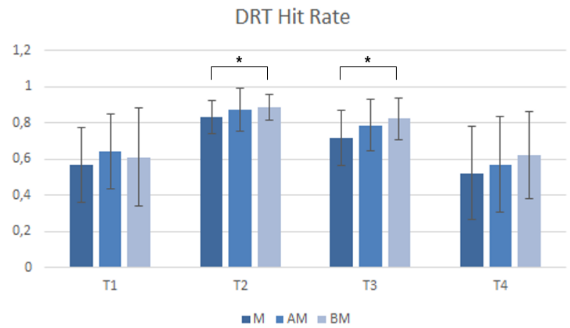
The second condition is that there is no significant difference between the driving performance (SDLP), task performance, DRT hit rate and DRT response time of the three sub-studies for every task during the usage of the infotainment system without the adaptive recommendation service (manual) in phase 4. The results are shown in Figure 8-12. A One-way ANOVA is conducted for every task to compare the effect of the three different groups on the driving performance (SDLP), task performance, DRT performance (hit rate and response time). The results of the analysis of variance for task 1 shows that the effect of the three different groups on SDLP is not significant, F(2, 57) = 0.88, p = 0.42. There is also no significant effect on task performance (F(2, 57) = 1.49, p = 0.231), DRT hit rate (F(2, 57) = 0.85, p = 0.431) and DRT response time (F(2, 57) = 0.02, p = 0.982).
For task 2, there were no significant effects for SDLP (F(2, 57) = 2.75, p = 0.068), task performance (F(2, 57) = 3.05, p = 0.051) and DRT response time (F(2, 57) = 1.99, p = 0.141). However, the results of the analysis of variance for task 2 shows that the effect of the three different groups on DRT hit rate is significant, F(2, 57) = 3.46, p = 0.035.
The results of the One-way ANOVA for task 3 shows no significant effect on SDLP (F(2, 57) = 2.23, p = 0.112) and DRT response time (F(2, 57) = 0.39, p = 0.68). For the analysis of the DRT hit rate a significant effect is shown for the three different groups (F(2, 57) = 5.77, p = 0.004) as well as for the task performance (F(2, 57) = 3.2, p = 0.044).
For task 4, the analysis of the variance shows that the effect of the three different groups is not significant for SDLP (F(2, 57) = 0.87, p = 0.422), task performance (F(2, 57) = 0.8, p = 0.45), DRT hit rate (F(2, 57) = 1.5, p = 0.227) and DRT response time (F(2, 57) = 0.42, p = 0.657).
The results of the ANOVAs show that for task 1 and task 4 the three different groups had no significant effect on the different parameters. This could not be shown for task 2 and task 3.



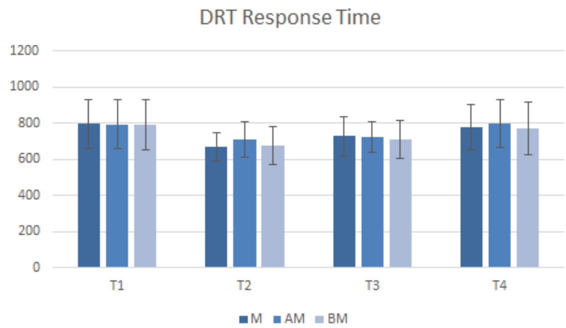
(a) SDLP



(b) Task Performance



(c) DRT Hit Rate



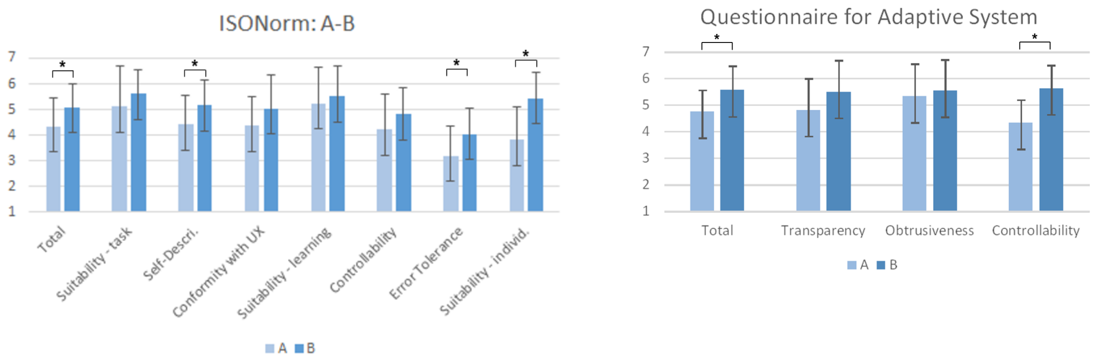
(d) DRT Response Time

Figure 8-12.: The variables driving performance (SDLP), task performance, DRT hit rate, and DRT response time are compared for the three different sub-studies during using the manual infotainment system.

8.5.3 Usability

For hypothesis H_1 the rating of variant A and variant B according to ISONorm questionnaire is considered. The analysis of the ratings shows higher ratings for all mean values of variant B in comparison to variant A for the total rating and all sub-categories. The mean values and standard deviation are shown in Figure 8-13(a). Independent-samples t-tests were conducted to compare the ratings of the ISONorm questionnaire in total and for each sub-category for variant A and variant B. There is a significant difference in the total ISONorm rating for variant A (Mean = 4.34, SD = 1.11) and variant B (Mean = 5.1, SD = 0.91); $t(38) = -2.37$, $p = 0.023$. In addition, there is a significant difference for the sub-categories self-descriptiveness ($t(38) = -2.28$, $p = 0.028$), error tolerance ($t(38) = -2.45$, $p = 0.019$) and suitability for individualization ($t(38) = -4.49$, $p < 0.0$). For the other categories no significant difference is shown (suitability for the task, $t(38) = -1.20$, $p = 0.241$; conformity with user expectations, $t(38) = -1.78$, $p = 0.084$; suitability for learning, $t(38) = -0.68$, $p = 0.498$; controllability, $t(38) = -1.59$, $p = 0.120$). For the hypothesis H_1 only the total rating is of interest. These results confirm the hypothesis H_1.
In addition to the ISONorm questionnaire rating, the ratings according to the questionnaire for adaptive systems and its sub-categories is considered for hypothesis H_1. The analysis of the ratings shows also higher ratings for all mean values of variant B in comparison to variant A for the total rating and all sub-categories. As analysis of the questionnaire for adaptive systems ratings, independent-samples t-tests were also conducted in total and for each sub-category. There is a significant difference in the total rating of the adaptive system questionnaire for variant A (Mean = 4.75, SD = 0.81) and variant B (Mean = 5.55, SD = 0.92); $t(38) = -2.95$, $p = 0.006$. Also for the sub-category controllability a significant difference is shown; $t(38)= -4.84$, $p = 0.001$. The t-tests

show no significant effect for the sub-categories transparency (t(38) = -1.87, p = 0.070) and obtrusiveness (t(38) = -0.60, p = 0.551). These results partially confirm the hypothesis H_1.



(a) ISONorm questionnaire

(b) Questionnaire for adaptive systems

Figure 8-13.: Variant A and variant B are compared to each other according to the ratings given by the participants with the ISONorm questionnaire and the additional questionnaire for adaptive systems. The rating for variant B is higher in total and for each criterion than the rating for variant A.

For hypothesis H_2 the ratings of variant A, variant B, and the infotainment system without recommendation service (M) with respect to the ISONorm questionnaire are considered. The results are shown in Figure 8-14. A One-way ANOVA is conducted to compare the effect of the three different groups on the rating of the ISONorm questionnaire for the total rating and every sub-category. An analysis of variance shows that the effect of the three different groups on the ISONorm rating in total is significant, F(2, 57) = 4.20, p = 0.020. This is also the case for sub-categories suitability for the task (F(2, 57) = 9.24, p < 0.0), conformity with user expectations (F(2, 57) = 4.90, p = 0.011), error tolerance (F(2, 57) = 3.40, p = 0.040), and suitability for individualization (F(2, 57) = 10.47, p < 0.0). The analysis of variance shows that the effect of the three different groups on the ISONorm rating for self-descriptiveness is not significant (F(2, 57) = 2.76, p = 0.072), as well as for suitability for learning (F(2, 57) = 0.61, p = 0.544) and controllability (F(2, 57) = 1.45, p = 0.244).

Independent-samples t-tests were conducted to compare the ratings of the ISONorm questionnaire for the different groups to determine which groups differ significantly. The result of the t-test for variant A (Mean = 4.34, SD = 1.11) and variant B (Mean = 5.1, SD = 0.91) show a significant difference in the total ISONorm rating; t(38) = -2.37, p = 0.023. For variant B (Mean = 5.1, SD = 0.91) and variant M (Mean = 4.25, SD = 1.03) the result of the t-test shows a significant difference in the total ISONorm rating; t(38) = 2.77, p = 0.009. These results do not match the result of the t-test for variant A (Mean = 4.34, SD = 1.11) and variant M (Mean = 4.25, SD = 1.03), showing no significant difference in the total ISONorm rating; t(38) = 0.27, p = 0.791.
For the hypothesis H_2 only the total rating is of interest. The results confirm hypothesis H_2 for variant B in comparison to the infotainment system without recommendation service.

8.5.4 Driver Distraction

Driver distraction is compared between the usage of an infotainment system with and without the recommendation service. For the evaluation of the parameters driving performance, task performance, and DRT performance, the data from sub-study 2 (variant A) and sub-study 3 (variant B) have been combined. During driving and the presentation of the recommendations, the

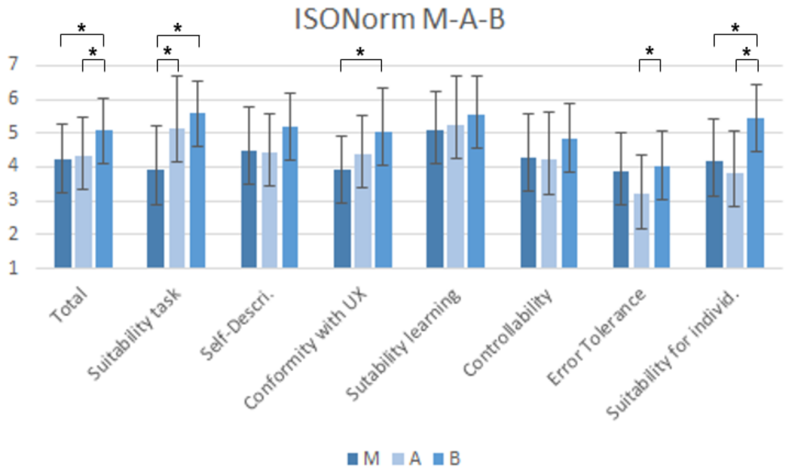


Figure 8-14.: Variant A and variant B are compared to the infotainment system without recommendation service according to the ratings given by the participants with the ISONorm questionnaire.

two variants differ only through the little indicator at the bottom of the recommendation message (see Section 6.6). After comparing variant A and variant B statistically for all variables, driving performance, task performance and DRT performance, no significant difference is determined. Therefore, it is possible to combine the data of variant A and variant B for the analysis of variables related to driver distraction. The analysis is done for each task separately. Independent-samples t-tests were conducted to compare the values of the two groups, without recommendation service (study 1, manual) and with recommendation service (study 2+3, variant A and variant B).

The task performance, represented by the task duration, needed to solve tasks with the infotainment system with and without recommendation service, is considered for H_3. The results are presented in Table 8-1 and Figure 8-15(a). The results of the t-tests for the infotainment system without recommendation service (manual) and the infotainment system with recommendation service (variant A and variant B) show a significant difference in the task duration for task 1 ($t(58) = -18.1$, $p < 0.0$), task 2 ($t(58) = -5.65$, $p < 0.0$), and task 3 ($t(58) = -10.9$, $p < 0.0$). The results confirm hypothesis H_3 for task 1, task 2, and task 3.

Table 8-1.: Task performance, represented by the parameter task duration, is compared between the usage of an infotainment system with and without an adaptive recommendation service for four different tasks.

Task Duration

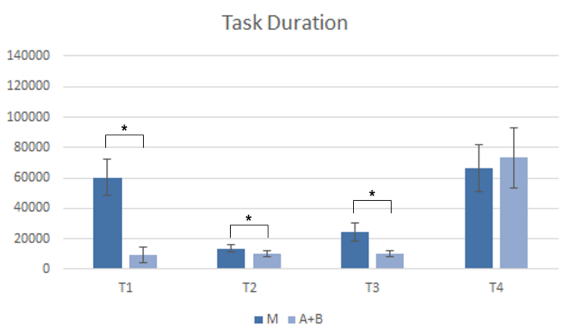
	without recommendation service		with recommendation service		t-Test	
Task	Mean	SD	Mean	SD	t(58)	p
T1	60295	11697	9499	5178	-18.1	<0.0
T2	13672	2408	10217	1828	-5.65	<0.0
T3	24697	5799	10114	2070	-10.9	<0.0
T4	66473	15201	73121	20134	1.42	0.162

For H_4 the driving performance is analyzed by interpreting the SDLP value. The mean values and standard deviation are visualized in Figure 8-15(b), and described in Table 8-2 together with the t-test results. The results of the t-tests for the infotainment system without recommendation service (manual) and the infotainment system with recommendation service (variant A + variant B) show a significant difference in the SDLP parameter for task 1 ($t(58) = -2.69$, $p = 0.013$) and task 2 ($t(58) = -2.09$, $p = 0.047$). The results confirm hypothesis H_4 for task 1 and task 2.

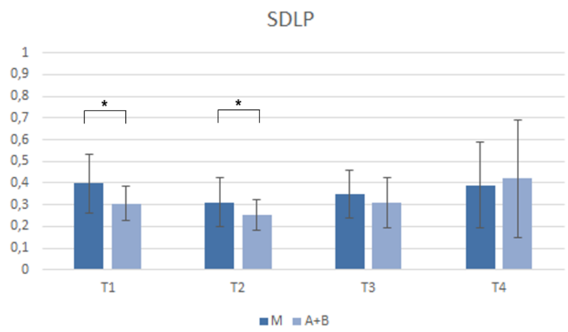
Table 8-2.: Driving performance, represented by the parameter SDLP, is compared between the usage of an infotainment system with and without an adaptive recommendation service for four different tasks. Differences between the two groups are an indicator for the distraction of the driver.

SDLP

	without recommendation service		with recommendation service		t-Test	
Task	Mean	SD	Mean	SD	t(58)	p
T1	0.397	0.137	0.306	0.081	-2.69	0.013
T2	0.311	0.112	0.254	0.069	-2.09	0.047
T3	0.35	0.111	0.311	0.116	-1.23	0.226
T4	0.391	0.197	0.420	0.272	0.48	0.633



(a) Task Duration



(b) SDLP

Figure 8-15.: Differences between two groups, regarding task duration as well as SDLP, are shown. Both parameters are related to driver distraction.

In addition to SDLP, the DRT performance, represented by the parameters hit rate and response time, refers to H_4.

The results for DRT hit rate are presented in Table 8-3 and Figure 8-16(a). The results of the t-tests for the infotainment system without recommendation service (manual) and the infotainment system with recommendation service (variant A + variant B) show a significant difference in the DRT hit rate for task 1 ($t(58) = 7.59$, $p < 0.0$), task 2 ($t(58) = 3.97$, $p < 0.0$), and task 3 ($t(58) = 3.73$, $p = 0.001$). The results confirm hypothesis H_4 for task 1, task 2, and task 3.

The results for DRT response time are shown in Table 8-4 and Figure 8-16(b). The results of the t-tests for the infotainment system without recommendation service (manual) and the infotainment system with recommendation service (variant A + variant B) show a significant difference in the DRT response time for task 1, $t(58)= -3.51$, $p = 0.001$. The results confirm hypothesis H_4 for task 1.

Table 8-3.: DRT Hit Rate is a parameter to measure cognitive load. The values of the two groups, one using the infotainment system without adaptive recommendation service and the other using it with adaptive recommendation service, are compared.

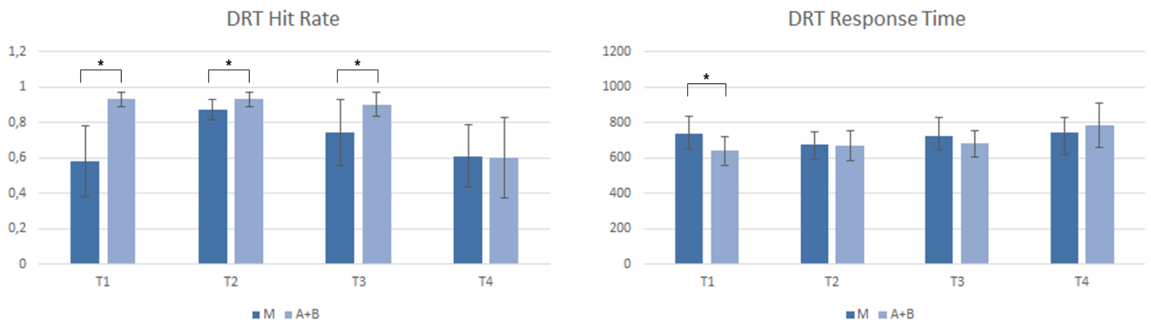
DRT Hit Rate

	without recommendation service		with recommendation service		t-Test	
Task	Mean	SD	Mean	SD	t(58)	p
T1	0.578	0.2	0.931	0.038	7.59	<0.0
T2	0.875	0.057	0.931	0.04	3.97	<0.0
T3	0.742	0.186	0.902	0.068	3.73	0.001
T4	0.609	0.177	0.603	0.226	-0.13	0.901

Table 8-4.: DRT Response Time is the time a participant needs to react to a stimulus presented on a screen. The values of two groups, one using the infotainment system without adaptive recommendation service and the other using it with adaptive recommendation service, are compared.

DRT Response Time

	without recommendation service		with recommendation service		t-Test	
Task	Mean	SD	Mean	SD	t(58)	p
T1	734	102	640	81	-3.51	0.001
T2	674	76	671	86	-0.13	0.9
T3	720	108	680	74	-1.51	0.143
T4	740	87	784	123	1.56	0.126



(a) DRT Hit Rate (b) DRT Response Time

Figure 8-16.: These figures show the mean values and standard deviation of the DRT hit rate (a) and DRT response time (b) of the two groups, one using the infotainment system without adaptive recommendation service and the other using it with adaptive recommendation service.

8.6 Discussion

The goal of this study is the evaluation of the recommendation service with regard to usability and driver distraction. In the case of usability, the recommendation service is analyzed regarding two aspects. The first aspect is the comparison to the state-of-the-art represented by variant A. According to the results, the mean values for the ratings of variant B are higher for all categories of the ISONorm questionnaire (I) and questionnaire for adaptive systems (A) in comparison to variant A. Significant results are found in the total ratings and categories self-descriptiveness (I), error tolerance (I), suitability for individualization (I) and controllability (A). As a consequence it can be said that the applied measures have improved the usability of the adaptive recommendation service.

It is conspicuous that the rating for self-descriptiveness (I) is significant while the rating of transparency (A) is not. The same refers to rating of controllability which is significant for the adaptive system questionnaire but not for the ISONorm questionnaire. Although, the results are not contradictory, they don't show the same effects. Here it is important to consider that the adaptive system questionnaire is specialized for the usability of adaptive systems and therefore has another focus. It is not possible to compare the results directly; they can be seen as complements. A next step is the further improvement of the questionnaire for adaptive systems, which includes the validation of the questionnaire, to use it as a reliable source of explanation. For the moment, it can be concluded that variant B has been improved especially regarding the categories with a significant difference. These categories match the requirements for adaptive systems.

Comparing the value of the ratings in this study with the results from Prümper (1997) as shown in Table 6-5 on page 89, it can be seen that the rating of variant B is lower for the categories controllability and error tolerance as the mean value of 41 studies. These are the categories with the lowest rating of the ISONorm questionnaire. Although the usability of the adaptive recommendation service has been improved through the taken measures, there is still potential of further improvement.

The second aspect regarding usability is the effect on the usability rating in comparison between an infotainment system with and without an adaptive recommendation service. The adaptive recommendation service should support the user and can improve the operability. If the support meets the user's requirements, the overall usability is expected to be improved. The results show a significant improvement of the usability comparing the rating of the infotainment system without recommendation service and the rating of the infotainment system with adaptive recommendation service in variant B. There is no significant difference between the ratings of the manual infotainment system and variant A. It can be concluded, that an adaptive recommendation service has a positive effect on the overall usability but the realization of the adaptive recommendation service has an important impact. While the usability of variant A is not rated as highly as the usability of variant B, only the usage of an infotainment system with variant B has a positive effect on the usability of the overall system.

The second part of the analysis is dedicated to driver distraction. The results are interpreted separately for the case of receiving a fitting recommendation and the case of receiving a false recommendation. In case of receiving a fitting recommendation it is proven that the manual distraction is reduced for all tasks. In addition to the manual distraction, the effects on visual and cognitive distraction are analyzed. Therefore, it is necessary to have a look at the overall results. Table 8-5 shows the results of the statistical tests for the analysis of driving performance (SDLP), task performance (task duration) and DRT performance (hit rate and response time). For task 1 a significant difference can be determined for all parameters related to driver distraction. It was expected that the adaptive recommendation service has a greater beneficial effect for tasks with a high difficulty level as it is the case for task 1. This can be confirmed.
The results for task 2 and task 3 must be interpreted carefully as the preconditions described in Section 8.5.2 are not satisfied. However, the results also show a reduction of distraction for both tasks. Although all results point in the same direction, a significant reduction cannot be detected for all parameters. Possibly, the effect for the tasks with a lower difficulty level is not big enough to detect it with the number of participants taken part within this study.
In general, it can be concluded that the adaptive recommendation service reduces the overall driver distraction in the case of receiving a fitting recommendation.

