Automotive User Experience Design Patterns: An Approach and Pattern Examples

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***Abstract*— Patterns are a methodology for capturing best practices and solutions to reoccurring problems in certain fields or disciplines. Applied to automotive interaction design they can combine empirical data, industry knowledge, and experts experience for state-of-the-art design solutions. In this paper, we present the patterns approach and its application to the automotive interaction domain, together with a newly generated set of eight in-vehicle user experience (UX) design patterns that describe answers to problems in automotive interaction design and engineering. These patterns are part of an ongoing project with the aim of providing a comprehensive, user experience focused, collection of design solutions for contemporary and future automotive designs. We present the pattern approach in general, the specific automotive approach and methodology, the patterns themselves, and finally discuss the benefits, drawbacks, and future work regarding patterns in the automotive domain.**

Keywords*— *design patterns; pattern identification and extraction; pattern reuse.

I. INTRODUCTION

This paper is an extended version of a full paper presented at PATTERNS 2016 [1]. The term ‘pattern’ has a wide range of meanings, both in everyday and academic language. Generally speaking, the term can be said to refer to a set of attributes that are common among a specific set of objects. In the context of this paper, however, it refers to a knowledge capturing and transfer method, first developed in the 19^{th} century for the architecture domain [2]. One key idea behind this method was that the solutions gained via said method should be reusable to solve similar and recurring problems; hence the term ‘patterns’.

The use of this method is well established in contemporary Human-Computer Interaction (HCI) and is considered advantageous for various reasons. First, patterns are a method to capture proven design solutions to reoccurring problems. Second, the use of patterns improves the design process (regarding both, time and effort spent) to a considerable degree [3][4]. Moreover, scientific research in HCI also strongly relies on communicating scientific findings to the industry. By translating these findings so that they convey relevant and useful information to designers and developers, patterns can help facilitate the design process by reducing time and effort that has to be put into it. Designing for a positive User Experience (UX) has become an increasingly important topic in academia and industry [5][6][7]. User Experience can be defined as *"the users sensory, emotional and reflective response to the interaction with a system in a context"* [8]. The car industry in particular has become a fast-paced global market that can draw substantial benefits from a modular and flexible documentation of best practices.

Automotive interface and interaction design is a complex and constantly evolving area. Driven by scientific findings and industrial progress, the number of interfaces and interaction devices, together with ways to interact with them, increases. The automotive domain, and the driver interaction space in particular, is a challenging environment to design in, given its emphasis on safety, minimizing distraction, and generally restrictive nature. There are no one-size-fits-all solutions for driver space design, and the challenge of providing contemporary solutions, which combine technological state of the art as well as driver and traffic needs, can be difficult. Due to the rapid progress in technology that is currently observable in the automotive domain, virtually every new day presents a new set of problems and challenges for designing novel interaction solutions.

Based on this consideration, we are in the process of creating a set of Contextual User Experience patterns for driver space design in the automotive domain, of which we present the eight most recent ones in this paper. In the following section, we will give an overview on the state of the art on Contextual UX patterns in general, and introduce our specific approach in Section III. In Section IV, we show each of the eight patterns and discuss these in Section V. We conclude the paper with a summary in Section VI.

II. RELATED WORK

In the original publication [1], we presented the eight automotive design patterns but outlined the pattern approach only very briefly and with no proper discussion. This extension aims to lend more context to the automotive patterns via a more extensive related work embedding, show our approach in greater detail, and discuss the initial pattern set, lessons learned, and remaining challenges. In this section, we will first introduce the original pattern approach and then talk about the relevance of patterns for User Experience design and research. After that, we introduce a number of existing pattern approaches in Human-Computer Interaction, which our approach draws from. We conclude this section with a brief overview of knowledge transfer and design information sources in the automotive domain.

A. Patterns

Patterns were first introduced by Christopher Alexander [2][9] as a way to capture and document solutions to recurring problems in the architecture domain. His work was adopted and expanded upon in several disciplines and, as a result, patterns have evolved towards a more widely applied means to capture problem solutions. HCI is among these disciplines and the pattern approach has been adopted in order to provide best practices and state of the art knowledge in this multi-disciplinary field [10][11]. Pattern approaches vary between disciplines, and, while attempts have been made, there is no widely accepted uniform cross-discipline pattern approach yet [12].

Köhne [13], who based his work on Quibeldey-Cirkel [14], presents a pattern finding process in several steps. The first step in this process is the so-called pattern mining, which consists of finding a solution and deciding whether or not it is adequate to solve a certain problem, after which it is written down, according to a predefined pattern structure. During the next step, the so-called *shepherding*, a domain expert (the *shepherd*) provides feedback regarding writing, formatting, and contents of the initial pattern to the pattern writer, who then iterates the pattern based on this feedback. This version is then discussed in a collaborative setting together with other pattern writers, after which the writer prepares the last non-public version of the pattern. This version is then put into a public online pattern repository, in which it is peer-reviewed. After any final edits to the patterns themselves have been made and the collection is deemed to be of good quality, it is published as a document and fully made available to the public.