Table 8-5.: Overview of the statistical results referring to driver distraction represented by the parameters SDLP, task duration, DRT hit rate and DRT response time, for each task.

	SDLP	Task Duration	DRT Hit Rate	DRT Response Time
T1	+	+	+	+
T2	+	+	+	o
T3	o	+	+	o
T4	o	o	o	o

In the case of a false recommendation no significant effect is detected for any of the observed parameters. Nevertheless, the mean values show a deterioration while using an infotainment system with adaptive recommendation service in comparison to using an infotainment system without adaptive recommendation service. This effect can be explained with the need to overwrite the actions of the adaptive recommendation service to solve the task successfully. It can be concluded that the adaptive recommendation service has no significant negative effect even in a worst case scenario. This still has to be confirmed with the conduction of equivalence tests. In addition to this result, the variance within the data, as for example for SDLP or DRT Hit Rate, is conspicuous. This indicates that the participants manage the worst case scenario very differently. An additional study is suggested to analyze this effect and cause in detail.
The results related to driver distraction show the same effect as in previous studies from Garzon (2013) and Lavie (2007) for driving performance and task performance. In comparison to these results, this study analyses whether a negative effect on cognitive load induced by the usage of the adaptive recommendation service can be detected. Such an effect is not discovered.

Apart from the analysis of usability and driver distraction, our method of evaluating an adaptive recommendation service was tested. Although the study is very extensive, the participants were able to understand the functionality of the adaptive recommendation service. The significant results show the success of this method to detect the effects of an adaptive recommendation service on driver distraction. In addition, the evaluation of its usability creates the basis for next steps. However, a higher focus on the usability problems of adaptive systems is needed to gain more detailed insights. Therefore, the elaborated questionnaire needs to be further improved.

9 Conclusion

An adaptive recommendation service is a promising approach to reduce driver distraction. In this work an adaptive recommendation service has been developed and evaluated. The results are summarized below and the different steps and approaches discussed. In addition, an outlook of next steps is given.

9.1 Summary

The adaptive recommendation service observes the interactions of the user with its infotainment system in the vehicle. It learns the usage behavior depending on the current context, so that it is able to give recommendations of preconfigured functions when the context is observed again. The recommendations help the user to reduce interaction steps necessary to access and configure a function of an available application, thereby allowing more time to concentrate on driving and with less distraction then when using the functions manually. The adaptive recommendation service is able to support all installed applications on the infotainment system and is therefore widely applicable.

Through the increasing number of available applications and functions, reduction of driver distraction caused through the usage while driving is gaining more importance. Driver distraction can only be reduced when the driver accepts the support, so the technology must be user friendly. Adaptive systems hold the risk that the user feels out of control, doesn't understand the behavior, or becomes annoyed through the obtrusiveness of the system. In literature, approaches to improve the usability of an adaptive system have been described.

For this work two research questions have been raised. The first addresses the issue of whether an extendable adaptive recommendation service is applicable to reduce driver distraction and will be accepted by the user. The second refers to the measures that can be taken to improve usability, and whether the usability of the adaptive recommendation service can be improved by measures already described within the state-of-the-art for the automotive domain. For the analysis of these two research questions, a driving simulator study was conducted. Prior to this, an adaptive recommendation service was developed focusing on a software architecture describing the components and interfaces and an interaction concept. In particular the requirement of extendibility influenced the solutions of software architecture and interaction concept.

The development of the adaptive recommendation service used in the driving simulator study included the following steps. First, a design for a reference architecture was created. This included a requirement analysis, which was the basis for a description of the components and their interfaces as a high-level architecture. This reference architecture of the adaptive recommendation service was integrated in an overall HMI architecture. One main requirement was the extendibility during run time to enable the support of later installed applications.

One component of the adaptive recommendation service is the user interface. The interaction concept for this was developed within five iterations of a user-centered development process, focusing on the improvement of usability through applied measures. Also the interaction concept had to support the extendibility regarding recently installed applications. First, the user requirements were collected with the help of a user interview and literature research and analyzed.

The following iterations included an additional user interview, an expert evaluation, and a Wizard of Oz study. Measures to improve the usability were applied to further develop the interaction concepts known from the state-of-the-art and evaluated for usage within the automotive domain. The overall approach of an adaptive recommendation service, requiring different support levels, needed information to ensure transparency of the adaptive recommendation services' behavior, and suitability of measures to improve controllability, were analyzed.
Both the software architecture and the interaction concept have built the basis for the implementation of a proof-of-concept as a high-fidelity prototype. This prototype has been integrated into an infotainment system used as a pre-development platform within Bosch, based on software and hardware used for series products.
The high-fidelity prototype includes two different interaction concepts which can be selected. One represents the state-of-the-art, the other is the further developed concept of this work. Both are compared to each other regarding usability and are taken to evaluate the effect of using an adaptive recommendation service on driver distraction within a driving simulator study. The challenge for this user study was to develop a suitable method enabling the user to experience the adaptive recommendation service and put the participant in the position to evaluate it authentically. Within the study, driving performance, as well as task performance and performance of conducting a Detection Response Task were measured and analyzed. For the evaluation of usability two different questionnaires were used; the standardized ISONorm questionnaire and a specially developed questionnaire for adaptive systems.
Looking at the research questions from the beginning, the results of this work show that the usability of the adaptive recommendation service has been improved through the applied measures in comparison to the state-of-the-art. Therefore, an approach has been found to apply the described measure from literature for the automotive domain. In addition, it was shown that the extendable adaptive recommendation service is applicable to reduce driver distraction when receiving a fitting recommendation and not causing significantly more distraction in case of a non-fitting recommendation. The adaptive recommendation service has a positive influence on the overall usability rating of the infotainment system. Therefore, it can also be supposed that the adaptive recommendation service is accepted by the user. This effect was only shown for the improved variant of the adaptive recommendation service developed within this work.

9.2 Discussion and Future Work

Different aspects, including a method for the evaluation of an adaptive system in the automotive context, a user-centered development process to develop an interaction concept for the adaptive recommendation service, and a software architecture, have been researched within this work. These methods, relevance of the results and open points are discussed in the following.
The evaluation of adaptive systems is a big challenge. In this work, it was possible to evaluate the adaptive recommendation service and get significant results with the developed method. Although the used prototype is in an early stage of development, the results can be used for further development of the adaptive recommendation service. The functional range of the high-fidelity prototype and the user story focused on the experience of the behavior of the adaptive recommendation service for different use cases.
However, due to the early stage within the development process, the transferability of the results need to be verified. Still, the participants experience only parts of the behavior and in a very short time. They need to imagine how the system could be beneficial or disruptive in real life and need to transfer it to evaluate the adaptive recommendation service. In future, the adaptive recommendation service needs to be evaluated in a context of real usage. A field study should be conducted. This leads to the question of which method can be used to measure driver distraction.

In the setup used in the conducted driver simulator study, where a user story was applied, the DRT method was suitable to evaluate cognitive load. A possibility is to use the DRT method also in the field test or replace the method through the evaluation of eye gaze. For the evaluation of usability or driver acceptance in a field study, the same questionnaires could be used or a diary written in a long-term study. Before using the extended questionnaire for adaptive systems in another study it should be validated. The results collected with the questionnaire were not contradictory to the results from the standardized ISONorm questionnaire but not as expected. A significant difference was detected only for one of three categories. Either there was no significant difference between the two variants of the adaptive recommendation service for the other two categories, the effect was not big enough, or the questionnaire was not applicable. This should be further evaluated to have a validated instrument for the evaluation of usability for adaptive systems.

The decision to use a user-centered development process for the development of the interaction concept was beneficial for the results. The interaction concept including the applied measures was evaluated regarding different aspects within each iteration. The order of the selected methods was suitable. Methods conducted with less effort and complexity were used first to get important insights from potential users and experts. Therefore, it was possible to improve the interaction concept very early and with little effort. The functionality and complexity of the prototypes increased with each iteration of the user-centered design process. This iterative approach is suitable to develop a concept with a high-quality already in an early stage of development.

The result is a further developed and evaluated interaction concept based on the state-of-the-art including measures for improvement of the usability. It is a big step from here to the direction of a real product but still some more thoughts must be made. A focus topic is transparency regarding the behavior of the adaptive recommendation service. The transparency has been improved through the applied measures, which was one result of the conducted user studies. However, different user groups have different requirements and the interaction concept needs to be evaluated for different users groups, as for example first-time users or routine users.

Two aspects, the design and content, are especially important for the interaction concept. The design is not just the look and feel but must support the understandability of the content. It is a fine line between showing as much information as needed to fully understand the system's abilities and not being distracted through the displayed information. An appropriate design can support the driver to capture the needed information easily without being distracted too much. A limiting factor is the size of the display but the trend of bigger displays in the vehicle can be beneficial in this direction, although it could possibly increase the effect in the other direction. Some improvements can be done with different design and display sizes.

The developed software architecture is the basis for further prototypes and products. It describes the interaction between the different involved components. This approach is the first software architecture taken into account the factor of extendibility. A software development kit (SDK) should be provided to infotainment system app developers, that they can use the interfaces provided by the adaptive recommendation service.

The high-fidelity prototype includes some components which are not fully functional because they were not in main focus of this work. These components need to be further developed, as for example the components containing algorithms to learn the usage behavior. One important requirement for these algorithms is that they must support the transparency of the adaptive recommendation service. This means that the learned behavior of the adaptive recommendation service must be extractable in a way that it can be shown to the users. Köhler (2017) as well as Kopp (2017) have developed different approaches to collect data for the training of these algorithms and have analyzed different forms of algorithms regarding their suitability for the adaptive recommendation service. The focus of their work was on the demonstration of the adaptive rec-

ommendation service with an included machine learning algorithm. Further work must be done to transfer the results to realistic conditions.
This work has made an important contribution to the development of an adaptive system for the usage within the vehicle.

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Glossar

AAM	Alliance of Automobile Manufacturers
AIDE	Adaptive Integrated Driver-vehicle Interface
AUI	Adaptive User Interface
ANOVA	Analysis of Variance
CAN	Controller Area Network
DALI	Driving Activity Load Index
DRT	Detection Response Task
DVE	Driver-Vehicle-Environment
ECU	Electronic Control Unit
ESoP	European Statement of Principles
FA	Fully Adaptive
GUI	Graphical User Interface
HMI	Human-Machine-Interface
HR	Hit Rate
ICA	Interaction and Communcation Assistant
IC	Interaction Controller
IF	Interface
IUI	Intelligent User Interface
IUN	Identification of User Needs
JAMA	Japan Automobile Manufactures Association
KPI	Key Performance Indicator
LCT	Lane Change Test
MOST	Media Oriented Systems Transport
MRT	Mean Response Time
NASA-TLX	NASA Task Load Index
NHTSA	National Highway Traffic Safety Administraction
OEM	Original Equipment Manufacturer
OS	Operating System
RSME	Rating Scale Mental Effort
RT	Response Time
SDK	Software Development Kit
SDLP	Standard Deviation of Lane Position
SUS	System Usability Scale
TAM	Technology Acceptance Model
TSOT	Total Shutter Open Time
TTT	Total Task Time
UA	User Approval
UI	User Interface
UM	Usage Model
US	User Selection
UTAUT	Unified Theory of Acceptance and Use of Technology

A User Interview Guideline

Datum:
Personencode:

Vorbefragungsbogen

Sehr geehrte(r) Teilnehmer(in),

zur Beschreibung der Versuchsteilnehmer benötigen wir nachfolgende Daten von Ihnen. Diese Daten werden absolut vertraulich behandelt und ausschließlich anonymisiert ausgewertet.

Persönliche Daten	
Geschlecht	☐ weiblich ☐ männlich
Alter	
Höchster erreichter Bildungsabschluss	☐ Noch in schulischer Ausbildung ☐ Kein allgemeinbildender Schulabschluss ☐ Haupt- / bzw. Volksschule ☐ Realschule bzw. gleichwertiger Abschluss ☐ Fach- / Hochschulreife (Abitur / EOS) ☐ FH / Universität
In welchem Beschäftigungsverhältnis befinden Sie sich?	☐ Angestellter ☐ Beamter ☐ Selbstständiger / Freiberufler ☐ In Ausbildung (Schüler, Auszubildender, Student) ☐ Rentner ☐ Hausfrau / -mann ☐ Nicht berufstätig ☐ Andere: ________________________________
Ausgeübter Beruf	
Andere halten mich für einen technisch begabten Menschen.	☐ stimme voll zu ☐ stimme eher zu ☐ stimme eher nicht zu ☐ stimme überhaupt nicht zu
Besitzen Sie ein eigenes Auto?	☐ ja ☐ nein
Nutzen Sie hauptsächlich Car Sharing oder ihr eigenes Auto?	☐ eigenes Auto ☐ Car-Sharing
Welches Fahrzeugmodell benutzen Sie hauptsächlich?	
Seit wann besitzen Sie einen Führerschein?	

Datum:
Personencode:

Erfahrung im Umgang mit Produkten	(fast) täglich	mehrfach wöchent-lich	mehrfach monatlich	seltener	noch nie
Wie oft benutzen Sie ein Radio-Navigations-System?	☐	☐	☐	☐	☐
Wie oft benutzen Sie ein Smartphone?	☐	☐	☐	☐	☐
Wie oft benutzen Sie ein Tablet?	☐	☐	☐	☐	☐
Wie oft benutzen Sie die Navigationsfunktion Ihres Smartphone?	☐	☐	☐	☐	☐
Falls Sie ein Radio-Navigations-System besitzen, welches und seit wann?	Hersteller: ____________________________________ Typ: ____ Seit:____				
Falls Sie ein Smartphone besitzen, welches und seit wann?	Hersteller: ____________________________________ Typ: ____ Seit:____				
Wie viele Kilometer fahren Sie ungefähr im Jahr?					

Datum: Personencode:

Gesprächsleitfaden

Die Datenerhebung teilt sich in die folgenden 6 Bereiche:

1. Allgemeine Einführung und organisatorische Punkte
2. Fragen zu Demografie, Technikaffinität und Erfahrung mit Produkten
3. Kurze Einführung in Thema adaptives HMI anschließend vertiefendes teilstrukturiertes Interview
4. Eigene Konzepte im Form von Szenarien als Stimuli präsentieren und Feedback einholen
5. Verabschiedung

Die Fragenteile 3, 4 und 5 sind grundsätzlich als Befragung mit paralleler Beobachtung ausgelegt. Dabei geben die Beobachtungen wichtige Hinweise für die weiterführende Befragung (auch Emotionale Regungen, Ausrufe, Gestiken etc. erfassen).

Zeitrahmen: Ungefähre Zeitdauer zu den einzelnen Bereichen ist bei der jeweiligen Überschrift mit angegeben.

Requisiten: Fotokamera, Audiorecorder mit Ersatzbatterien, Interviewmaterial (Leitfaden, Einverständniserklärung /Vertraulichkeitsvereinbarung, Visitenkarte), Klemmbretter.

Kursive Textabschnitte sind nur als Hinweise für den Interviewer gedacht und werden dem Probanden nicht vorgelesen.

Datum: Personencode:

1. Einführung		Material
Ort : Treffpunkt, außerhalb Auto	**Dauer:** 5 min (__:__ bis __:__)	**Leitfaden**
Begrüßung	Schön, dass Sie sich Zeit nehmen, an unserer Studie teilzunehmen. *Vorstellung der Beteiligten*	
Ziel der Studie	Wir untersuchen **verschiedene Bedienmöglichkeiten von technischen Produkten** oder Systemen im Auto, die nebenher beim Fahren genutzt werden. Um die spätere Entwicklung entsprechend der Nutzerbedürfnisse lenken zu können, möchten wir mehr über Ihre Erwartungen und Wünsche, Ihre **bisherigen Erlebnisse mit der aktuellen Bedienung und Ihre üblichen Handlungsabläufe** erfahren. Uns interessieren auch die Dinge, die bereits gut funktionieren und die Sie eher schlecht finden. Die Ergebnisse werden dann in die Neuentwicklung einfließen.	
Ablauf	Der Termin wird ca. - h dauern und folgendermaßen ablaufen: Zunächst haben wir ein **paar Fragen zu Ihrer Person**. Uns interessiert Ihr **Umgang mit Geräten in Ihrem Fahrzeug** (z.B. Radio, Telefon, Media-Player und Navi), und Ihre persönliche Meinung, was daran gut gelöst ist, was Sie daran weniger gut finden, wo Sie vielleicht Hilfsmittel oder andere Lösungen hinzuziehen, also alles, was Ihnen bei der Bedienung auffällt. Der zweite Teil wird bei **Bosch vor Ort** ablaufen. Hier werden wir Ihnen ein Bedienkonzept genauer vorstellen.	
Teilnahme-erklärung	Vorab benötigen wir eine Unterschrift zu Geheimhaltung und Datenschutz.	Teilnahme-erklärung
Grundsätzliches	Sie können das Interview jederzeit ohne Nachteile für Sie unterbrechen oder abbrechen. Falls wir das Interview unterbrechen sollen oder Sie eine Pause benötigen, geben Sie bitte sofort Bescheid.	

Datum: Personencode:

<table>
<tr><td colspan="2">2. Vorbefragung</td><td colspan="2"></td><td>Material</td></tr>
<tr><td colspan="2">Ort : Im Auto</td><td colspan="2">Dauer: - min (__:__ bis __:__)</td><td></td></tr>
<tr><td colspan="4">Interview mit Fragebogen</td><td>Vorbefragungs-bogen</td></tr>
<tr><td>Nutzungs-verhalten Infotainment-system</td><td colspan="3">Welche Funktionen Ihres Radio-Navigationssystem benutzen Sie hauptsächlich?
1.
2.
3.
4.
5.

Welche zusätzlichen Funktionen bzw. Informationen würden Sie gerne im Auto nutzen (Was, evtl. Funktionen, die bisher nur auf dem Smartphone verfügbar sind)?</td><td></td></tr>
<tr><td>Typische Nebentätig-keiten</td><td colspan="3">Welche Handlungen führen Sie neben dem Fahren aus? Wie häufig (täglich, wöchentlich,…)? In welcher Situation?
(Wenn nötig, Fokus auf Interaktionen mit dem Infotainmentsystem, Smartphone oder Funktion des Fahrzeugs lenken)
1.
2.
3.
4.
5.

Weitere:</td><td></td></tr>
</table>

Datum: Personencode:

Bewertung	1. Wie unterstützen Sie Ihre bisherigen Systeme bei diesen Tätigkeiten? 2. Nutzen Sie dabei unterschiedliche Lösungen? 3. Was ist daran gut gelöst? Warum ist das so? 4. Was ist weniger gut gelöst? Warum ist das so? 5. Gibt es etwas, was Ihnen fehlt, um die Bedienung zu erleichtern?	
Erfahrung mit bisherigen Systemen	6. Wie lange nutzen Sie schon die bisherigen Systeme? 7. Wie haben Sie sich mit der Bedienung vertraut gemacht?	

Datum: Personencode:

3. Adaptive Unterstützung		Material
Ort : Im Auto	**Dauer:** - min (von __ bis___)	
Wünsche für Bedienung	Stellen Sie sich vor, ihr Auto könnte sich an Sie anpassen um Sie bei der Bedienung von Funktionen besser zu unterstützen. Gibt es Handlungen, bei denen Sie gerne unterstützt werden möchten? Wenn ja, welche? Warum? Wie? Wie könnte das Fahrzeug Sie unterstützen?	

Datum: Personencode:

4. Interaktionskonzept adaptives HMI			Material
Ort : Leonberg		**Dauer:** - min (von __ bis___)	
Interaktions-konzept	Präsentation des Interaktionskonzept anhand verschiedener Szenarien		Folien
Stufe 1	**System Status: Manuell**		Folien 1, 2, 3a-6a
	Weitere Fragen zum Interaktionskonzept: 1. Wie gut hat Ihnen die Bedienung insgesamt gefallen? (Skala) Was war gut daran? Was war schlecht? 2. Wie einfach oder schwierig war die Bedienung? (Skala) Was war intuitiv? Was war nicht intuitiv? 3. Wie würden Sie die Bedienbarkeit beschreiben? (Ergonomie und Erlernbarkeit) 4. Wie <u>nützlich</u> und hilfreich ist das Interaktionskonzept für Sie bei der Fahrt? 5. Was muss noch verbessert werden? Haben Sie eine Idee, wie man das verbessern kann? 6. Gibt es bei Ihnen Bedenken? 7. Würden Sie sich ein solches System ins Auto einbauen lassen? Wenn ja, unter welchen Voraussetzungen?		

Datum: Personencode:

Stufe 2	**System Status: User Selection**	Folien 1, 2, 3b-4b
	Weitere Fragen zum Interaktionskonzept: 1. Wie gut hat Ihnen die Bedienung insgesamt gefallen? (Skala) Was war gut daran? Was war schlecht? 2. Wie einfach oder schwierig war die Bedienung? (Skala) Was war intuitiv? Was war nicht intuitiv? 3. Wie würden Sie die Bedienbarkeit beschreiben? (Ergonomie und Erlernbarkeit) 4. Wie nützlich und hilfreich ist das Interaktionskonzept für Sie bei der Fahrt? 5. Was muss noch verbessert werden? Haben Sie eine Idee, wie man das verbessern kann? 6. Gibt es bei Ihnen Bedenken? 7. Würden Sie sich ein solches System ins Auto einbauen lassen? Wenn ja, unter welchen Voraussetzungen? 8. Welchen Mehrwert sehen Sie in der Verwendung dieses Bedienkonzepts im Verhältnis zu einer manuellen Bedienung (ggf. bisherigen System)? 9. Wie positiv ist Ihr Nutzungserleben im Verhältnis zu einer manuellen Bedienung (ggf. bisherigen System)?	

Datum: Personencode:

Stufe 3	System Status: User Approval	Folien 1, 2, 3c-4c
	Weitere Fragen zum Interaktionskonzept: 1. Wie gut hat Ihnen die Bedienung insgesamt gefallen? (Skala) Was war gut daran? Was war schlecht? 2. Wie einfach oder schwierig war die Bedienung? (Skala) Was war intuitiv? Was war nicht intuitiv? 3. Wie würden Sie die Bedienbarkeit beschreiben? (Ergonomie und Erlernbarkeit) 4. Wie nützlich und hilfreich ist das Interaktionskonzept für Sie bei der Fahrt? 5. Was muss noch verbessert werden? Haben Sie eine Idee, wie man das verbessern kann? 6. Gibt es bei Ihnen Bedenken? 7. Würden Sie sich ein solches System ins Auto einbauen lassen? Wenn ja, unter welchen Voraussetzungen? 8. Welchen Mehrwert sehen Sie in der Verwendung dieses Bedienkonzepts im Verhältnis zu einer manuellen Bedienung (ggf. bisherigen System)? 9. Wie positiv ist Ihr Nutzungserleben im Verhältnis zu einer manuellen Bedienung (ggf. bisherigen System)?	

Datum: Personencode:

Stufe 4	**System Status: Fully adaptive**	Folien 1, 2, 3d
	Weitere Fragen zum Interaktionskonzept: 1. Wie gut hat Ihnen die Bedienung insgesamt gefallen? (Skala) Was war gut daran? Was war schlecht? 2. Wie einfach oder schwierig war die Bedienung? (Skala) Was war intuitiv? Was war nicht intuitiv? 3. Wie würden Sie die Bedienbarkeit beschreiben? (Ergonomie und Erlernbarkeit) 4. Wie nützlich und hilfreich ist das Interaktionskonzept für Sie bei der Fahrt? 5. Was muss noch verbessert werden? Haben Sie eine Idee, wie man das verbessern kann? 6. Gibt es bei Ihnen Bedenken? 7. Würden Sie sich ein solches System ins Auto einbauen lassen? Wenn ja, unter welchen Voraussetzungen? 8. Welchen Mehrwert sehen Sie in der Verwendung dieses Bedienkonzepts im Verhältnis zu einer manuellen Bedienung (ggf. bisherigen System)? 9. Wie positiv ist Ihr Nutzungserleben im Verhältnis zu einer manuellen Bedienung (ggf. bisherigen System)?	

Datum: Personencode:

	Vergleich zwischen den Systemen	
	1. Welchen Mehrwert sehen Sie in der Verwendung eines sich anpassenden Systems im Verhältnis zu einer manuellen Bedienung (ggf. bisherigen System)? 2. Welche der vorgestellten Konzepte hat ihnen am besten gefallen? 3. Denken sie, dass eines der Konzepte Vorteile oder Schwächen gegenüber dem anderen hat? Wenn Ja, welche und warum? 4. Für welche Interaktion im Auto würden sie sich eines der Konzepte wünschen? Welches und warum? *(Wenn nötig auf weitere Interaktionen Hinweisen. Navigation, Mail / SMS, Telefon, Climate, Radio, CD)* 5. Was möchten sie den Entwicklern noch mitgeben?	

5. Verabschiedung		**Material**
Ort : Leonberg	**Dauer:** - min	
	Hiermit kommen wir zum Ende des Interviews. Vielen Dank für Ihre aktive Unterstützung!	

B Heuristics

1. Sichtbarkeit des Systemstatus: "Der Benutzer sollte den Systemstatus jederzeit erkennen können."
2. Kompatibilität zwischen System und realer Welt: "Das System sollte die Sprache des Anwenders sprechen, mit Worten, Phrasen und Konzepten, welche dem Benutzer vertraut sind."
3. Kontrolle / Freiheit / Aufdringlichkeit: "Der Benutzer sollte das System kontrollieren können, er sollte Aktionen selbst starten, die Geschwindigkeit der Interaktion selbst bestimmen und nicht nur auf das Gerät reagieren müssen."
4. Fehlervermeidung: "Macht der Benutzer in den Eingaben einen Fehler, sollte er jederzeit die Möglichkeit haben, diesen wieder rückgängig zu machen oder zu verbessern."
5. Konsistenz: "Die Darstellungen sollten konsistent sein, ähnliche Funktionen sollten ähnlich aufgebaut sein, damit der Benutzer das Interaktionskonzept wiedererkennen kann."
6. Dem Benutzer sollten immer die relevanten Informationen gezeigt werden, nicht mehr und nicht weniger. Besonders während der Fahrt ist es wichtig, die richtige Information zur richtigen Zeit zu haben.
7. Systeme sollten den Fahrer nicht von seiner Fahraufgabe ablenken, zum Beispiel nicht fahrrelevante Informationen (besonders ablenkende Bilder, Animationen und Filme) sollten dem Fahrer nicht angezeigt werden.
8. Systemverhalten: Das Systemverhalten sollte zu jedem Zeitpunkt vom Anwender nachvollzogen werden können.
9. Bedienbarkeit: Das System sollte intuitiv bedienbar sein.

C Findings of Heuristic Evaluation

Table C.1.: Findings of the heuristic evaluation related to concept US1 (H = Heuristic, S = Severity, F = Frequency)

Beschreibung	Lösung	H	S	F
im Homescreen wirkt das normale Menü ausgegraut, da die Leiste greller ist; nicht ersichtlich, ob noch alle Funktionen verwendbar sind	...	1	3	1
Shortcut ist nicht mehr verfügbar nach einmaligem Ausführen	Shortcut weiterhin anbieten, wenn dieser einmal gewählt aber dann abgebrochen wurde	6	3	1
unterschiedliche Wahrscheinlichkeiten bei mehreren Vorschlägen nicht erkennbar	sortieren der Vorschläge nach Wahrscheinlichkeit	6	2	1
Anzahl der Vorschläge nicht wichtig	keine Symbole für Anzahl der Vorschläge	6	2	1
Leiste ueberflüssig wenn keine Vorschläge aktiv	Leiste entfernen wenn kein Vorschlag aktiv	6	2	1
Wechsel des Screens obwohl Ausführung des Vorschlags nicht die visuelle Ausgabe benötigt	Screenwechsel nur wenn visuelle Informationen angezeigt werden, sonst aktuellen Screen beibehalten	6	1	1
zu wenig Informationen zu Shortcuts um nachvollziehen zu können warum diese angezeigt werden	ausführliche Erklärung direkt beim Shortcut	8	3	1
ausgefahrene Leiste ueberflüssig wenn kein Vorschlag angezeigt wird	im Homescreen Leiste eingeklappt, wenn kein Vorschlag vorhanden ist	8	4	2
unklar welche Inhalte die Leiste anzeigt	Liste sollte benannt werden	9	3	1
für Erstbenutzer ist die Bedienung schwierig	bei erstmaligem Benutzen kurze Erklärung der Funktionen	9	3	1
kleine blaue Punkte zu klein und unauffällig, Bedeutung unklar	kleine Zahlen benutzen	9	4	1
Anordnung der blauen Punkte nicht nachvollziehbar (Mapping unklar)	von oben auffüllen oder ortsfeste Position	1, 2, 5	4	4
Reihenfolge der Shortcuts wird nach Auswahl anders erwartet	Reihenfolge und Platzierung beibehalten	2, 8, 9	4	2
Bedienelement zum Einklappen der Leiste ohne Funktion im Homescreen	im Homescreen Leiste auch einklappbar gestalten oder Einklapp-Element entfernen	5, 9	4	2

Table C.2.: Findings of the heuristic evaluation related to concept US2 (H = Heuristic, S = Severity, F = Frequency)

Beschreibung	Lösung	H	S	F
Priorität der Vorschläge nicht erkennbar	Reihenfolge der Shortcuts von oben nach unten mit abnehmender Priorität, oder von oben nach unten auffüllen	6	2	1
häufig genutzte Funktionen werden nur abhängig von der Situation angezeigt	Funktionen die oft benutzt werden, aber in keiner bestimmten Situation, auch als Shortcut anzeigen		0	1
Vorschläge auch im Homescreen eingefahren	im Homescreen immer ausgefahren lassen	6	1	2
Wechsel des Screens obwohl Ausführung des Vorschlags nicht die visuelle Ausgabe benötigt	Screenwechsel nur wenn visuelle Informationen angezeigt werden, sonst aktuellen Screen beibehalten	6	1	2
Shortcuts schwer zu unterscheiden, da ähnliche Icons	mehr Icons einführen	6	1	1
eingefahrener Shortcut zeigt zu wenig Informationen an	Stichwort hinzufügen z.B. SWR3, Office	6	2	1
Reihenfolge der Shortcuts sollte nicht dynamisch sein	Position des Shortcuts soll gleich bleiben	8	4	1
immer nur ein Shortcut ausklappbar	mehrere Shortcuts auf einmal ausklappbar	9	3	2
nicht erkennbar wie Vorschlag ausgeführt werden kann	um Aktion auszuführen das Icon als Button verwenden	3, 5, 9	4	6
nicht eindeutig, wie Shortcuts einzuklappen sind	wischen/schieben für rein/raus	3, 5, 9	4	5
Blickerkennung ungeeignet zur Steuerung	Shortcuts nach einer gewissen Zeit einfahren	7, 9	4	1

Table C.3.: Findings of the heuristic evaluation related to concept UA (H = Heuristic, S = Severity, F = Frequency)

Beschreibung	Lösung	H	S	F
keine Möglichkeit Vorschläge direkt zu deaktivieren	Auswahl Ja/Nein/Nie wieder zum deaktivieren, Menü enthält nur Zustimmung zum allgemeinen Lernen, spezielle Fälle bei Popup deaktivieren können	3	2	1
Aufdringlichkeit sehr hoch, man ist gezwungen zu reagieren, fehlende Kontrolle über restliche Funktionen des Systems		3	2	6
Wechsel des Screens obwohl Ausführung des Popups nicht die visuelle Ausgabe benötigt	Screenwechsel nur wenn visuelle Informationen angezeigt werden, sonst aktuellen Screen beibehalten	6	1	2
Aktion und Ziel im Popup optisch besser trennen	Schriftgröße, Schriftart, Schriftfarbe, Bilder für SWR3	1, 2	3	2
Navi Popup nur wenn notwendig anzeigen z.B. bei Stau			0	1
nur bei sehr hoher Sicherheit/Wahrscheinlichkeit darf das System Vorschläge machen			0	1

Table C.4.: Findings of the heuristic evaluation related to concept FA (H = Heuristic, S = Severity, F = Frequency)

Beschreibung	Lösung	H	S	F
Aufdringlichkeit zu hoch		3	3	2
kompletter Kontrollverlust, keine Entscheidungsmöglichkeit, Fahrer wird vom System gesteuert	Konzept nur bei Einstieg ins Auto	3	3	4
keine Freiheit, man ist gezwungen, Vorgang abzubrechen wenn dieser nicht gewollt ist		3	3	3
keine Möglichkeit Vorschläge direkt zu deaktivieren	neben Cancel Button "Cancel everytime" zum Deaktivieren der Einstellung	3	2	1
Cancel-Button zu unauffällig	kurzes Popup mit Cancel für ca. 10s	3	2	1
Wechsel des Screens obwohl die visuelle Ausgabe benötigt wird	Screenwechsel nur wenn visuelle Informationen angezeigt werden, sonst aktuellen Screen beibehalten	6	1	2
Aktion nicht nachvollziehbar		8	2	1
Button um direkt zum vorherigen Screen zurückzukommen	Geste z.B. wischen		0	1

D User Interview "Explanation Menu"

Datum: Personencode:

Gesprächsleitfaden

Die Datenerhebung teilt sich in die folgenden Bereiche:

1. Allgemeine Einführung und organisatorische Punkte
2. Vorbefragung Fragen zu Demografie und Technikaffinität
3. Kurze Einführung in Thema adaptives HMI.
4. Vorstellen des Use-Case mit einem Konzept eines Adaptiven Systems.
5. Befragungsteil 1
6. Erläutern der Problemstellung und Ziele dieser Arbeit
   Kurze Erklärung was in dieser Arbeit entwickelt werden soll, was die die Ziele sind.
7. Starten eines Prototypen mit der Aufgabe, die Detailinformationen zu den gezeigten Vorschlägen zu finden.
8. Befragungsteil 2
9. Verabschiedung

Datum: Personencode:

<table>
<tr><th colspan="3">2. Vorbefragung</th><th>Material</th></tr>
<tr><td colspan="2">Ort :</td><td>Dauer:</td><td></td></tr>
<tr><td colspan="3">Interview mit Fragebogen</td><td>Vorbefragungs-
bogen</td></tr>
<tr><td>Zur Person</td><td colspan="2">Wie alt sind sie?

Wie viele Km pro Jahr fahren sie Durchschnittlich?

Wie lange besitzen sie einen Führerschein?

Haben Sie ein eigenes Auto?

Würden sie sich selbst als Technikaffin beschreiben?
Ja I 5 4 3 2 1 INein</td><td></td></tr>
</table>

Datum: Personencode:

5. Befragungsteil 1			Material
Ort :		**Dauer:**	
	Vorstellen des Use-Case mit einem Konzept eines Adaptiven Systems, des Typs„User Approval".		PDF Mockup
Gefühlseindruck	1. Wie ist ihr Gefühl nachdem sie die gesehen haben, wie sich das System an sie anpasst und ihnen Vorschläge unterbreitet? 2. Würden sie sich ein solches System für ihr Fahrzeug wünschen?		
Fragen an das System	1. Welche Fragen würden sie dem System stellen wollen?		
Informationen über Verhalten und Wissen	1. Welche Informationen bezüglich dem Verhalten und dem Wissen des Systems hätten sie gerne?		

Datum: Personencode:

8. Befragungsteil 2		Material
	Präsentation eines der Konzepte	PDF Mockup
Gefühlseindruck	1. Hat sich ihr Gefühlseindruck bezüglich eines Systems welches sich an sie anpasst geändert? 2. Würden sie sich ein Adaptives System mit dieser Erweiterung in ihr Auto einbauen?	
Transparenz	1. Welche Fragen würden sie dem System jetzt noch stellen wollen? 2. Welche Informationen bezüglich dem Verhalten und dem Wissen des Systems hätten sie jetzt noch? 3. Würden sie sagen, dass sie durch das gezeigte Menü, besser verstehen können wie sich das System verhält? 4. Welcher der folgenden Aussagen würden sie zustimmen? Ich verstehe das Verhalten des Systems. (1) Ich verstehe das System weitestgehend. (2) Es gibt noch einige Unklarheiten wie sich das System verhält.(4) Es ist mir überhaupt nicht klar wie sich das System verhält.(5)	

Welche Fragen würden sie dem System stellen wollen? Welche Informationen bezüglich dem Verhalten und dem Wissen des Systems häten sie gerne?

Vorher	Kategorie	Konzept 1	Konzept 2	Konzept 3	Kommentare
Erkennt mich das Auto automatisch?		x			2 x Output
Reagiert das Fahrzeug für alle Fahrer gleich / unterschiedlich?	Output	x			2 x How
Woher weiß das Auto was ich will / was ich nicht will?	How	x	x	x	2 x What if
Lassen sich Vorschläge anpassen?	Configurability	x		x	3 x Input
Welche Dinge werden vom Fahrzeug gemessen	Input	x			3 x Configurability
Für welche Applikationen macht es mir Vorschläge		x	xx	x	1 x Certainty
Beispielsituation zum Verständniss erstellt und Verhalten erfragt	What if		x	x	
Sind meine Daten sicher?				x	
Entspricht der Vorschlag auch wirklich meinem Wunsch	Certainty			x	
Wie lernt das System?	How			x	
Welche Parameter spielen eine Rolle?	Input			x	
Kann ich es für bestimmte Applikationen abstellen?	Configurability			x	
Was passiert wenn der Vorschlag falsch ist?	What if			x	
Kann man das Wissen zurücksetzen?	Configurability			x	
Aus was setzt sich der Vorschlag zusammen?	Input			x	
Wird der Vorschlag irgendwann automatisch ausgeführt?	Output			x	

Nachher	Konzept 1	Konzept 2	Konzept 3	
Algorithmik			x	Diese Fragen können nur gestellt werden, wenn ein grundsätzliches Verständnis vorhanden ist
Ab wann wird der Vorschlag gezeigt (ab welcher Certainty)			x	
Für welche Applikationen gibt es Vorschläge?	x	x	x	
Beschränkt es sich auf eine bestimmte Anzahl von Vorschlägen in einer Situation?			x	
Können eigene Vorschläge erstellt werden?			x	
Kann das System abgeschaltet werden?	x	x		Werden in überarbeiteten Version beantwortet
Können einzelne Vorschläge gelöscht werden?		x		
Wie werden die Daten gemessen (Sensorik)?		x		

Würden sie sagen, dass sie durch das gezeigte Menü besser verstehen können wie sich das System verhält?

Alle Probanden antworteten mit Ja.

Verständnis des Verhaltens	Konzept 1	Konzept 2	Konzept 3	
Bewertung des Verständnis	1,75	1,5	2	Zwei der Personen, denen Konzept 3 gezeigt wurde, waren daran interessiert wie die Algorithmik funktioniert. Daher schneidet das System evtl. etwas schlechter ab. Lim & Dey äußerten bereits, dass Personen mit hoher Technikaffinität tiefergehende Informationen fordern.

Würden sie sich ein solches System in ihr Fahrzeug einbauen?	Vorher	Nachher	
abhängig von den Kosten	6	3	Zwei Probanden (Konzept 2) wechsen zu Ja, ein Proband (Konzept 3) zu Ja
Nein	3	2	Nachher: Beide Probanden erlebten Konzept 1, ein Proband (Konzept 2) ändert seine Meinung,
Ja	3	7	Vier Probanden haben Konzept 2 erlebt, drei Probanden Konzept 3, keine Konzept 1

E Wizard of Oz

Vorbefragung

Wie alt sind sie?

____

Wie viele Km pro Jahr fahren sie durchschnittlich?

____

Seit wie vielen Jahren besitzen sie einen Führerschein?

____

Haben sie ein eigenes Auto?

____

Wie hoch würden sie ihre technikaffinität einschätzen?

5 4 3 2 1

Höchster Bildungsabschluss

____

____

____

Befragungsbogen

Bemerkung: Proband darauf hinweisen, die Frage so ausführlich wie möglich zu beantworten. Wird die Frage nur knapp beantwortet – Nachfragen! Ankreuzen der Teile die von ihm benannt werden.

Vorschlag 1

Beschreiben sie, warum ihnen das Infotainmentsystem diesen Vorschlag unterbreitet hat.

Beschreiben sie die Situation in welcher ihnen dieser Vorschlag unterbreitet wird.

Mit welcher Sicherheit kann, das System sagen, dass dieser Vorschlag für sie Relevant ist.

Gibt es Alternativdarstellungen der Vorschläge? Welche?

Bemerkungen:

Vorschlag 2

Beschreiben sie, warum ihnen das Infotainmentsystem diesen Vorschlag unterbreitet hat.

____

Beschreiben sie die Situation in welcher ihnen dieser Vorschlag unterbreitet wird.

Mit welcher Sicherheit kann, das System sagen, dass dieser Vorschlag für sie Relevant ist.

Gibt es Alternativdarstellungen der Vorschläge? Welche?

Bemerkungen:

Vorschlag 3

Können sie beschreiben, aus welchen Gründen ihnen das System keinen Vorschlag unterbreitet hat.

Beschreiben sie, warum ihnen das Infotainmentsystem am Ende der Fahrt, keinen Vorschlag unterbreitet hat.

Beschreiben sie die Situation in welcher ihnen ein weiterer Vorschlag unterbreitet worden wäre

Mit welcher Sicherheit kann, das System sagen, dass dieser Vorschlag für sie Relevant ist.