Pattern mining is usually done by looking at actually implemented design solutions. But practical knowledge is not the only potential source for patterns - they can also be gained from scientific research. Martin et al. [15] mined patterns from ethnographical study results and then tried to generalize the observed phenomena and provide and/or apply them to other domains.

B. User Experience and the Need for Consolidated Solutions

In HCI, User Experience (UX) design is considered to be an important topic with relevance in both academic and industrial aspects [16][6]. In its most general meaning, User Experience research and design is a shift from a system-centered to a user-centered paradigm, in which the expected effects on the user are the focus of implementation and design decisions. However, putting this paradigm shift into practice is not a simple process and there are a vast number of UX approaches in academically oriented HCI studies alone. Reference to industry norms and standards can be helpful in such cases and mediate between the academic and practical sides of a multidisciplinary area such as HCI. For example, according to the ISO DIS 9241-210 standard, User Experience can be defined as "a person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service." [17]. This specifies the concept of UX somewhat but more can be done. There is a need for a way to consolidate the information and recommendations from academia, standards, guidelines, and practical experience into realizable solutions.

C. Contextual User Experience Patterns

Recently, specific domains in HCI, such as UX research, employed patterns to collect and structure their knowledge based on empirical findings [4][11][18]. This is illustrated, e.g., by Martin et al. [19] and Crabtree [20] who use patterns for organizing and presenting ethnographic material. In 2010, Blackwell and Fincher [7] suggest adopting the idea of patterns and UX in the form of Patterns of User Experience (PUX). Such patterns should help HCI professionals to understand what kind of experiences people have with information structures.

In the same year, Obrist et al. [4] developed 30 UX patterns for audiovisual networked applications based on a wide range of collected empirical data, which was further categorized into main UX problem areas. An extension of these UX patterns, are the so-called Contextual User Experience (CUX) patterns. Accordingly, patterns are used to describe the knowledge on how to influence the users experience in a positive way by taking context parameters during the interaction with a system into account. Within their work, the authors provide a detailed description of how to structure CUX patterns in the car context. Three years later, Krischkowsky et al. [18] presented a step-by-step guidance for HCI researchers for generating patterns form HCI study insights. In particular, they intended to support User Experience (UX) researchers in converting their gathered knowledge from empirical studies into patterns. The structural foundation for the intended patterns is the so-called Contextual User Experience (CUX) patterns format, as mentioned before.

Following in the footsteps of Obrist et al. [11], we decided to pursue a three pronged approach towards driver space design and cover three major UX factors via appropriate design patterns.These factors are:

- *Mental Workload Caused by Distraction* [21]: Safety is paramount in an automotive environment, and distraction is one of the major contributing factors to accidents on the road [22][23]. Especially in UX, where functionalities and interface complexities are ever increasing, this is one of the most important factors to consider regarding driver safety.
- *Perceived Safety* [24]: The increased safety gained by designing for decreased mental workload and less distraction needs to be communicated to the driver. The difference between objective and perceived safety can be relatively large. For many situations, it has to be evaluated if car interfaces should increase or decrease perceived safety.

- *Joy of Use* [25][26]: Cars have more and more become instruments that are not simply means of transportation but are also used for entertainment. Thus, it becomes important that car interfaces can be used not only without frustration, but also in a way that makes using them a joyful experience.

We choose to focus on each of these factors for specific reasons. Mental Workload Caused by Distraction was chosen because it has been identified as one of the most safety-critical factors in traffic safety and because in-vehicle interactive systems bear particular inherent distraction potential. Perceived Safety was chosen because the communication of safety measures to the driver, which are not only limited to reducing in-vehicle distraction, needs to be ensured for successful interaction, thus complementing the first UX factor. Lastly, Joy of Use was chosen to make sure the eventual solutions are still suitable for a consumer-driven market, which the automotive domain is. We consider it important to keep in mind that the safest car is of little use if nobody has any intention to buy it.

D. Norms and Guidelines in Automotive Design and Engineering

The importance of norms and standards for the automotive domain has been stressed by Green in 2012 [27]. He argues that it should be required to include references to norms and standards when conducting experiments in the automotive domain, such as [28] or [29], in order to improve replicability and applicability of driver interface research.

There are several norms, standards, and guidelines that can supplement existing domain knowledge and aid automotive designers and engineers to follow basic human factors and usability rules. On one hand, there are norms and guidelines for the the general design of interactive systems. An example is the ISO 9241-110 [30], which provides general dialogue design principles and is part of the ISO 9241 standards family, which is a multi-part standard from the International Organization for Standardization covering different aspects of ergonomics of human-computer interaction. On the other hand, there are guidelines for automotive designs often provided by automobile stakeholders, such as the AAM principles on Automotive User Interface (AUI) design [31], the JAMA guideline for in-vehicle display systems [32], the EU recommendation on safe and efficient in-vehicle information and communication systems [33], or the ISO 15005 norm on ergonomic aspects of dialogue management principles in road vehicles [34]. These often contain rather high level recommendations, which leaves a broad range of interpretation space for a designer. Yet, there are also very specific standards, such as the ISO 15008 [35], in which recommendations for alphanumerical character dimensions are given.

III. The Automotive Pattern Finding Process

The pattern finding process for car user experience patterns is described in detail by Mirnig et al. [36] and shall be reproduced here briefly and concisely; an illustrated overview can be found in Figure 1. In general, the process proceeds with the following five steps:

1) Problem finding and knowledge transfer workshop: The pattern finding process begins with an initial workshop, in which a small number (2-4 each) of both HCI researchers and automotive engineers and/or design experts participate. In this initial workshop, the focus is on knowledge transfer between the areas of academic HCI and automotive industry. The engineers are introduced to the pattern approach and the granularity of problems pattern solutions can be applied to. In a following discussion, the HCI researchers gather common and reoccurring problems, which the engineers face in their work. This happens in a top-down discussion, where overall issues or problem sources are defined first and are then broken down and refined during the course of the discussion. At the end of the workshop, the identified problems are compiled in a list and rated on 3-point priority scale (high, medium, and low priority).

2) Initial pattern mining: The initial pattern mining is done by HCI researchers, who are each assigned a number of problems with high to medium priority ratings. The number of patterns per researcher varies, depending on the number of researchers available, time constraints (if any), and number of high priority problems. In general, three to five problems (keeping in mind that one problem might result in more than one pattern) is a good number to aim for and keeps the workload for the individual at a manageable level. Naturally, the researchers should be competent regarding the academic aspect of the problems they are assigned. In the case of the UX automotive pattern collection, this meant that all of them should be familiar with UX and interface design, with specialization in the automotive domain being an additional plus, although not absolutely necessary. The first step is deciding whether or not the problem is a low or high level problem and whether or not its level of granularity is such that it requires one or several patterns. Each researcher then mines publications, demos, prototype presentations, and other available sources for solutions to the problem in question. These solutions can be partial, so that the researcher then combines all partial solution into one full solution for the eventual pattern. The pattern is written according to the structure outlined in the previous section and is then handed to another researcher for a first internal iteration. After this, the initial pattern or pattern draft is complete.

3) First iteration workshop: The initial patterns are presented to a group of automotive engineers in another workshop. Ideally, this workshop consists of some of the participants from the initial knowledge transfer workshop as well as participants who were not involved previously, in order to have a varied amount of viewpoints. The patterns are then read thoroughly by each participant and rated via a rating sheet based on the rating system developed by Wurhofer et al. [37]. Each pattern subcategory (Name, solution, etc.) is rated individually on a 5-point scale. When a pattern receives a rating of around or lower than 3 in any given subcategory, then it is marked for iteration. The workshop concludes with a discussion, in which the overall quality and

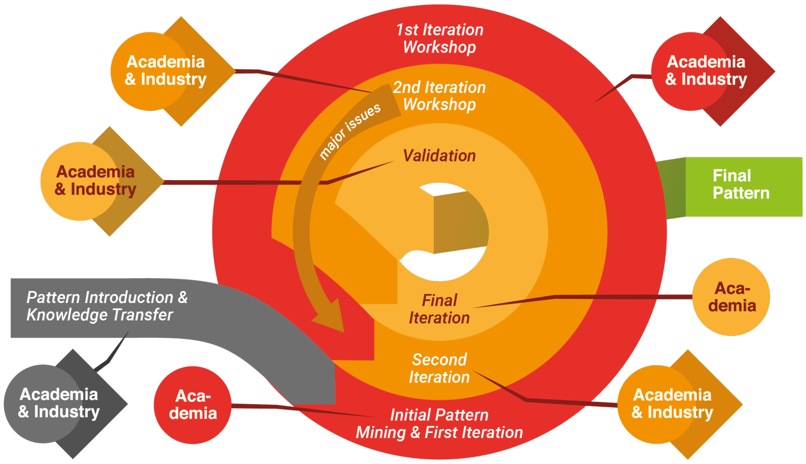

Figure 1. Overview of the Pattern Finding and Iteration Process.

cohesiveness of the pattern collection is discussed and any particular problematic patterns are identified.

4) Second iteration and workshop: After the workshop, the patterns undergo a second round of iterations, based on the ratings and feedback from the workshop. This time, they are iterated by at least one HCI researcher and at least one automotive engineer, in order to improve and ensure their practical relevance. The automotive engineer puts particular focus on supplementing the pattern with additional implementation examples (if available) and industry best practices. Like in the initial pattern writing, each pattern is cross-iterated by another researcher or engineer for typos, minor errors, structure, etc., before the second iteration is complete. The aim of the second iteration is content completion, i.e., the pattern solutions should be complete and fully described – all further iterations should only serve to improve structure, readability, and understandability. Once this iteration is completed, a second pattern workshop is conducted. The workshop proceeds like the first workshop, with the same rating system and discussion structure. In order to provide a fresh and unbiased view on the patterns and potentially identify new issues, the second workshop should, if possible, have some participants who were not part of the first workshop.