Bemerkungen:

Auswertung ISONORM 9241-110

Anzahl der Fragebögen:	19

Faktor	Frage: Aspekt der Frage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Summe Einzelfragen	Summe Einzelfragen / Anzahl Fragebögen	Summe Faktor	ISONORM-Wert	
		Wert aus dem Fragebogen (Wert liegt zwischen 1 (---) und 7 (+++))																								
Aufgabenangemessenheit	Kompliziertheit	7	6	5	5	6	7	5	6	5	7	6	7	5	6	5	6	5		5	7	111	5,8			
	Vollständigkeit	7	7	6	6	5	7	6	7	6	7	6	6	5	6	5	5	6		2	5	110	5,8			
	Aufwandsminimierung	7	6	5	7	7	6	7	7	3	7	6	7	6	6	4	5	7		6	6	115	6,1	29,5		
	überflüssige Eingaben	7	6	4	6	6	7	5	7	2	7	6	7	6	7	5	4	5		7	6	110	5,8			
	Passung	7	6	6	6	6	6	6	7	4	7	6	7	6	6	5	7	6		6	5	115	6,1			Ø= 5,9
Selbstbeschreibungsfähigkeit	Überblick Funktionsangebot	7	6	6	6	5	6	6	7	6	7	6	7	5	6	7	3	6		5	6	113	5,9			
	Begrifflichkeiten	6	7	6	3	5	5	6	5	6	7	6	7	6	6	6	6	6		4	6	109	5,7			
	Informationsgehalt	7	6	7		5	6	6	6	5	7	6	7	6	6	6	4	5		5	6	106	5,6	27,8		
	Unterstützungsmöglichkeit	7	5	6	7	6	2	5	7	5	7	6	7	5	4	7	6	4		2	6	104	5,5			
	Unterstützungsangebot	7	4	6	7	6	7	5	6	5	1	6	7	5	4	2	6	5		5	3	97	5,1			Ø= 5,6
Erwartungskonformität	Gestaltungskonsistenz	7	7	6	7	6	6	7	7	6	7	5	7	5	6	7	4	7		5	6	118	6,2			
	Feedback	7	7	6	7	5	7	7	7	7	7	7	7	2	5	6	6	6		2	5	113	5,9			
	Transparenz	6	7	5	2	6	7	5	7	2	7	6	7	2	5	6	6	7		6	2	101	5,3	30,2		
	Vorhesagbarkeit	7	7	6	7	7	7	6	7	4	7	7	7	4	6	7	6	7		7	6	122	6,4			
	Bedienkonsistenz	7	7	6	7	7	6	7	7	7	7	6	7	5	6	6	4	6		6	6	120	6,3			Ø= 6,0
Lernförderlichkeit	Erlernbarkeit	7	7	7	4	6	6	6	6	7	7	6	7	6	6	5	7	7		5	7	119	6,3		175,5	
	Ermutigt neues zu versuchen	6	7	7	5	6	7	7	6	6	7	6	6	2	6	6	6	6		6	7	115	6,1			
	Denkanspruch	7	7	6	5	6	6	7	5	6	3	6	7	6	4	6	2	5		3	6	103	5,4	29,8		
	Einprägung von Wissen	7	7	7	6	6	7	6	7	6	7	4	7	6	6	7	6	6		5	5	118	6,2			
	Erschließbarkeit	7	7	6	4	6	7	6	5	6	7	3	6	6	6	5	6	7		7	5	112	5,9			Ø= 6,0
Steuerbarkeit	Unterbrechung ohne Verlust	7	7	5	7	7	7	5	7	5	7	6	6	5	6	6	6	4		6	4	113	5,9			
	Flexibilität	7	6	5	7	6	6	6	6	5	7	4	6	2	6	6	4	5		7	4	105	5,5			
	Wechselmöglichkeit	7	6	6	6	6	6	6	6	6	7	5	6	5	6	7	7	5		7	7	117	6,2	29,9		
	Informationskontrolle	7	6	6	7	6	6	6	6	6	7	7	7	5	7	5	5	6		7	2	114	6,0			
	Unterbrechungsfreiheit	7	7	6	7	5	7	6	7	6	7	6	7	5	6	5	6	6		7	7	120	6,3			Ø= 6,0
Individualisierbarkeit	Erweiterbarkeit	3	5	5	7	6	6	7	7	1	7	6	7	4	6	6	5	5		6	7	106	5,6			
	Personalisierbarkeit	7	5	6	7	5	7	7	7	2	7	5	7	6	6	7	7	6		7	6	117	6,2			
	Anfänger und Experten	7	4	6	5	6	5	7	7	2	7	4	7	6	6	5	4	6		2	5	101	5,3	28,1		
	Aufgabenflexibilität	3	4	6	7	6	5	7	7	1	7	5	7	4	6	6	7	6		6	6	106	5,6			
	Darstellung	7	5	6	5	6	5	7	7	1	7	5	7	4	6	6	6	5		5	4	104	5,5			Ø= 5,6
	Summe	199	184	176	172	177	185	185	196	139	200	169	204	145	174	172	162	173	0	159	163			Ø	5,8491228	

AttrakDiff Wizard of Oz

ProbandenZahl 19

Proband	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mittelwert	
Stilvoll/Stillos	2	1	1	0	2	2	2	2	2	2	2	2	2	1	2	0	2		2	2	1,631578947	HQI
Voraussagbar/unberechenbar	2	2	2	-1	2	2	2	1	-2	3	1	3	2	1	1	0	2		2	3	1,473684211	PQ
wertvoll/minderwertig	2	2	1	1	1	3	2	2	1	3	2	1	2	2	1	1	2		2	3	1,789473684	HQI
einbeziehend/ausgrenzend	3	2	1	-2	1	1	2	3	0	3	2	2	2	2	1	1	2		2	0	1,473684211	HQI
bringt mich Näher / trennt mich	3	1	0	-2	0	2	1	2	-2	0	0	3	0	0	-1	1	1		2	0	0,578947368	HQI
vorzeigbar/nicht vorzeigbar	3	2	1	2	1	3	2	3	2	3	2	3	2	2	3	2	3		0	3	2,210526316	HQI
einladend/zurückweisend	3	1	2	1	1	2	1	3	1	3	2	3	2	2	1	2	2		1	2	1,842105263	ATT
Kreativ/Phantasielos	1	2	2	2	2	-1	1	3	2	3	2	1	2	2	2	2	1		1	3	1,736842105	HQS
gut/schlecht	2	2	2	0	2	3	2	3	0	3	2	3	2	2	2	2	2		2	2	2	ATT
menschlich/technisch	2	0	-1	-3	0	-1	-1	0	-2	-2	1	0	-2	1	-1	0	0		-2	0	-0,578947368	PQ
verbindend/isolierend	3	1	1	-1	0	0	1	0	-2	3	0	2	0	0	1	2	2		1	2	0,842105263	HQI
angenehm/unangenehm	3	2	2	0	1	2	0	3	0	3	2	3	2	2	2	2	3		2	2	1,894736842	ATT
originell/Konventionell	2	0	1	1	1	-1	0	2	0	3	2	1	2	1	2	0	1		2	2	1,157894737	HQS
einfach/kompliziert	3	2	3	2	2	2	2	2	-1	3	1	3	1	2	2	2	2		-1	3	1,842105263	PQ
fachmännisch/laienhaft	0	-1	-2	0	0	0	0	1	-1	3	1	3	2	0	1	0	-2		2	0	0,368421053	HQI
schön/hässlich	2	0	1	1	2	2	2	2	0	1	2	1	2	1	2	2	2		2	2	1,526315789	ATT
praktisch/unpraktisch	3	2	2	3	1	2	2	3	0	2	2	3	2	2	2	3	2		3	3	2,210526316	PQ
sympathisch/unsympathisch	3	1	1	0	2	2	1	3	-1	3	1	1	1	1	2	0	2		1	3	1,421052632	ATT
direkt/umständlich	3	2	2	3	2	1	1	2	2	3	1	3	1	2	2	2	1		0	2	1,842105263	PQ
übersichtlich/verwirrend	3	2	2	2	1	2	1	2	0	3	1	3	2	2	2	1	2		2	3	1,894736842	PQ
anziehend/absoßend	2	1	1	1	2	3	1	1	0	3	1	1	2	1	1	0	2		1	2	1,368421053	ATT
mutig/vorsichtig	0	1	0	3	0	0	1	0	1	3	1	0	0	0	1	0	0		1	1	0,684210526	HQS
innovativ/konservativ	3	1	1	2	2	1	1	2	2	3	2	3	3	1	1	0	1		3	1	1,736842105	HQS
fesselnd/lahm	2	1	1	0	0	1	1	2	1	3	2	1	2	1	1	0	0		1	2	1,157894737	HQS
herausfordernd/harmlos	0	-1	-2	0	-1	-2	0	1	0	-2	1	0	0	0	1	1	0		0	2	-0,105263158	HQS
motivierend/entmutigend	2	2	1	2	1	3	1	0	0	3	2	1	2	0	2	3	2		2	2	1,631578947	ATT
neuartig/herkömmlich	3	1	2	3	2	1	1	2	2	3	2	2	2	1	3	2	1		3	1	1,947368421	HQS
handhabbar/widerspenstig	3	1	2	3	0	2	2	3	1	3	2	3	2	2	2	-1	3		2	2	1,947368421	PQ