5) Final Iteration and Validation: After the workshop, the patterns are once again reworked based on the issues identified in the workshop. These should mostly be minor issues, although it is possible that major issues are found, which need to be dealt with. In that case, the pattern in question needs a content rework and is then put back in the loop for another content iteration workshop. Since it is usually not very efficient to schedule a workshop for only a handful of problematic patterns, these patterns are put aside temporarily. They are taken up again when a new batch of patterns is created and the appropriate iteration phase (and workshop) is reached. Once the patterns are reworked, the collection is provided to the industry experts for rating. Each pattern is rated individually, using the same rating system as before, and there is no need to do this in a workshop setting. In case a pattern receives a rating of around 3 or below at this stage, it is reworked and re-rated. It should be noted that this rarely, if ever, happens, since problematic patterns are usually identified before this stage. Once the patterns are all validated, the pattern collection is considered complete.

The resulting refined pattern structure consists of 9 parts: *Name* (a description of the solution of the pattern), *Intent* (a short abstract to allow quick judgment whether the pattern can be applied in a certain context), *Topics* (problem scope and addressed automotive user experience factor), *Problem* (a short but more detailed description of the problem which should be solved by the pattern), *Scenario* (an example application context of the pattern), *Solution* (the proposed solution), *Examples* (concrete examples of best practices), *Keywords* (other topics related to the pattern), and *Sources* (origin of the pattern).

IV. PATTERN COLLECTION

We developed a list of design problems together with designers and engineers working in the automotive industry and applied the aforementioned pattern generation approach, involving the industry stakeholders at several stages in the process. The following is one part of a resulting collection of patterns, which combines scientific and industry know-how into concrete problem solutions for UX-centered driver space design problems in the automotive domain. These patterns were edited regarding formatting and keywords as well as sources were removed for this publication. They are otherwise content-identical to the internally developed versions.

A. *Pattern 1: Menu Depth and Number of Options*

Intent: This pattern is about reducing distraction caused by navigating visual menus as a secondary task.

Topics: Workload caused by distraction, driver, haptic, input

Problem: While driving, navigation of in-vehicle user interface menus causes distraction. Given the safety implications of visual distraction, it is important to minimize visual demand of these menus.

Scenario: Drivers interact with visual menus to access information, communication and entertainment systems. Navigating menus with high visual demand severely distracts the driver and can thus lead to road deviations and crashes. Visual demand of menus is determined by a depth/breadth-trade-off. The deeper a menu, the less menu options per page there should be. A National Highway Traffic Safety Agency (NHTSA) guideline based on current research recommends that a driver should be able to complete a task in a series of 1.5 second glances with a cumulative time spent glancing away from the roadway of not more than 12 seconds [38].

Solution: Designing menus with limited depth allow drivers to complete secondary tasks in a relatively short time period. With the help of an empirically derived formula provided by Burnett et al. [39], it is possible to calculate different menu structures that comply with design guidelines:

$$T = D(0.87 + 1.24 * log(B)$$

where T = *time to complete the task*, D = *depth of menu* where B = *number of menu options*. Table I shows acceptable menu structures that comply with maximum task completion time according to the NHTSA guideline, as calculated using this formula.

TABLE I
MENU DEPTH AND NUMBER OF OPTIONS FOLLOWING NHTSA GUIDELINES

Menu Depth	Menu Breadth
3	12
4	5
5	3
6	2

Examples: see Figures 2 and 3.

B. Pattern 2: Display Touch Field Size

Intent: This pattern is about determining the optimal touch screen target size.

Topics: Workload caused by distraction, driver, touch screen, visual, haptic, input

Problem: Navigating in-vehicle displays while driving causes distraction, leading to road deviations and possibly to crashes. Thus, visual demand of touch screen menus has to be minimized while preserving maximum usability.

Scenario: Because they are easy to use and to understand, touch-screen interfaces are more and more used for operating in-vehicle systems. Drivers use them to control entertainment and navigation features provided by these systems as a

Figure 2. BMW iDrive - accessing vital information requires only three navigation steps.

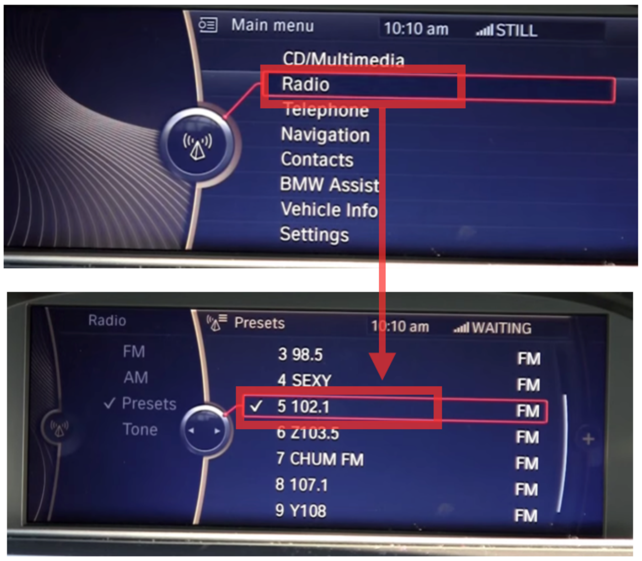

Figure 3. BMW iDrive - changing the radio station requires only two steps.

secondary task. The key factor for navigating these displays easily is the size of the touch target like a menu button [40]. Subjective usability ratings, as well as objective measures like task completion time and error rate heavily depend on this factor.

Solution: Touch targets need to be large enough in order to minimize task completion time and error rate. Design guidelines suggest a minimum contact surface area of 80 mm [38]. However, in a recent driving simulation study that focused on touch target size for in-vehicle information systems, the authors determined that a touch key size of at least 17.5x17.5 mm minimizes navigation error rate, lane deviations, driving speed variation and glance time while maximizing subjective usability ratings [41]. While touch screen size and overall visual complexity of the menu always have to be taken in consideration, the recommended touch key size may serve as a starting point for menu design.

Examples: See Figure 4.

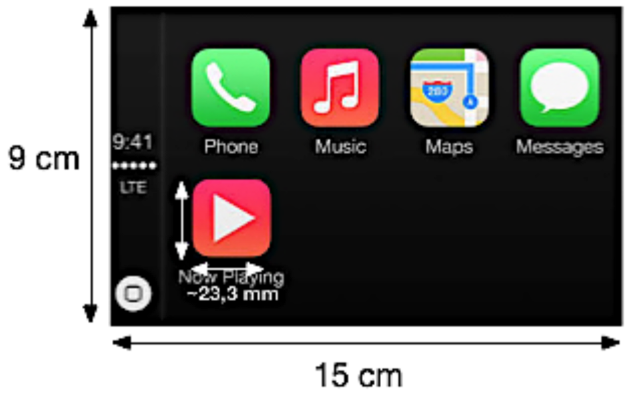

Figure 4. Apple Car Play menu.

C. Pattern 3: Auditory Information and Warnings

Intent: This pattern is about designing auditory information and warnings that are quick to capture and easy to comprehend.

Topics: Perceived safety, driver, acoustic, output

Problem: When using only visual warnings, driver distraction can occur. Still, drowsiness and inattentiveness increase the risk of traffic accidents. Thus, it is still necessary to direct the drivers attention to potential dangers by different means.

Scenario: Well-designed auditory warning systems can serve this purpose. Perceptibilty of auditory warnings depends on loudness, background noise and complexity. Also, the driver needs to know which actions have to be taken to react appropriately.

Solution: Different warning techniques are appropriate for different situations. According to Bliss and Acton [42], verbal speech notifications and auditory icons (sounds with real-world representations, e.g., the sound of a car engine) are equally efficient when it comes to response accuracy and reaction time. Auditory warnings also have to convey enough information to be accurately understood. Due to driving comfort reasons, warnings of low urgency should not be annoying and can even be quite pleasant, while high-urgency warnings are bound to be annoying [43].

Examples: Table II shows auditory warnings for some common situations of varying urgency. Empirical work on the perceived urgency of speech based warnings has been done [44].

D. Pattern 4: Choosing the Best Modality for Warning Displays

Intent: This pattern is about choosing the right warning display modality for different situations, combining different modalities if adequate.

Topics: Perceived safety, driver, multimodal, output

Scenario: In-vehicle information system (IVIS) information needs to be delivered effectively while minimizing the interference with driving. Display modality has a significant impact on the performance of in-vehicle information systems. Visual, auditory and tactile displays all have their advantages and disadvantages [45]: Visual warnings can be inspected at the drivers own pace and can be viewed multiple times. However, they cause visual distraction from the driving task and can be overlooked. Auditory warnings can be picked up without causing visual distraction, but they require the drivers full attention when they are displayed. Tactile warnings are highly noticeable, not influenced by noise and have no visual demand, but they are limited to a few types of information, such as simple alerts. In order to maximize IVIS efficiency, designers have to choose carefully between the different modalities.

Solution: When choosing between auditory and visual presentation, Table III offers decision guidelines based on current empirical research for a variety of cases. Some of these cases will probably benefit if combined with another display modality.

Examples: Figure 5 shows combined auditory and visual warnings. See [46] for a live demonstration.

E. Pattern 5: IVIS System Response Time

Intent: This pattern addresses the role of system response time while operating in-vehicle information systems by touch interfaces or hardware keys and its influence on driver distraction and comfort.