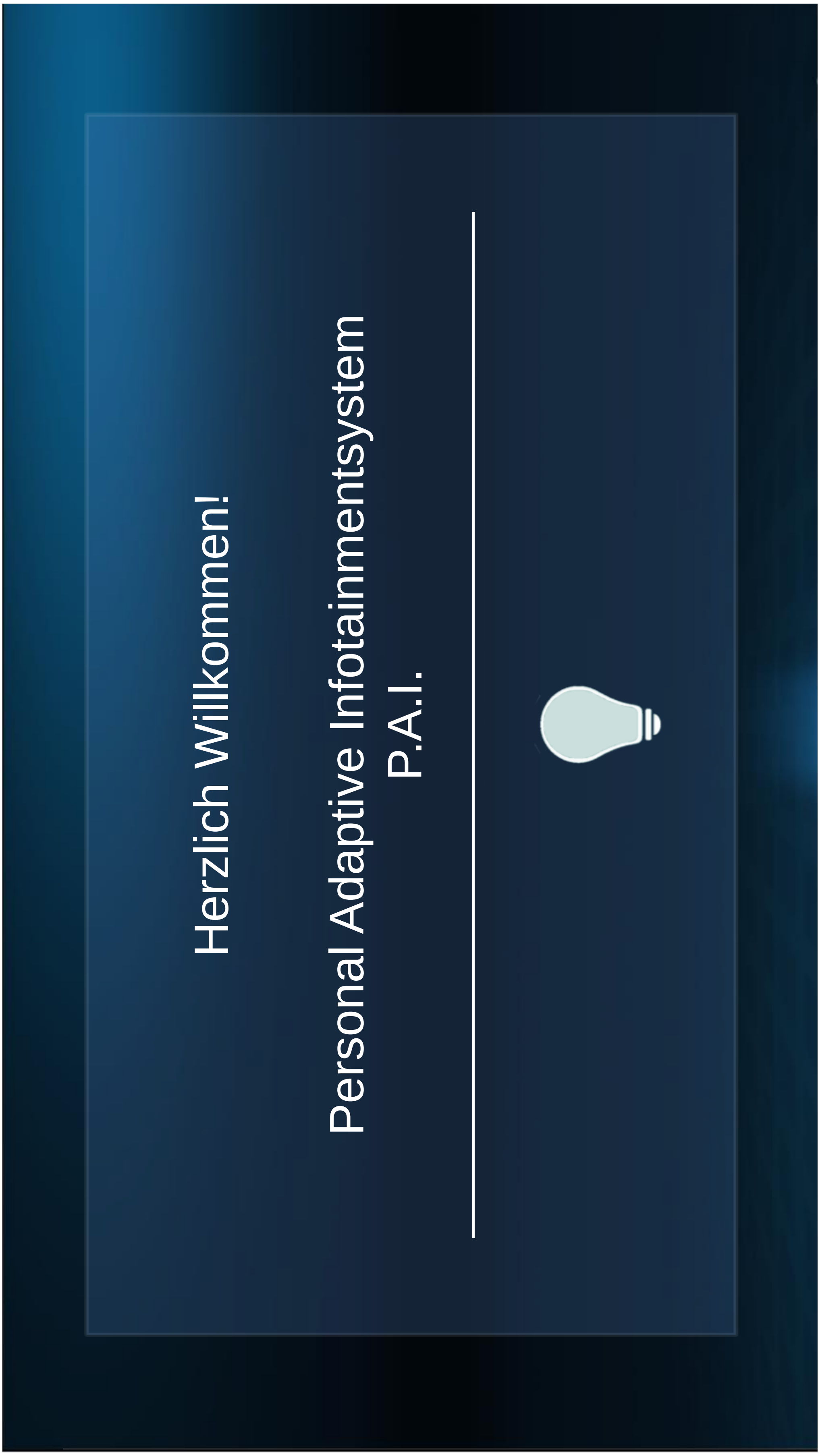
Befragungsbogen

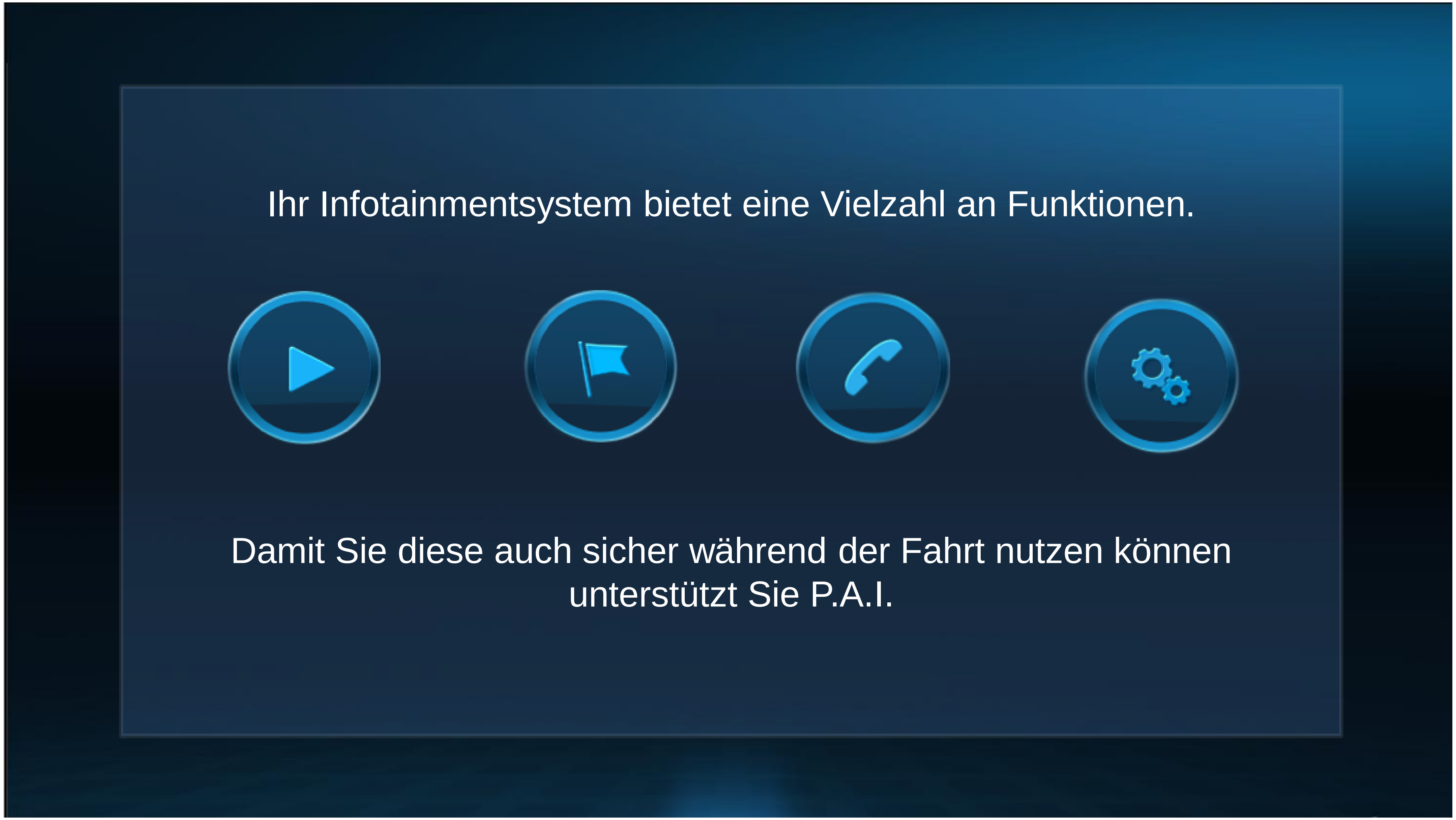
Probandenzahl = 19

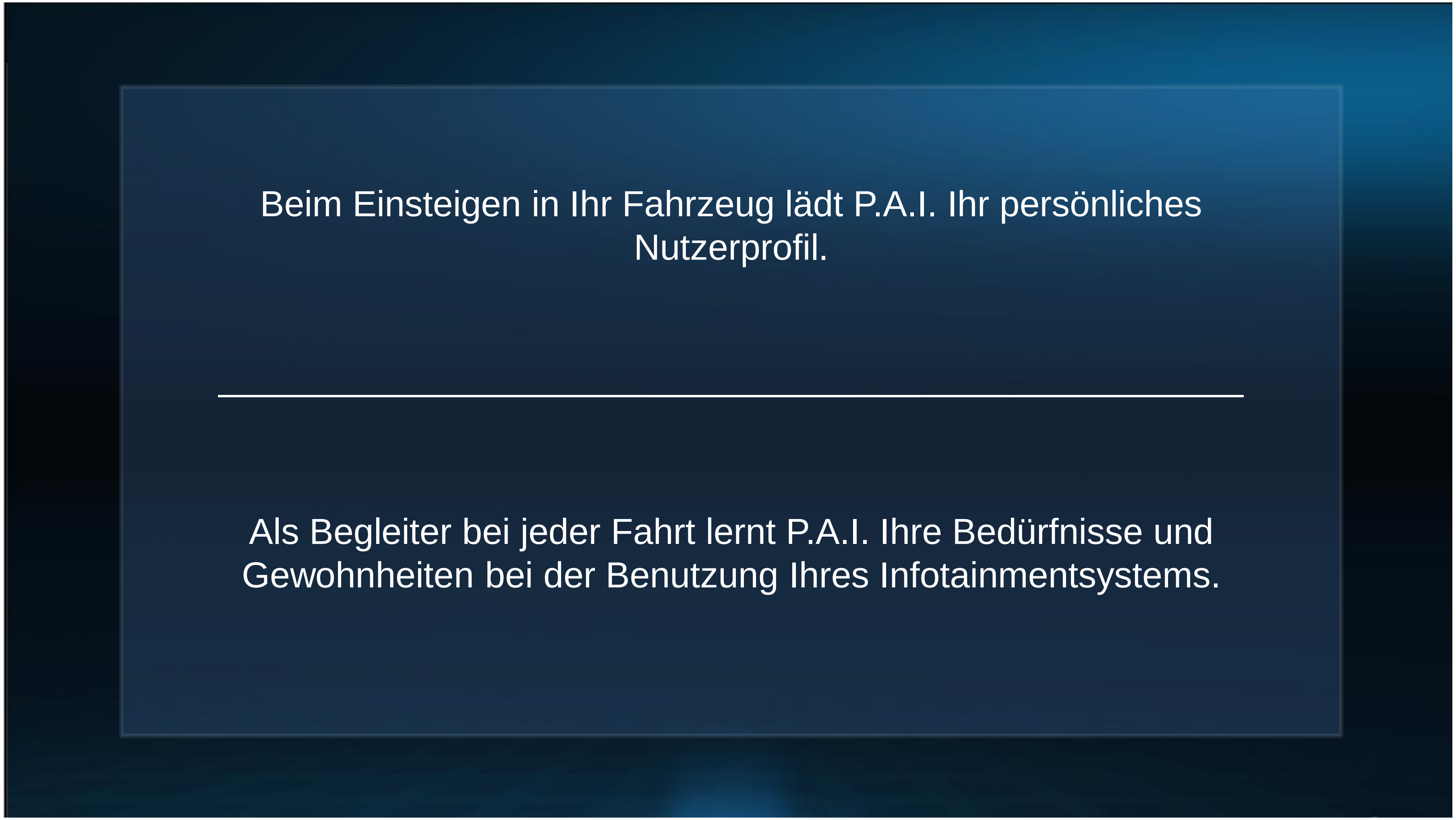
Proband	Vorschlag 1 – Frage 1: Beschreiben sie warum ihnen das Infotainmentsystem diesen Vorschlag gemacht hat	richtig / falsch	Frage 2: Beschreiben sie die Situation in welcher ihnen dieser Vorschlag unterbreitet wird	richtig / falsch	Frage 3: Mit welcher Sicherheit kann, das System sagen, dass dieser Vorschlag für sie Relevant ist.	richtig / falsch	Frage 4: Gibt es Alternativdarstellungen der Vorschläge? Welche?	richtig / falsch	Bemerkungen:	Vorschlag 2 – Frage 1: Beschreiben sie warum ihnen das Infotainmentsystem diesen Vorschlag gemacht hat	richtig / falsch	Frage 2: Beschreiben sie die Situation in welcher ihnen dieser Vorschlag unterbreitet wird	richtig / falsch	Frage 3: Mit welcher Sicherheit kann, das System sagen, dass dieser Vorschlag für sie Relevant ist.	richtig / falsch
1	Weil ich an dieser Position und zu dieser Zeit immer die Navigation starte, das hat sich das System gemerkt	richtig	Stehe auf dem Parkplatz zur selben Zeit 2:00	richtig	100%	richtig	Pop-Up	teilweise		Weil ich immer wenn ich wenn ich in den Tunnel fahre, dieses Lied spiele	richtig	Fahre in den Tunnel um 2:00	richtig	100%	richtig
2	Weil ich die letzten zwei Tage um 2:00 auf dem Parkplatz die Navigation gestartet habe	richtig	Parkplatz, 2:00	richtig	100%	richtig	Pop-Up	teilweise		Immer wenn ich in den Tunnel Fahre das Lied spiele	richtig	Tunnel	teilweise	100%	richtig
3	Weil ich jeden Tag um diese Uhrzeit nach Hause Fahre. Aus Gewohnheit	richtig	Parkplatz, 2:00	richtig	100%	richtig	Shortcut / Automatisch	richtig		Weil ich das im normalfall immer mache.	richtig	Tunnel	teilweise	100%	richtig
4	Es merkt sich, dass ich in der selben Situation das Selbe mache	richtig	Parkplatz immer nach Feierabend, 2:00	richtig	100%	richtig	Pop-Up / Shortcut	richtig		Weil es sich gemerkt hat, dass ich, wenn ich in den Tunnel Fahre die Musik auswähle	richtig	Tunnel	teilweise	100%	richtig
5	Vorhergehende Verhalten	richtig	Parkplatz 2;00	richtig	-	FALSCH	Shortcut / Automatisch	richtig		Es hat gelernt, dass im Tunnel dieses Lied gespielt werden soll	richtig	Tunnerl und 2:00	richtig	-	FALSCH
6	Aus meinen Gewohnheiten	richtig	2:00 auf dem Parkplatz	richtig	-	FALSCH	Pop-Up / Automatisch	richtig		Es geht davon aus, weil ich es schon 2 mal gesehen hat, dass ich es mache	richtig	Uhrzeit und Position	richtig	-	FALSCH
7	Erkennt mich zu dieser Zeit an diesem Ort. Wurde wiederholt beobachtet - Muster erkannt und Vorschläge generiert	richtig	Parkplatz 2:00	richtig	100%	richtig	Pop-Up / Shortcut	richtig		Mehrfach wiederholt wahrgenommen und auf Nachfrage Vorschläge erstellt	richtig	Tunnel	teilweise	100%	richtig
8	Weil es meine Gewohnheiten Trackt, zeigt mir meine Gewohnheiten als Vorschläge an,	richtig	2:00, Parkinglot	richtig	100%	richtig	Pop-Up / Automatisch	richtig		Weil ich im Tunnel um 2:00 immer dieses Lied spiele	richtig	Weil ich im Tunnel um 2:00 immer dieses Lied spiele	richtig	100%	richtig
9	Um diese Uhrzeit fahre ich immer nach Hause wenn ich auf dem Parkplatz stehe	richtig	Um diese Uhrzeit fahre ich immer nach Hause wenn ich auf dem Parkplatz stehe	richtig	-	FALSCH	Shortcut / Automatisch	richtig		System hat es gelernt	richtig	Tunnel	teilweise	-	FALSCH
10	Regelmäßig das selbe mache	richtig	2:00, Parkinglot	richtig	100%	richtig	Pop-Up / Automatisch	richtig		Normalerweise spiele diesen song, das System weis es	richtig	2:00 Tunnel	richtig	100%	richtig
11	Weil ich bestimmte Dinge zur selben Zeit am Sleben Ort erledige	richtig	2:00 Parkplatz	richtig	-	FALSCH	Shortcut / Automatisch	richtig		Aufgrund der Regelmäßigkeit	richtig	Mountaintunnel 2:00	richtig	-	FALSCH
12	Aus meinen Gewohnheiten und wie häufig ich bestimmte Dinge mache.	richtig	Standort und Uhrzeit	richtig	-	FALSCH	Pop-Up / Shortcut	richtig		Habe ich bisher immer im Tunnel gemacht, erkennt dass ich es wieder amchen möchte	richtig	Tunnel und 2:00	richtig	100%	richtig
13	System hat sich meine Gewohnheiten gemerkt	richtig	14:00 nach der Arbeit auf dem Parkplat	richtig	-	FALSCH	-	FALSCH		System hat sich meine Gewohnheiten gemerkt	richtig	Tunnel	teilweise	-	FALSCH
14	Es lernt meine Gewohnheiten um Bedienvorgägne zu vermindern	richtig	Parkplatz 2:00 wenn ich das Auto starte	richtig	100%	richtig	Pop-Up / Automatisch	richtig		Hat es gelernt	richtig	um 2:00 im Tunnel	richtig	100%	richtig
15	Aufgrund von Gewohnheiten und wiederkehrendes Ausführen von Interaktionen	richtig	2:00 nach Hause fahre	teilweise	100%	richtig	Pop-Up / Shortcut	richtig		Aufgrund von Gewohnheiten und wiederkehrendes Ausführen von Interaktionen	richtig	2:00 im Mountaintunnel	richtig	100%	richtig
16	Es kennt mich und die Bedingungen die eintreffen müssen	richtig	Parkplatz und Zeit	richtig	-	FALSCH	Shortcut / Automatisch	richtig		Es kennt mich und die Bedingungen die eintreffen müssen	richtig	Uhrzeit 2:00 und Tunnel	richtig	-	FALSCH
17	Es betrachtet die Umgebungsvariablen wenn ich eine Interaktion ausführe und berechnet dann dadurch wie häufig ich etwas mache wie warscheinlich es ist, dass ich es erenuet machen möchte	richtig	Parkplatz, 2:00	richtig	100%	richtig	Pop-Up / Automatisch	richtig		Aus meinen Gewohnheiten. Bestimmte Interaktionen in bestimmten Kontext häufig ausgeführt. Berechnet dann wie warscheinlich es ist, dass ich es wieder amchen möchte	richtig	Tunnel, 2:00	richtig	100%	richtig
18															
19	Weil sich die Abläufe wiederholt haben und der Kontext stets der Selbe war	richtig	14:00: Parkplatz	richtig	-	FALSCH	Pop-Up / Automatisch	richtig		Weil sich die Abläufe wiederholt haben und der Kontext stets der Selbe war	richtig	14:00. Tunnel	richtig	-	FALSCH
20	Es versteht, dass ich bestimmte Dinge immer wieder asuführe	richtig	Parkplatz und Uhrzeit	richtig	100%	richtig	Pop-Up / Shortcut	richtig		Weil ich etwas immer wieder mache	richtig	Tunnel 2:00	richtig	100%	richtig
		19		18		11		16			19		13		12
				1				2					6		
		0		0		8		1			0		0		7

			Vorschlag 3							
Frage 4			Frage 1		Frage 2		Frage 3			
Gibt es Alternativdarstellungen der Vorschläge? Welche?	richtig / falsch	Bemerkungen:	Beschreiben sie, warum ihnen das Infotainmentsystem am Ende der Fahrt, keinen Vorschlag unterbreitet hat.	richtig / falsch	Beschreiben sie die Situation in welcher ihnen ein weiterer Vorschlag unterbreitet worden wäre	richtig / falsch	Mit welcher Sicherheit kann, das System sagen, dass dieser Vorschlag für sie Relevant ist.	richtig / falsch	Bemerkungen:	
Pop-Up	teilweise		Kein Stau	richtig	Stau	teilweise	100%	richtig	Es wurde nicht wahrgenommen, dass der Anruf auch abhängig von der Uhrzeit ist	
Pop-Up	teilweise		Kein Stau	richtig	Stau	teilweise	100%	richtig		
Shortcut / Automatisch	richtig		Kein Stau	richtig	Stau und Uhrzeit	richtig	100%	richtig		
Pop-Up / Shortcut	richtig		Kein Stau	richtig	2:15 und Stau	richtig	100%	richtig		
Shortcut / Automatisch	richtig		Kein Stau	richtig	2:15 und Stau	richtig	-	FALSCH	Certainty wurde überhaupt nicht wahrgenommen	
Pop-Up / Automatisch	richtig		Uhrzeit passt, aber kein Stau	richtig	2:15 und Geschwindigkeit wie im Stau	richtig	-	FALSCH	Menü word als sehr positiv empfunden und hilfreich um zu verstehen, warum bestimmte Votshlä#ge gemacht werden. Bearbeitungsmenü und New Reocmmendations als sehr übersichtlich und gut strukturiert beschrieben.	
Pop-Up / Shortcut	richtig		Es war 2:15 aber kein Stau	richtig	2:15 und Stau	richtig	100%	richtig		
Pop-Up / Automatisch	richtig		Kein Stau	richtig	Stau, 2:15	richtig	100%	richtig		
Shortcut / Automatisch	richtig		Kein Stau	richtig	Stau und Uhrzeit	richtig	-	FALSCH		
Pop-Up / Automatisch	richtig		Da kein Stau war	richtig	Stau, 2:15	richtig	100	richtig		
Shortcut / Automatisch	richtig		kein Stau	richtig	Stau auf nachhauseweg	teilweise	-	FALSCH		
Pop-Up / Shortcut	richtig		Kein Stau	richtig	Stau	teilweise	100%	richtig		
-	FALSCH		kein Stau	richtig	Stau	teilweise	-	FALSCH		
Pop-Up / Automatisch	richtig		Kein Stau	richtig	Stau bzw Stop and Go zu der Uhrzeit	richtig	100%	richtig		
Pop-Up / Shortcut	richtig		Kein Stau	richtig	Stau 2:15	richtig	100%	richtig		
Shortcut / Automatisch	richtig		nicht beide nötigen bedingungen erfüllt	richtig	Stau und 2:15	richtig	-	FALSCH		
Pop-Up / Automatisch	richtig		Es gab keinen Stau	richtig	2:15 und Stau	richtig	100%	richtig		
Pop-Up / Automatisch	richtig		Kein Stau	richtig	14:15 und Stau	richtig	-	FALSCH		
Pop-Up / Shortcut	richtig		kein Stau	richtig	14:15 und Stau	richtig	100%	richtig		
	16			19		14		12		80,861244
	2					5				7,65550239
	1			0		0		7		11,4832536

F Tutorial


Herzlich Willkommen!
Personal Adaptive Infotainmentsystem
P.A.I.

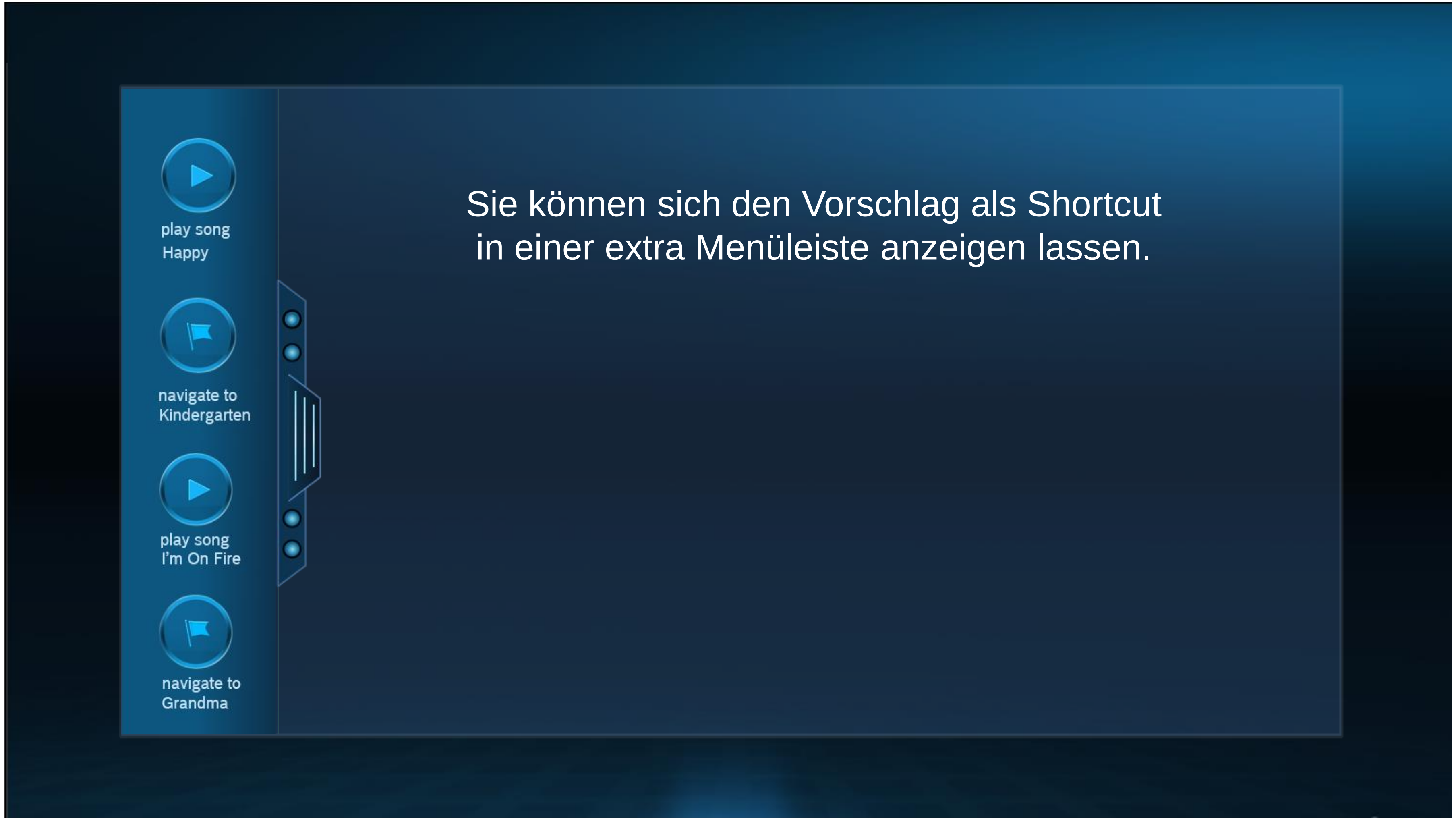

Ihr Infotainmentsystem bietet eine Vielzahl an Funktionen.
Damit Sie diese auch sicher während der Fahrt nutzen können
unterstützt Sie P.A.I.

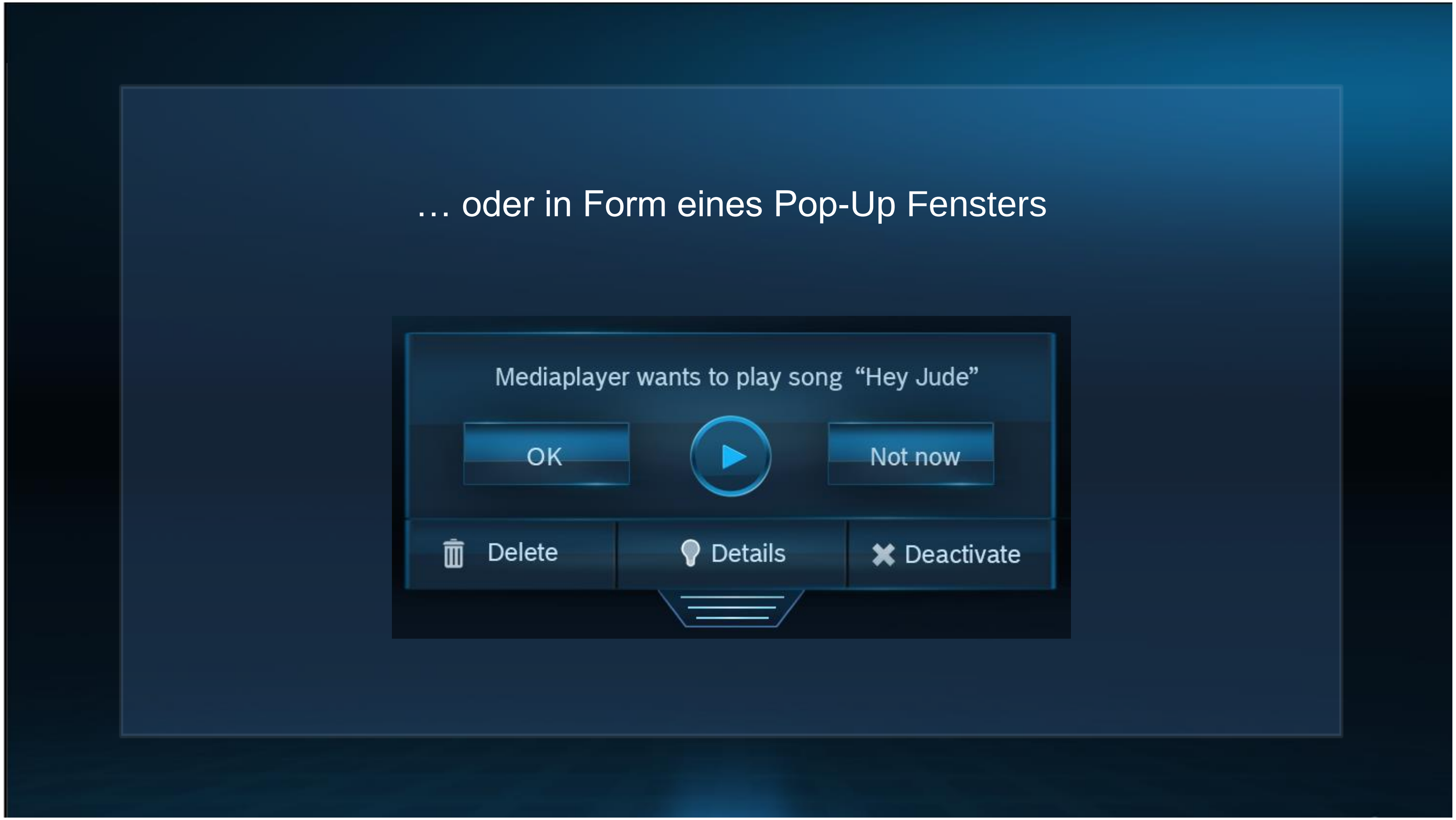

Beim Einsteigen in Ihr Fahrzeug lädt P.A.I. Ihr persönliches Nutzerprofil.
Als Begleiter bei jeder Fahrt lernt P.A.I. Ihre Bedürfnisse und Gewohnheiten bei der Benutzung Ihres Infotainmentsystems.

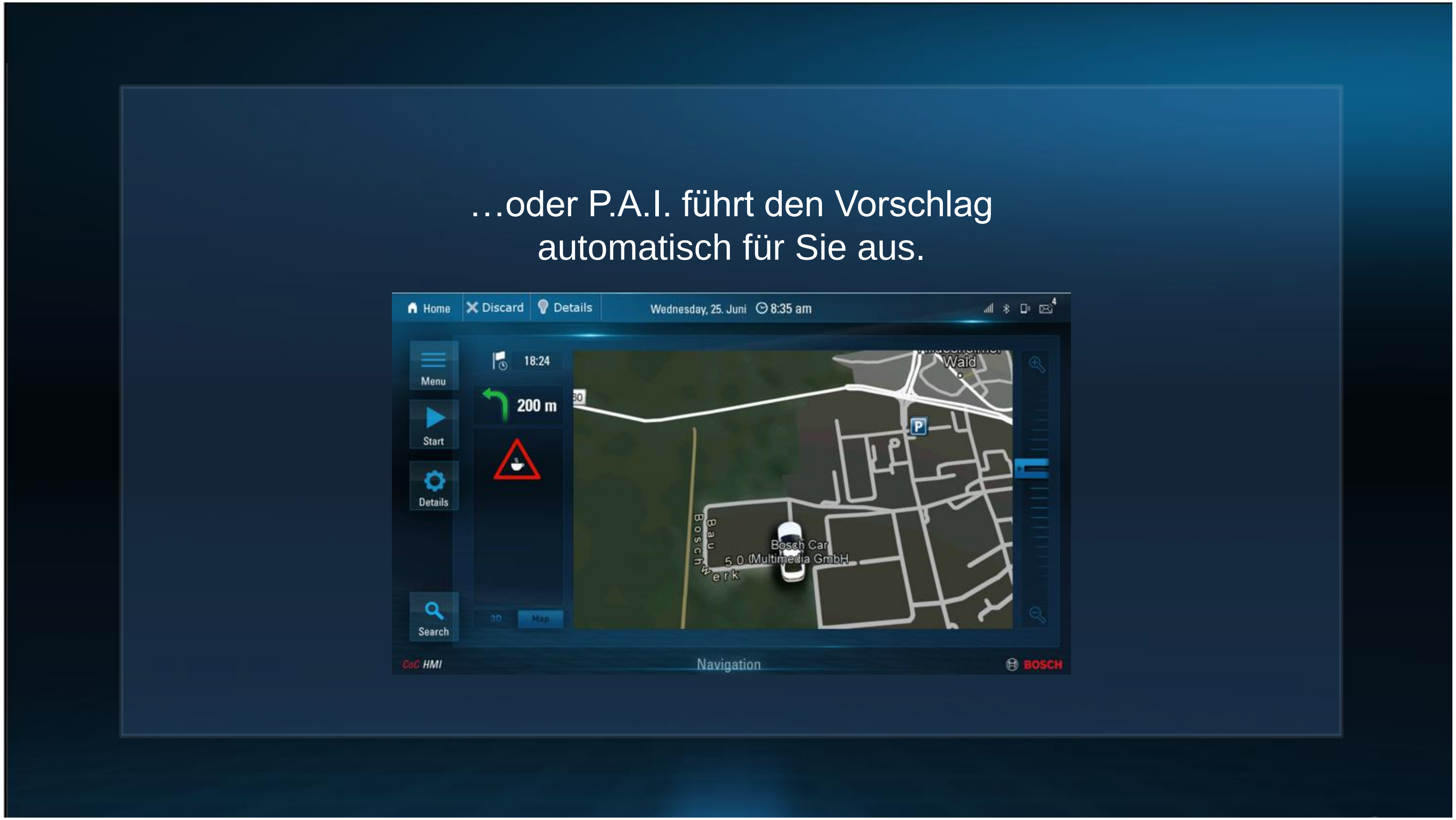
P.A.I. erkennt Situationen wieder und unterstützt Sie, indem es Ihnen vorschlägt, bestimmte Aufgaben für Sie zu übernehmen.