Topics: Workload caused by distraction, joy of use, driver, keys, visual, haptic, input

Problem: While getting more and more complex, many modern in-vehicle information systems possess significant delays when using them because of the sheer amount of information that they have to process. The influence of system response time - the delay of a systems response after user input until it is ready to take new commands - has

TABLE II
RECOMMENDED WARNINGS FOR COMMON SITUATIONS OF VARYING URGENCY

Urgency	Speech Based Warnings	Auditory Icons	Appropriate Situation
Informational (low)	Signal words that convey low urgency: ”Notice”, ”Information”	Pouring water, steam, released air	Low petrol and oil levels, low tire pressure
Warning (moderate)	Signal words that convey medium urgency: Warning, Caution	Shutting car door, Roaringmotor sound, squeaking sound	Car door opened, speed limit exceeded, hand brake on
Critical (high)	Signal words that convey high urgency: Danger	Car horn, car crash, alarm siren	Blind spot overtaking, car drifting off road, collision possible

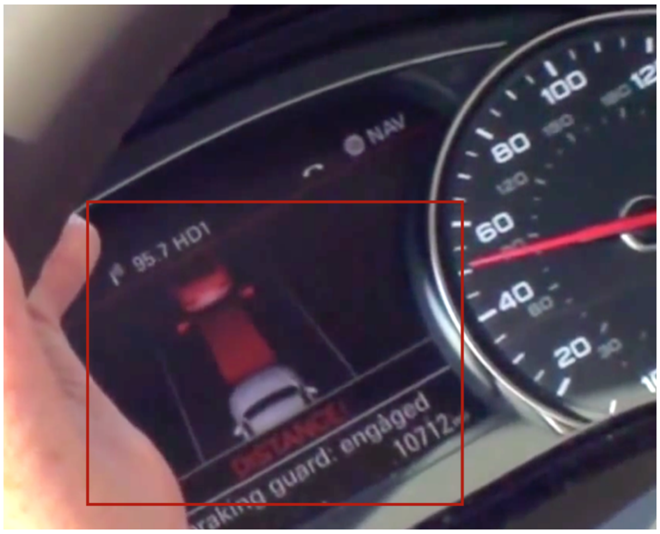

Figure 5. Audi A8 Distance Warning through a combination of auditory and visual warning displays.

been discussed as a potential source of driver distraction and annoyance [47].

Scenario: Drivers use in-vehicle information systems for a wide variety of functions. While navigating their menus, the IVIS processes large amounts of information, which may lead to long and uncertain loading times.

Solution: Keep system response time below 250 ms. According to current design guidelines [38], control feedback should be given within 250 ms after the input. A study by Utesch and Vollrath [48] showed that longer feedback delays (500 or 1000 ms) did not impair driving performance but caused significant annoyance in drivers. Keep system response times constant. It has also been shown in this study that delays that vary in their length distract the driver, while constant delays cause less off-road glances. It can be concluded that feedback delays should be kept constant so that waiting times for system response are predictable. For longer delays, use additional feedback modalities. According to guidelines of the European Commission [49], if system responses take longer than 250 ms, the system should inform the driver that it has recognized the input. If longer delays (500 ms and above) are inevitable, Utesch and Vollrath [48] recommend using acoustic or tactile feedback to indicate system readiness, as this will reduce off-road glances.

Examples:
1. Demonstration of a 2015 Audi MMI System, showing constant and short system response times [50].
2. Demonstration of a BMW 5 Series iDrive, showing long but constant delays [51].
3. Demonstration of an Apple CarPlay IVIS in the Ferrari FF showing long and variable delays. This might cause distraction and annoyance [52].

F. Pattern 6: In-Vehicle Display Icon Size

Intent: This pattern addresses recommended IVIS icon sizes.

Topics: Joy of use, driver, icons, visual

Problem: IVIS displays transport various pieces of information, some of which require quick and accurate recognition. However, as in-vehicle displays have to convey more and more information, available space on in-vehicle displays becomes sparse.

Scenario: Icons are a way of presenting information in a spatially condensed, yet clearly understandable way. When relying on icons, the driver needs to be able to quickly grasp and process information, which in turn requires that icons can be easily recognized.

Solution: According to Zwaga [64], icons perform better than text displays only if they are well designed. According to FHWA guidelines [65], choosing the adequate size for an icon can be determined with the following set of formulæ. See Figure 6 for an illustration of visual angle, distance and symbol height (where Symbol Height = the height of the symbol; Distance = distance from viewers eyepoint to the display; Visual Angle = angle in degrees. Height and Distance use the same unit of measure).

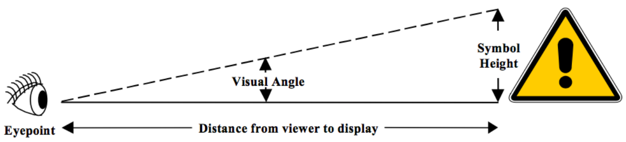

Figure 6. Relationship between Viewing Distance, Symbol Height and Visual Angle.