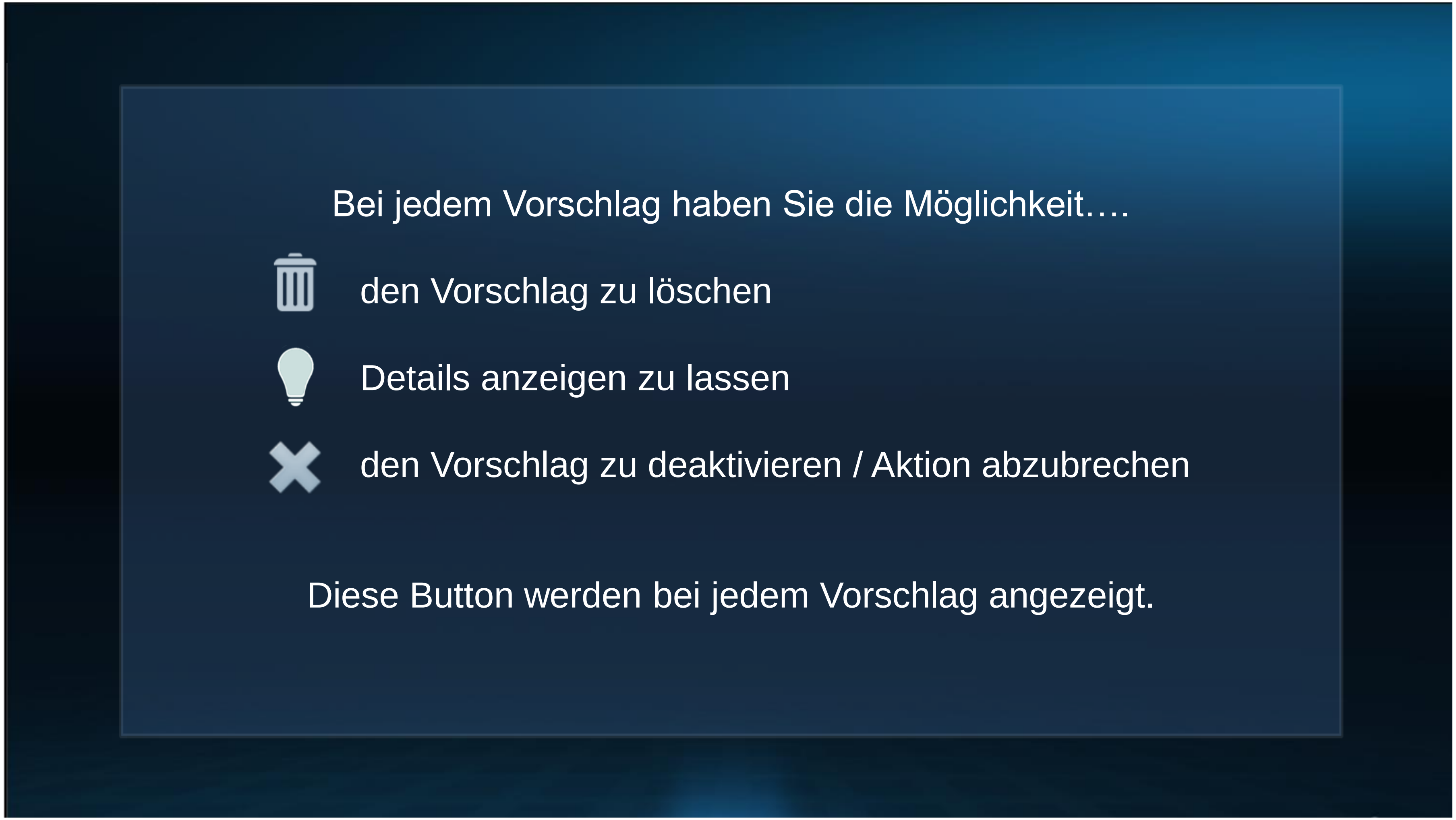
Dadurch bleiben Ihnen lange Bedienvorgänge erspart und Sie können sich besser auf den Verkehr konzentrieren.

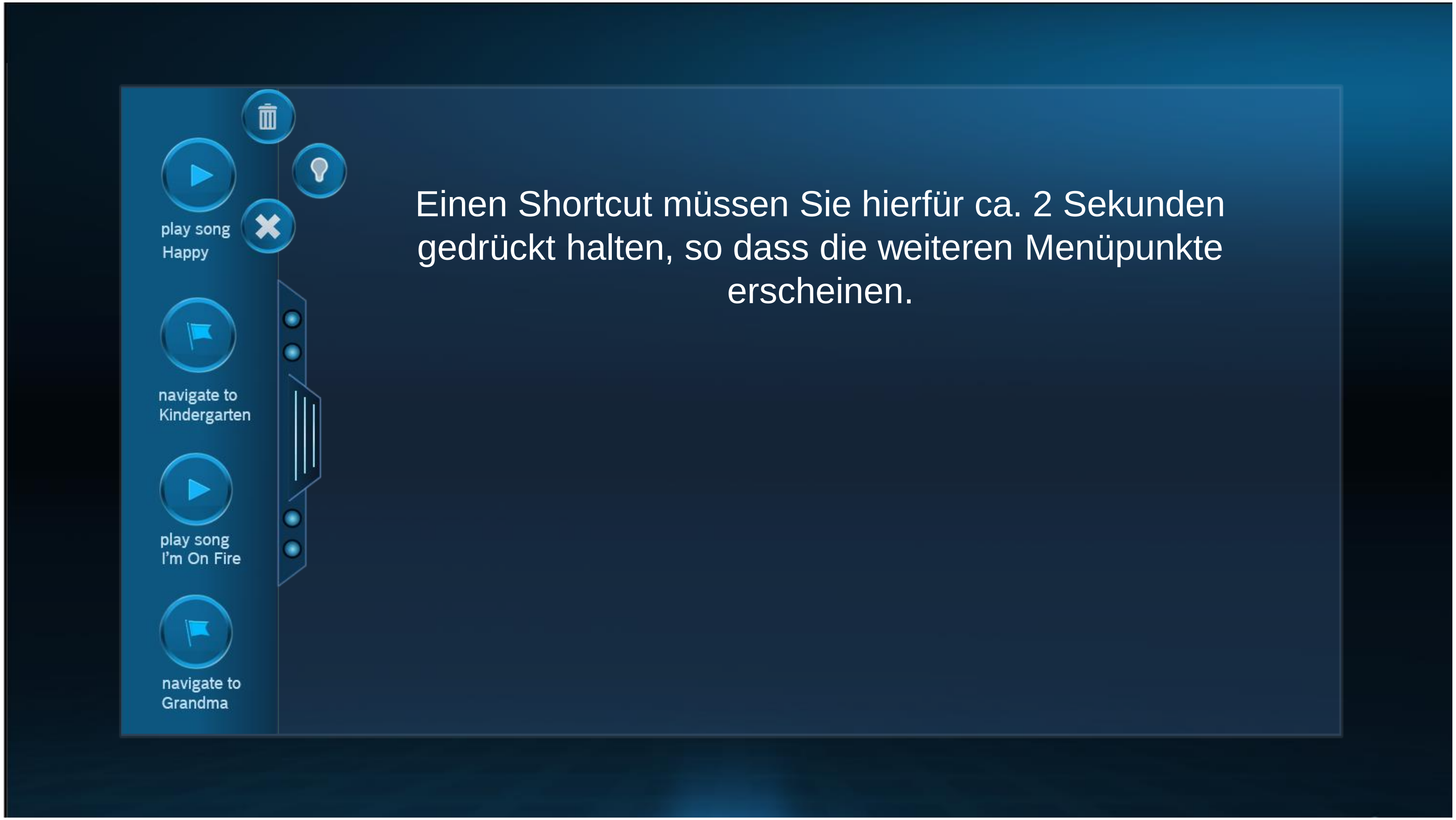
Es gibt verschiedene Möglichkeiten wie Ihnen ein Vorschlag angezeigt werden kann. Für welche Sie sich entscheiden bleibt Ihnen überlassen.

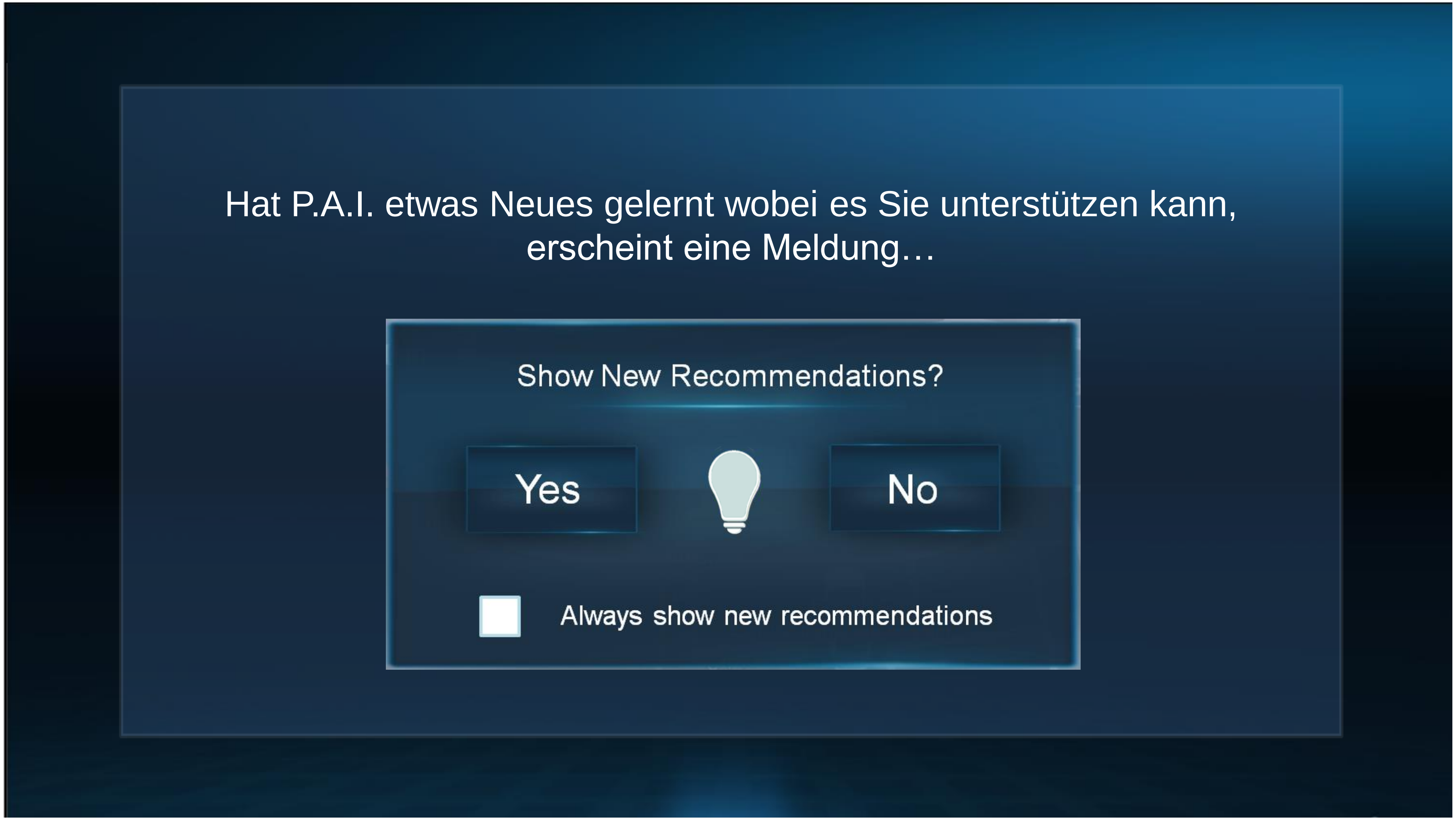

Sie können sich den Vorschlag als Shortcut
in einer extra Menüleiste anzeigen lassen.
play song
Happy
navigate to
Kindergarten
play song
I'm On Fire
navigate to
Grandma

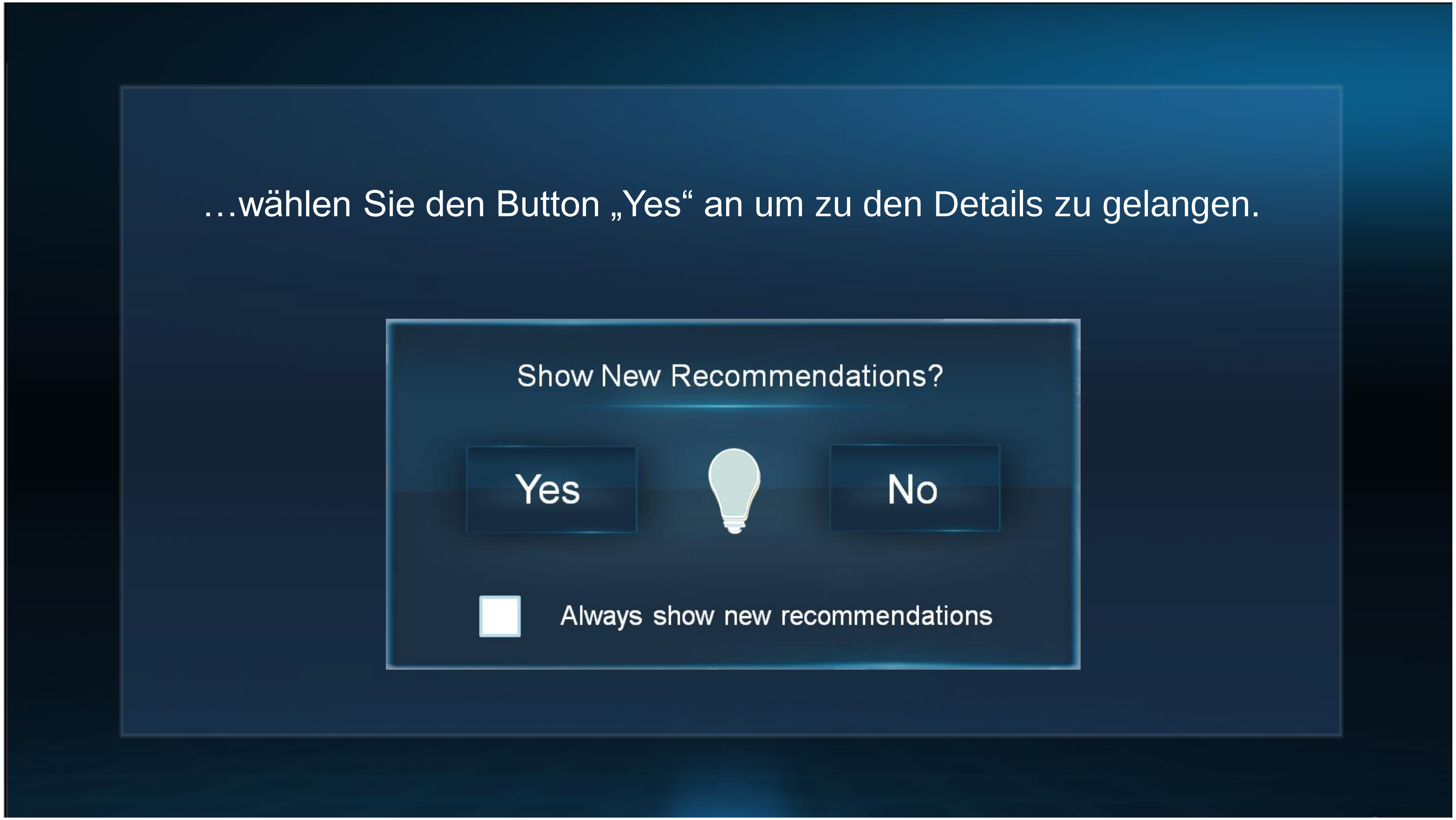

… oder in Form eines Pop-Up Fensters
Mediaplayer wants to play song “Hey Jude”
OK
Not now
Delete
Details
Deactivate

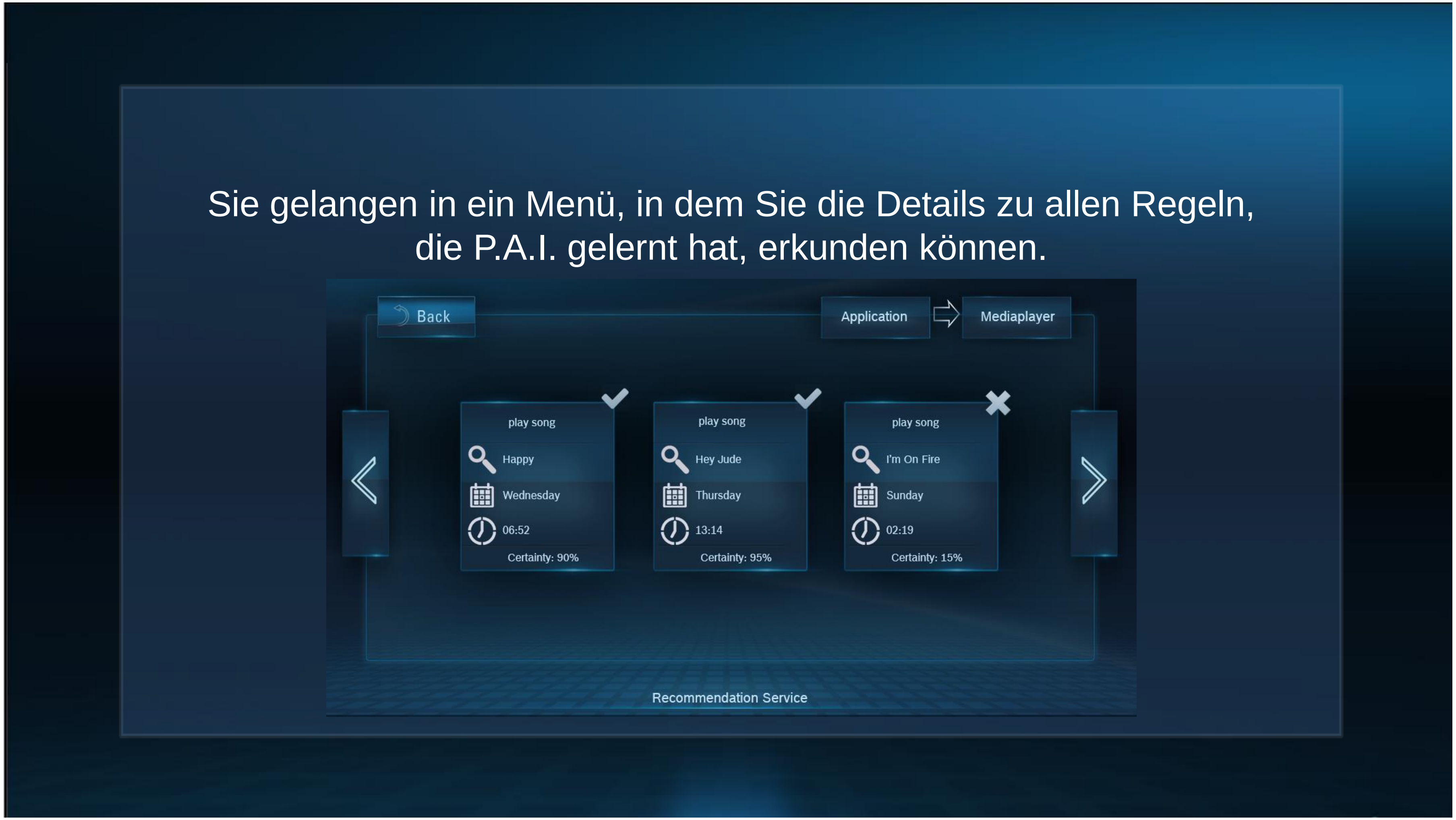

…oder P.A.I. führt den Vorschlag
automatisch für Sie aus.
Home
Discard
Details
Wednesday, 25. Juni
8:35 am
Menu
Start
Details
Search
18:24
200 m
Map
Wald
Bosch Car
Multimedia GmbH
Navigation
CoC HMI
BOSCH


Bei jedem Vorschlag haben Sie die Möglichkeit….
den Vorschlag zu löschen
Details anzeigen zu lassen
den Vorschlag zu deaktivieren / Aktion abzubrechen
Diese Button werden bei jedem Vorschlag angezeigt.