1. If viewer distance and Symbol Height are known,

TABLE III
RECOMMENDED WARNINGS FOR COMMON SITUATIONS OF VARYING URGENCY

Case	Primary Modality	Reason	Combine with...
High priority messages	Auditory [53][54]	Visual warnings alone are likely to be overlooked	Tactile [55] for decreased reaction times
Complex secondary task	Auditory [56][57][58]	Further distraction due to increased glance duration	Visual [59] for reduced reaction times and less navigation errors
Driving task is highly demanding, e.g., high driving speed	Auditory [56][57][58]	Divided visual attention poses a security risk	
Displaying instructions, commands, warnings or alarms	Auditory [60]	Speech is more suitable for this information type	Tactile [61]
Auditory message cannot be kept short and precise	Visual [62]	Auditory messages that are too long cause severe distraction	
Driver performs auditory tasks	Visual [44]	Auditory perception is partially or completely blocked	Tactile [63] for reduced lane deviations and annoyance, increased pleasantness

the following formulæ will calculate the distance.

$$arctan(\frac{Symbolheight}{Distance}) \quad (1)$$

or

$$\frac{3438\frac{Height}{Distance}}{60} \quad (2)$$

2. If distance and visual angle are known.

$$Distance[tan(VisualAngle)] \quad (3)$$

3. If visual angle and symbol height are known, the following formulæ will calculate the distance.

$$\frac{Symbolheight}{tan(VisualAngle)} \quad (4)$$

Examples: See Figure 7.

Figure 7. Audi A4 2008 Dashboard Icons, taken from the users manual [66].

G. Pattern 7: Visual Display Colour Choices

Intent: This pattern is about choosing adequate colours for visual displays.

Topics: Joy of use, driver, colors, visual

Problem: IVIS displays transport various pieces of information, some of which require quick and accurate recognition. However, as in-vehicle displays have to convey more and more information, they still need to be processed quickly.

Scenario: IVIS displays have to display information in a clear and efficient way. One way to achieve this is picking adequate colors for displays, so that reading and recognizing symbols can be accomplished without delay.

Solution: According to NHTSA guidelines, visual display colors should comply to a number of standards.

- Avoid using red/green and blue/yellow combinations so that color blind drivers can process the display easily.
- According to a survey conducted by Lee and Park [67], senior people prefer combinations with distinctive brightness contrasts between foreground and background color because of their better legibility.
- Displays that are too colorful distract the driver in various ways. Excluding black and white, a maximum of five different colours should be used.
- Use different colours for different priorities, e.g., red for critical alerts, amber for warnings, white for information.

Visual displays are easier to process if high color contrasts are used. A driving simulation study showed that inefficiently designed car displays strongly increase reaction times in driving tasks. They also increase reading errors [68]. Table IV shows color contrasts that guarantee high legibility.

TABLE IV
RECOMMENDED COLOR CONTRASTS FOR IVIS DISPLAYS

Black/yellow	Black/yellow
Black/white	Black/white
Black/orange	Black/orange
Blue/white	Blue/white
Green/white	Green/white
Red/white	Red/white

Examples: See Figure 8. This dashboard relies on white-on-black and orange-on-black contrasts which are highly visible. Orange is the only color used (beside black and white).

Figure 8. Dashboard with color contrasts that are highly visible.

Figure 9. BMW iDrive screen, showing blue-on-white contrasts with an orange highlight.

H. Pattern 8: Physical Buttons versus Touch Screen Interfaces

Intent: This pattern addresses the question whether touch screens or physical buttons should be used.

Topics: Workload caused by distraction, driver, touch screen, visual, haptic, input

Problem: Current touch-screen devices provide no tactile feedback concerning control orientation, location, separation from one another. While driving, they can not be operated with eyes on the road, which in turn leads to long off-road glances. NHSTA guidelines [38] suggest that touch interfaces should not be operated while driving. On the other hand, touch screen devices provide much more flexibility, which is needed to operate modern, feature-rich in-vehicle information systems.

Scenario: Drivers use in-vehicle information systems for a wide variety of functions. Ways to navigate through the increasing number of functions are getting more and more complex. Touch screen interfaces are getting more and more popular, but navigating them while driving is highly distracting.

Solution:

1) While driving, limit the amount of time spent to interact with touch devices. NHTSA recommends a maximum of six touches for every 12 seconds period [69]. Physical buttons do not require such strict regulations as their functionality is limited and they are not as visually distracting. Thus, functions that must be available to the driver while the car is moving should be represented by physical buttons or clearly identifiable, big touch buttons. Recommended limitations are as follows
   - For touch devices **without** haptic feedback, limit touch screen interactions to six touches for every 12 seconds.
   - For touch devices **with** haptic feedback, limit touch screen interactions only to certain functions.
   - No restrictions apply to physical buttons while driving.
   - No restrictions apply while standing.
2) Equip touch devices with haptic feedback. According to Harrison and Hudson [70], touch screens lead to a high number of off-road searching glances and require long periods of operation time. They also found that this could be mitigated by provide touch screens with haptic feedback, which is confirmed by other studies [71]. Studies suggest that this kind of feedback greatly increases performance and reduces operation time. If haptic feedback is used, touch devices still should to be limited to the functionality provided by traditional physical buttons.
3) Also, consider alternative input methods that do not require visual attention (e.g., voice interaction).