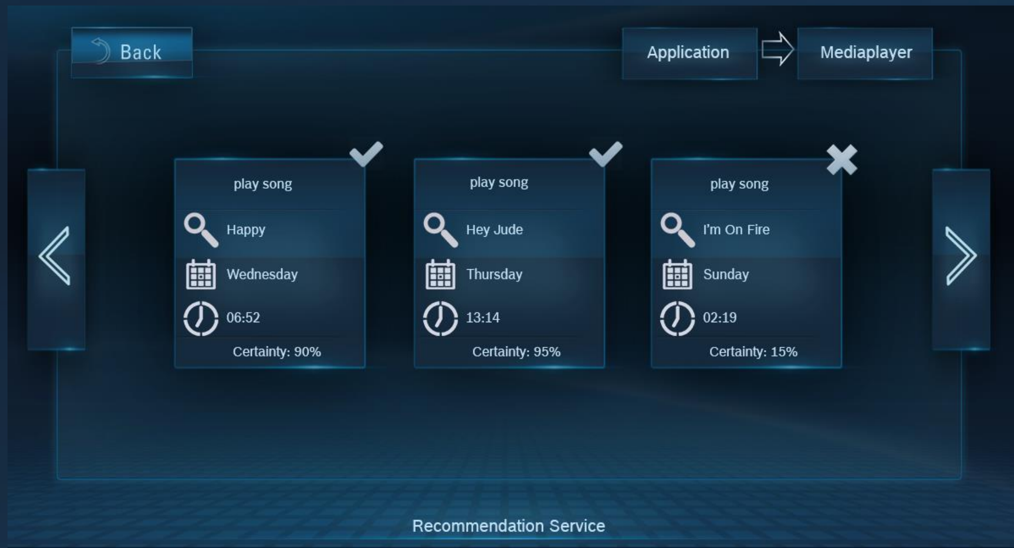

Einen Shortcut müssen Sie hierfür ca. 2 Sekunden gedrückt halten, so dass die weiteren Menüpunkte erscheinen.
play song
Happy
navigate to
Kindergarten
play song
I'm On Fire
navigate to
Grandma

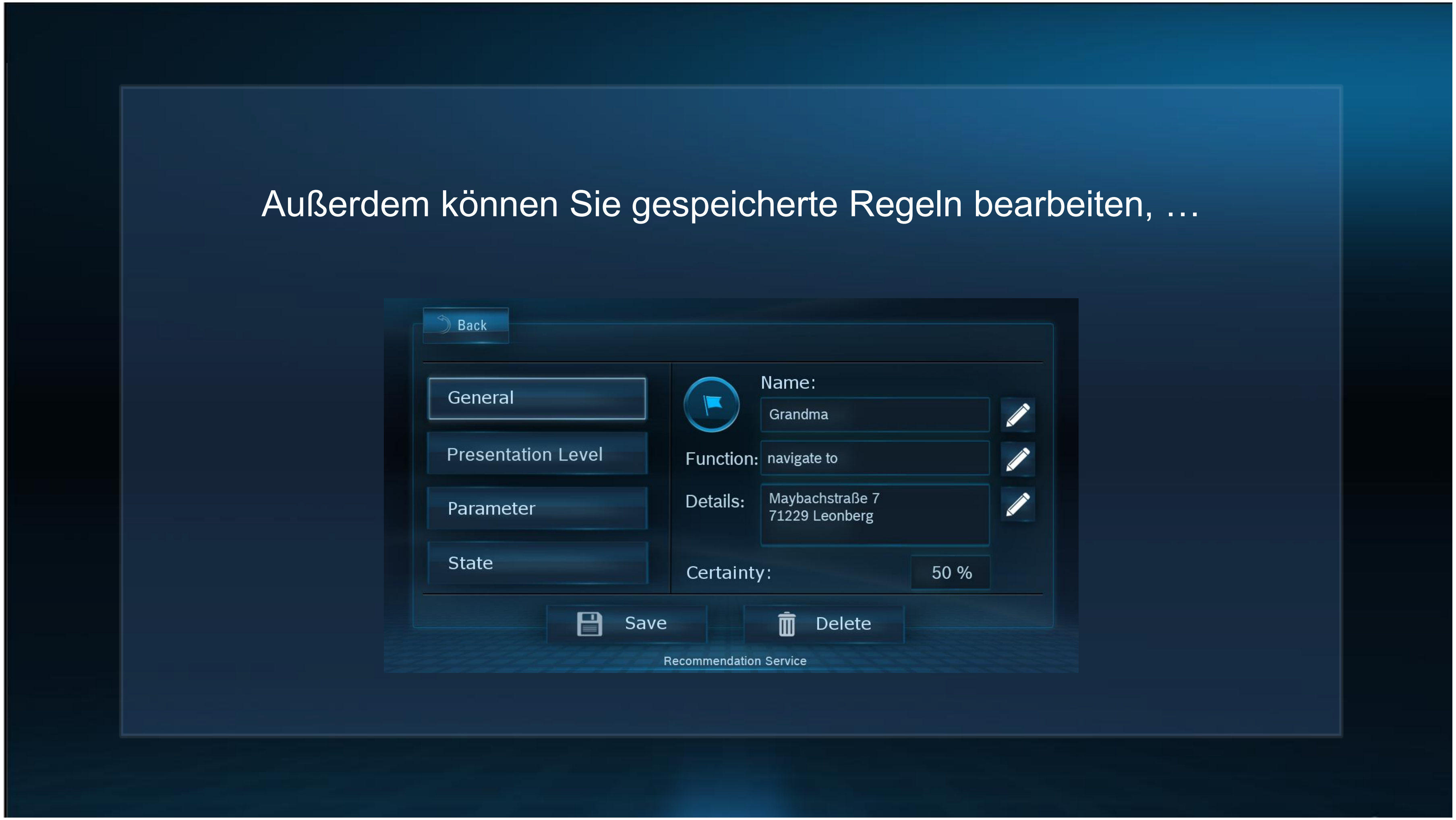

Hat P.A.I. etwas Neues gelernt wobei es Sie unterstützen kann, erscheint eine Meldung…
Show New Recommendations?
Yes
No
Always show new recommendations


…wählen Sie den Button „Yes“ an um zu den Details zu gelangen.
Show New Recommendations?
Yes
No
Always show new recommendations

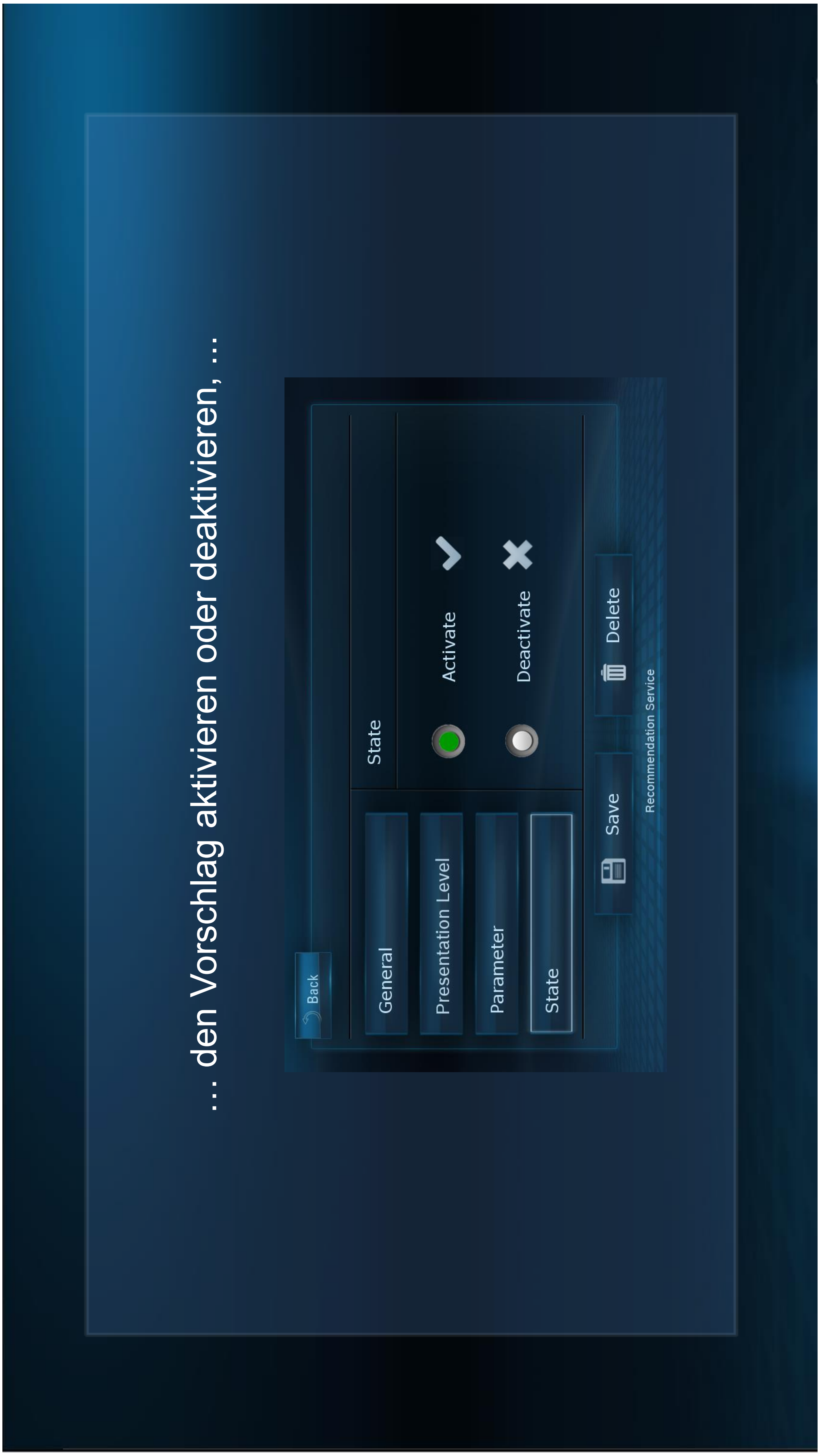

Sie gelangen in ein Menü, in dem Sie die Details zu allen Regeln, die P.A.I. gelernt hat, erkunden können.
Back
Application
Mediaplayer
play song
Happy
Wednesday
06:52
Certainty: 90%
play song
Hey Jude
Thursday
13:14
Certainty: 95%
play song
I'm On Fire
Sunday
02:19
Certainty: 15%
Recommendation Service

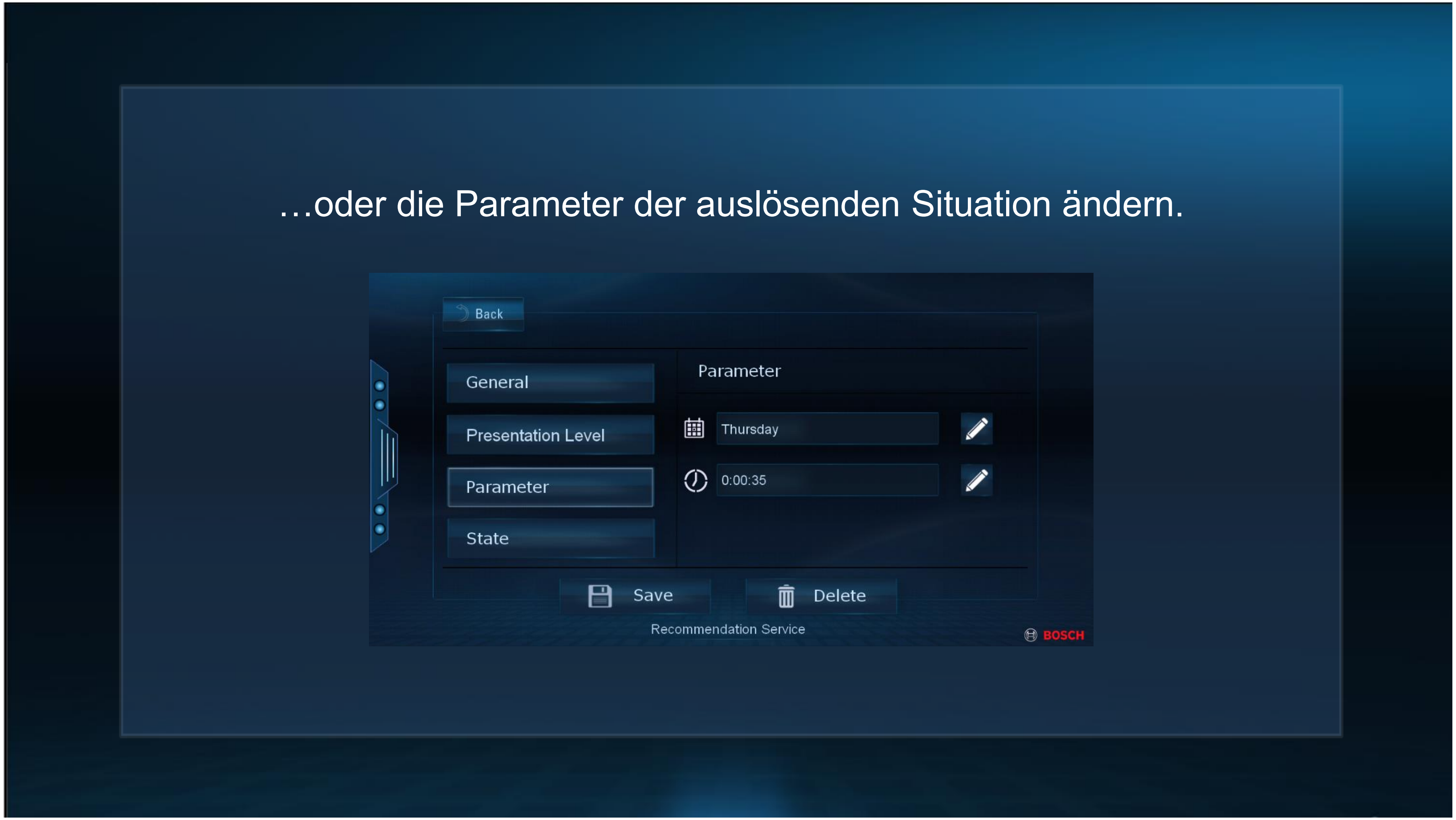
Aufgrund dieser gelernten Regeln unterbreitet Ihnen P.A.I in Zukunft Vorschläge, die Sie unterstützen sollen.

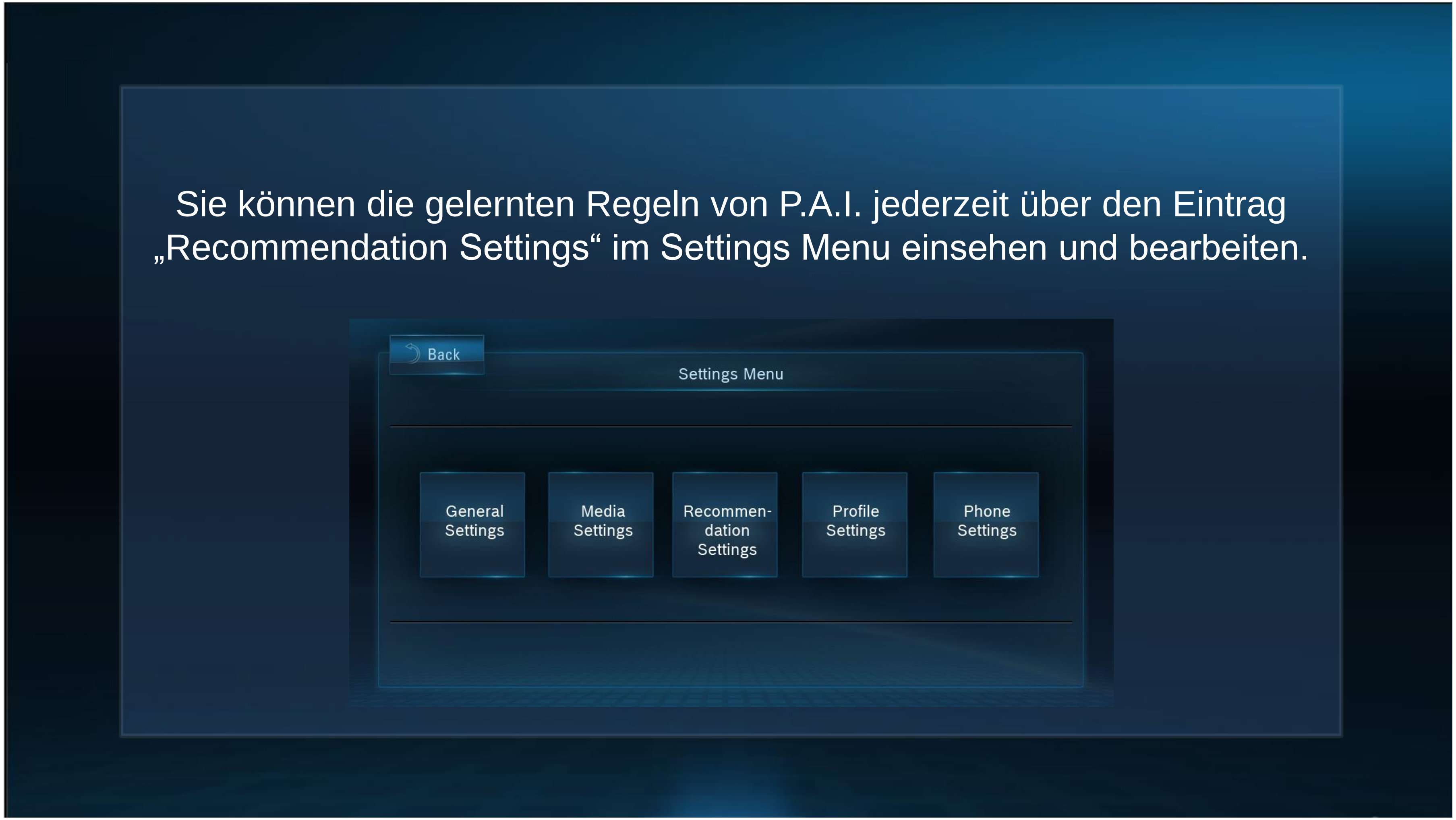


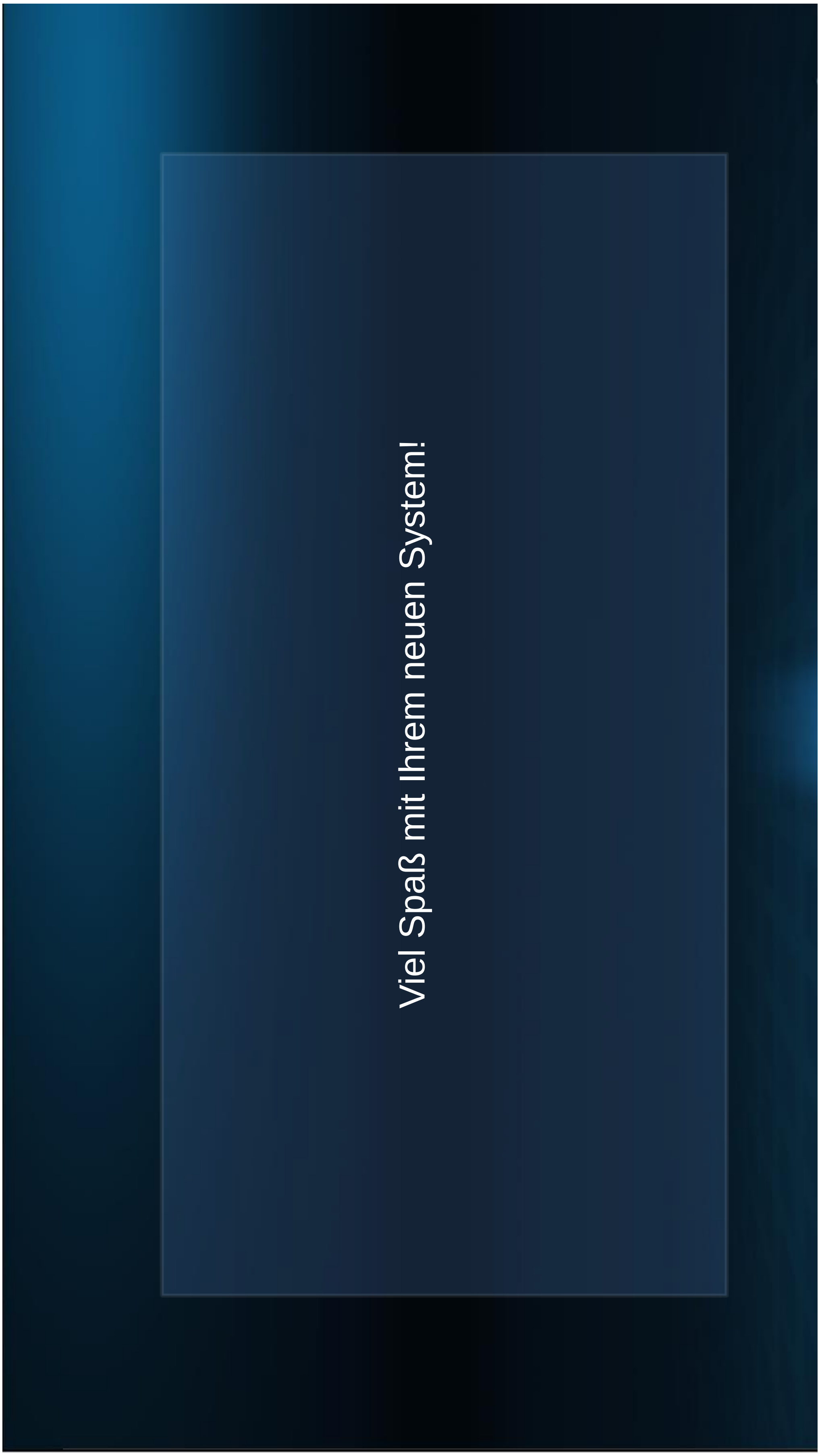

Außerdem können Sie gespeicherte Regeln bearbeiten, …
Back
General
Presentation Level
Parameter
State
Name:
Grandma
Function:
navigate to
Details:
Maybachstraße 7
71229 Leonberg
Certainty:
50 %
Save
Delete
Recommendation Service


… den Grad der Automatisierung anpassen, …
Back
General
Presentation Level
Parameter
State
Recommend as:
Shortcut
Pop-Up
Start Automatically
Save
Delete
Recommendation Service


… den Vorschlag aktivieren oder deaktivieren, …
Back
General
Presentation Level
Parameter
State
State
Activate
Deactivate
Save
Delete
Recommendation Service

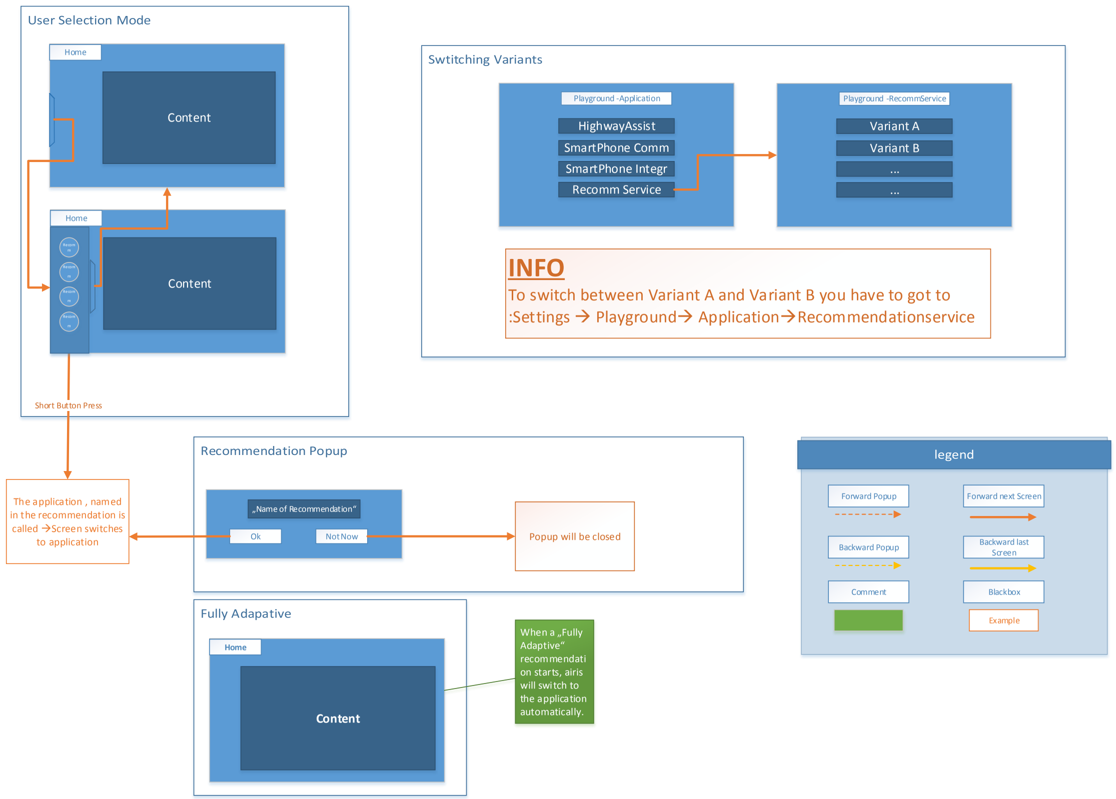

…oder die Parameter der auslösenden Situation ändern.
Back
General
Presentation Level
Parameter
State
Parameter
Thursday
0:00:35
Save
Delete
Recommendation Service
BOSCH


Sie können die gelernten Regeln von P.A.I. jederzeit über den Eintrag „Recommendation Settings“ im Settings Menu einsehen und bearbeiten.
Back
Settings Menu
General Settings
Media Settings
Recommen-dation Settings
Profile Settings
Phone Settings

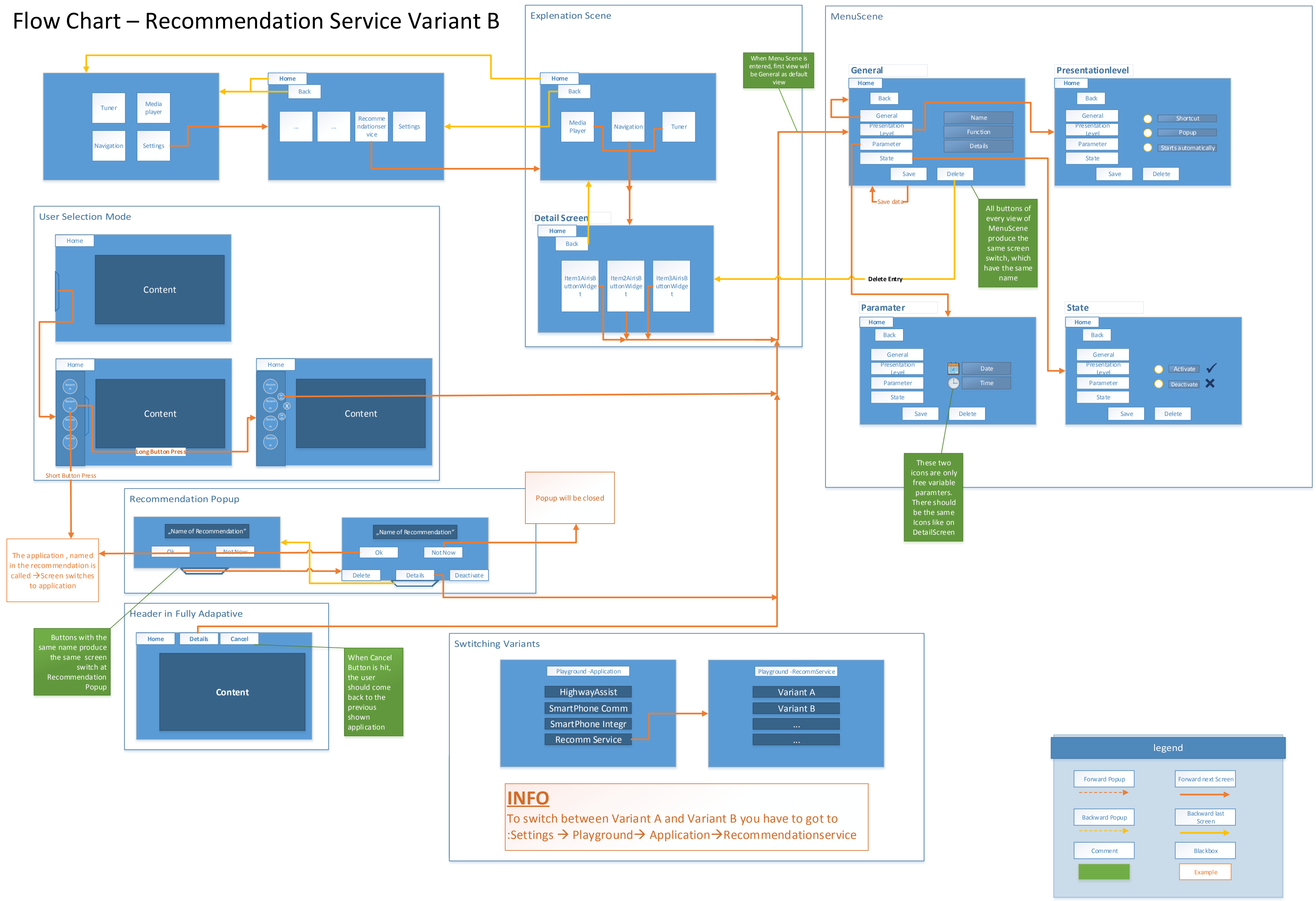

Viel Spaß mit Ihrem neuen System!

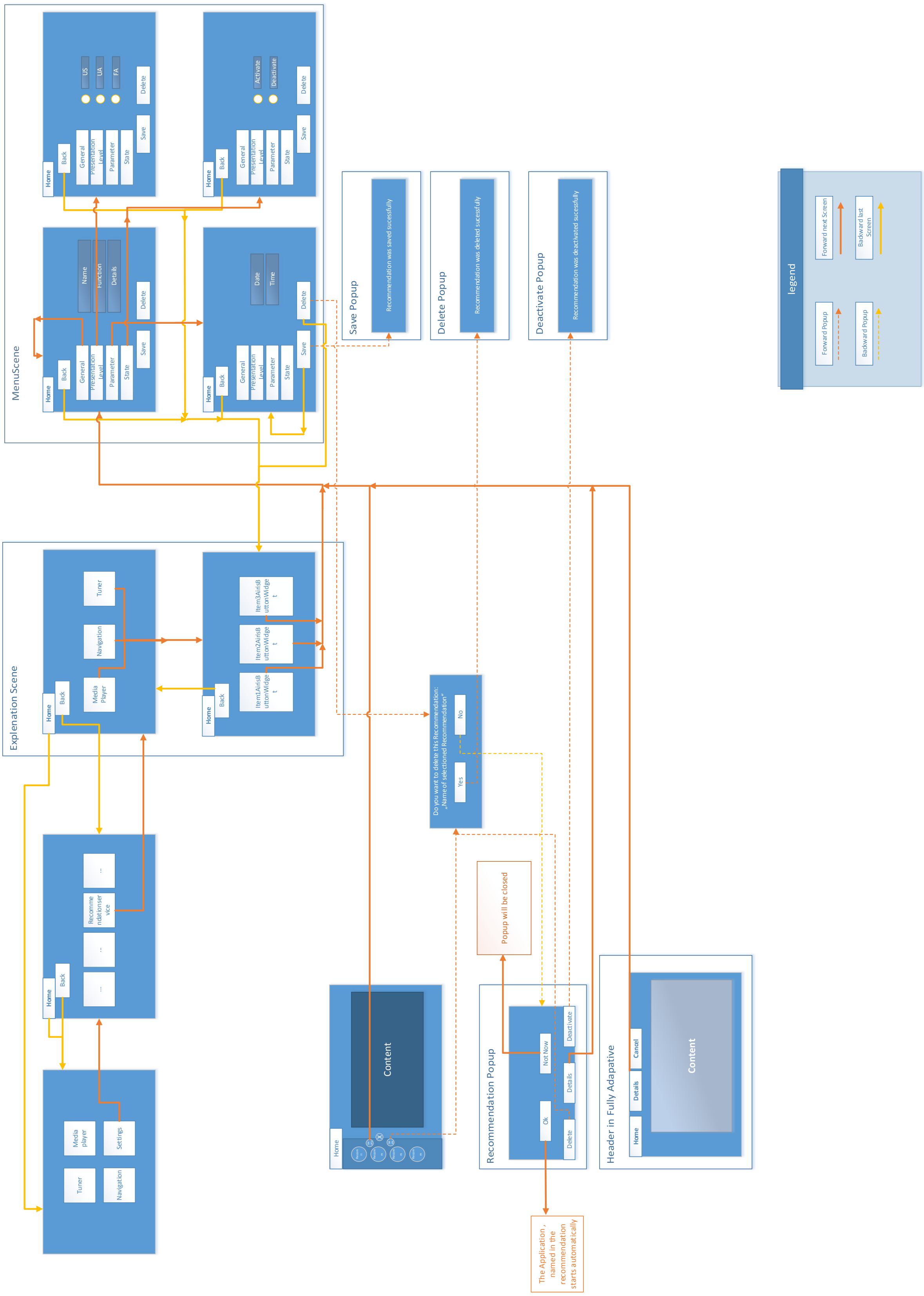
G Flow Charts of the Recommendation Service - Variant A and Variant B

Flow Chart – Recommendation Service Variant A



Flow Chart – Recommendation Service Variant B




MenuScene
Explenation Scene
Save Popup
Recommendation was saved sucessfully
Delete Popup
Recommendation was deleted sucessfully
Deactivate Popup
Recommendation was deactivated sucessfully
legend
Forward next Screen
Backward last Screen
Forward Popup
Backward Popup
Recommendation Popup
Header in Fully Adapative
Content
Popup will be closed
The Application , named in the recommendation starts automatically
Home
Back
Save
Delete
Ok
Not Now
Details
Deactivate
Cancel
Yes
No

H Questionnaires of the Driving Simulator Study

Probanden ID: ____________________
Variante name: ____________________
Adaption Level: ____________________

Demographischer Fragebogen

Geschlecht	☐ männlich ☐ weiblich
Alter	____
Welchen höchsten Bildungsabschluss haben Sie?	☐ Noch in schulischer Ausbildung ☐ Keinen allgemeinbildenden Abschluss ☐ Haupt- / Volksschule ☐ Realschule bzw. gleichwertiger Abschluss ☐ Fach- / Hochschulreife ☐ FH / Universität
In welchem Beschäftigungsverhältnis befinden Sie sich?	☐ Angestellter ☐ Beamter ☐ Selbstständiger / Freiberufler ☐ In Ausbildung (Schüler, Auszubildender, Student) ☐ Rentner ☐ Hausfrau / -mann ☐ Nicht berufstätig ☐ Andere: ____________________________________
Welchen Beruf üben Sie aus?	____
Wie hoch würden Sie Ihre Technikaffinität einschätzen?	Sehr niedrig ☐ ☐ ☐ ☐ ☐ sehr hoch
Haben Sie eine Farbfehlsichtigkeit?	☐ Ja ☐ Nein ☐ weiß nicht
Nutzen Sie ein Smartphone / Tablet?	☐ Ja ☐ Nein
Besitzen Sie ein eigenes Auto?	☐ Ja ☐ Nein
Seit welchem Alter besitzen Sie einen Führerschein?	____
Wie regelmäßig nutzen Sie ein Auto?	☐ (fast) Täglich ☐ Mehrmals wöchentlich ☐ Mehrmals monatlich ☐ Selten

Probanden ID: ___________________
Variante name: ___________________
Adaption Level: ___________________

Wie viele Kilometer fahren Sie ungefähr im Jahr?		☐ < 5.000 km ☐ 5.000 – 10.000 km ☐ 10.000 – 15.000 km ☐ 15.000 – 20.000 km ☐ > 20.000 km	
Welchen Straßentyp befahren Sie überwiegend?		☐ Stadt ☐ Autobahn ☐ Überlandfahrt	
Was für Strecken legen Sie hauptsächlich mit dem Auto zurück?		☐ Kurzstrecken (bis 10 km) ☐ Mittelstrecken (zwischen 20 und 30 km) ☐ Langstrecken (ab 30 km)	
Nutzen Sie ein Radio-Navigations-System (Infotainmentsystem) im Auto?		☐ Ja ☐ Nein	
Welche Funktionen nutzen Sie während der Fahrt?		Infotainmentsystem (eingebaut)	mobil (z.B. Smartphone)
	Radio	☐	☐
	Navigation	☐	☐
	Telefon	☐	☐
	Media Player	☐	☐
	Internet	☐	☐
	Sonstiges: ________________	☐	☐
Haben Sie Erfahrung mit Fahrsimulatoren?		☐ Ja ☐ Nein	
Haben Sie Erfahrung mit adaptiven/ personalisierten/ intelligenten Systemen (z.B. GoogleNow)?		☐ Ja, mit ________________________________ ☐ Nein	

Probanden ID: ___________________
Variante name: ___________________
Adaption Level: ___________________

Fragebogen zum adaptiven Assistenten

Können Sie als Benutzer oder Benutzerin die vorgeschlagenen Empfehlungen des Infotainmentsystems nachvollziehen? Wie aufdringlich empfinden Sie die Empfehlungen?

	---	--	-	-/+	+	++	+++	
Es ist nicht nachvollziehbar, welche Vorschläge gegeben werden.	☐	☐	☐	☐	☐	☐	☐	Es ist nachvollziehbar, welche Vorschläge gegeben werden.
Es ist nicht nachvollziehbar, in welchen Situationen Vorschläge angezeigt werden.	☐	☐	☐	☐	☐	☐	☐	Es ist nachvollziehbar, in welchen Situationen Vorschläge angezeigt werden.
Es ist nicht nachvollziehbar, welche Informationen genutzt werden, um neue Regeln für Vorschläge zu erlernen.	☐	☐	☐	☐	☐	☐	☐	Es ist nachvollziehbar, welche Informationen genutzt werden, um neue Regeln für Vorschläge zu erlernen.
Es ist nicht nachvollziehbar, wie neue Regeln für Vorschläge entstehen.	☐	☐	☐	☐	☐	☐	☐	Es ist nachvollziehbar, wie neue Regeln für Vorschläge entstehen.
Es ist nicht nachvollziehbar, wann sich das Verhalten des adaptiven, intelligenten Assistenten ändert.	☐	☐	☐	☐	☐	☐	☐	Es ist nachvollziehbar, wann sich das Verhalten des adaptiven, intelligenten Assistenten ändert.
Es ist nicht nachvollziehbar, wie sicher der adaptive, intelligente Assistent sich mit dem Vorschlag ist.	☐	☐	☐	☐	☐	☐	☐	Es ist nachvollziehbar, wie sicher der adaptive, intelligente Assistent sich mit dem Vorschlag ist.
Es ist nicht nachvollziehbar, auf welche Applikation und Funktion sich ein Vorschlag bezieht.	☐	☐	☐	☐	☐	☐	☐	Es ist nachvollziehbar, auf welche Applikation und Funktion sich ein Vorschlag bezieht.
Es werden zu viele/zu wenig relevante Vorschläge angezeigt.	☐	☐	☐	☐	☐	☐	☐	Es werden in genau dem richtigen Maße relevante Vorschläge angezeigt.
Die Art der Vorschläge ist unangemessen.	☐	☐	☐	☐	☐	☐	☐	Die Art der Vorschläge ist angemessen.
Der Grad der Automatisierung ist nicht ausreichend (mit-) bestimmbar.	☐	☐	☐	☐	☐	☐	☐	Der Grad der Automatisierung ist ausreichend (mit-) bestimmbar.
Gelernte Regeln für Vorschläge können nicht bearbeitet werden.	☐	☐	☐	☐	☐	☐	☐	Gelernte Regeln für Vorschläge können bearbeitet werden.

Probanden ID: ____________________
Variante name: ____________________
Adaption Level: ____________________

	---	--	-	-/+	+	++	+++	
Vorschläge/Systemaktionen lassen sich nicht einfach und schnell abbrechen.	☐	☐	☐	☐	☐	☐	☐	Vorschläge/Systemaktionen lassen sich einfach und schnell abbrechen.
Vorschläge/Systemaktionen lassen sich nicht rückgängig machen.	☐	☐	☐	☐	☐	☐	☐	Vorschläge/Systemaktionen lassen sich rückgängig machen.

Feedback:

1. **Haben sie eine Aufgabe nicht abschließen können?**

   ☐ Ja ☐ Nein

   Falls ja: Warum haben Sie die Aufgabe nicht abschließen können?

____

____

____

2. **Was hat Ihnen am adaptiven Assistenten besonders gut gefallen?**

____

____

____

3. **Was muss noch verbessert werden?**

____

____

____

4. **Würden Sie den adaptiven Assistenten in Zukunft nutzen?**

   ☐ Ja ☐ Nein ☐ Vielleicht

   Begründung:

Probanden ID: ___________________
Variante name: ___________________
Adaption Level: ___________________

____

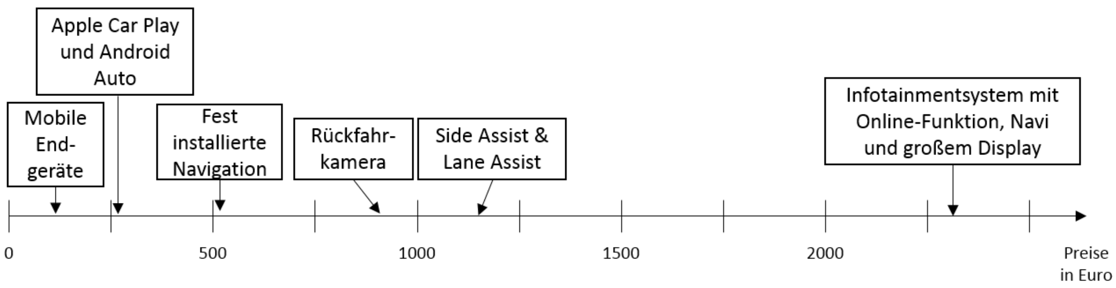
____

____

5. **Würden Sie den adaptiven Assistenten kaufen?**

☐ Ja ☐ Nein ☐ Vielleicht

6. **Welchen Preis finden Sie für den adaptiven Assistenten gerechtfertigt?**



7. **Haben Sie weitere Anregungen?**

____

____

____

____

____

____