Examples: See Figure 10.

Figure 10. VW Passat dashboard which combines few physical buttons with a well-readable touch display.

V. DISCUSSION

A. Patterns in Use

The approach presented in this paper covers the pattern generation process from its initial problem finding stages up until the final validation of the eventual patterns. However, one thing the approach does not cover is something, which could be considered one of the more important metrics of the quality of a pattern - the successful application of a pattern. The evaluation phases all rely on the informed, but still subjective, judgments of industry experts. It can be assumed that these judgments are reliable due to the expertise of those making them. Still, an improved pattern approach would include an actual application or re-application of a pattern's described solution and another evaluation of the pattern, based on that implementation's success.

B. The Rule of One-Two-Three

A solution described in a pattern is expected to satisfy certain conditions. One of these is that the solution should be a *proven* one, meaning that it has worked or successfully been implemented in more than just one instance. A commonly applied rule in pattern writing is the so-called *Rule of Three* [72], which – when summed up roughly – considers a solution as proven if it has been successfully implemented at least three times. But is rather unusual to find the exact same information in two or more independent publications. In addition, the beyond state of the art nature of a good number of our solutions made it difficult to find an appropriate number of full solution implementations with adequate documentation. However, the combination of all sources yielded a substantial enough body to lend a certain degree of support to the viability and reproducibility of the described solutions. The fact remains, however, that many of the solutions described in our patterns do not satisfy the Rule of Three in a strict sense.

C. Experts vs. Novices

In our approach, we opted for more concise and shorter patterns in order to meet our industry partner's needs. The idea was to provide an eventual "patterns handbook", which could be consulted on-demand and at any time during their work. In doing so, we omitted deeper scenario descriptions, optional references and source material, and kept the number of illustrative examples to a minimum. This restructuring brought the desired increase in efficiency, but we expect that it is not without its drawbacks. In this case, our patterns are very likely to be less useful for novices than for experts, since they contain only the most essential information, in order to implement the described solution, which negates this one important benefit of patterns. Thus, we recommend for anyone who intends to adopt the pattern approach to decide whether or not increased efficiency or a broader pattern audience are more important, as it is unlikely that both goals can be realized at once.

D. Academia and Industry Access

Lastly, we should note that the approach we pursue is a rather particular one, with input taken from not only working implementations but also other sources, and integrated with industry stakeholders – both to enrich the pattern content and to better fit the eventual patterns to the stakeholders' needs. Pursuing such an approach requires sufficient available resources as well as access to both academic and industry experts, which is not always possible. Thus, the approach we pursue and briefly outlined in this paper is likely not suitable for everyone. The resulting patterns, however, should be.

VI. CONCLUSION

In this paper, we presented a collection of patterns, which deals with recurring questions of automotive design as reported by designers working in that area. By relying on design guidelines as well as empirical research, the collection tries to bridge the gap between regulations, standards, scientific findings, and industry knowledge. These patterns are intended to be of direct practical use for automotive designers. The pattern structure and length, which we described in earlier work [36], has been further adapted to fit automotive industry stakeholder needs, resulting in patterns with an increased emphasis on brevity and conciseness.

The automotive User Experience patterns proposed in this paper constitute a small part of a constantly growing collection of design knowledge. The speed of innovations, the complexity, and the range of functions of car interfaces is increasing constantly. In addition, even if there are more and more connections between single car interfaces, innovations do not necessarily occur in parallel. Thus, an equally dynamic approach to document best practices in design is required. As stated before, pattern collections are less holistic than guidelines and never really finished. New problems arise, new solutions to old problems are found, and sometimes proven solutions are found to not work as well as initially thought. This makes patterns arguably less suitable for traditional publishing as paper volumes, since these can, once printed, not be updated, save for issuing a new edition and print run. A database solution would be the obvious answer. A good example for such an online pattern resource is the Portland Pattern Repository Wiki [73]. Unlike a paper volume, however, such a database requires constant maintenance, dedicated moderation in case of crowdsourced editing and commenting functions and, of course, the initial infrastructure and server capacity.

Thus, the final pattern collection is still envisioned as a printed document, with the possibility of a later database conversion. While it is less dynamic than the more resource intensive database variant, this pattern collection shows how a pattern approach to car UX design can meet the demands of at least contemporary and near-future automotive design and the collection will continue to grow into a substantial body of car UX design knowledge. The goal of the first "complete" version of the pattern collection is expected to encompass 50 patterns, which cover some of the more important UX factors for driver space design [10].

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