Human-centered User Interfaces for Automated Driving – (Un-)exploited Potentials

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Abstract. Designing user interfaces for (highly) automated driving is a complex task since users vary considerably regarding their needs and preferences. Therefore, a one-size-fits-all approach will not be sufficient for designing these interfaces. Thus, in this paper we aim to identify unexploited potentials in this area. We do so by performing a systematic literature review. Our contributions are 1) a systematization of human-centered user interface design for automated driving in four key aspects, 2) the research intensity per aspect, 3) the unexploited potential within each aspect and 4) the potentials of the relations between them. Concretely, current research lacks frameworks supporting the customization of the named interfaces based on user characteristics. Among others, personalization of displayed information shows unexploited potentials for acceptance and usability. Thus, we recommend future research to focus on human-centricity accounting for individual needs instead of the interface itself.

Keywords: Human-Machine Interaction, Human-centered Interface Design, (Semi-)Automated Driving, Autonomous Driving

1 Introduction

As with most technological transformations, the transition from manual to automated driving (AD) takes place gradually. From supporting assistants (level 2) over highly AD allowing for non-driving side activities (level 3) to fully automated vehicles (AV) (level 4), responsibility passes over step-by-step from the user to the vehicle [1]. For the design of the user interfaces (UI) this results in radical different needs compared to the time without automatization. This holds true for hard factors, where in AVs the interface needs to show crucial driving information to the user. The user needs them at the right detail level at the right moment for fulfilling his part of the driving task [2]. For soft factors, the challenge of gaining the users' trust is harder when they give up the control [3, 4].

When striving to address these challenges, UI design usually considers "standard" users or personas as proxies for the possible drivers. However, when personal automated mobility becomes available to a broader public and not only to a small customer segment, the potential user can vary strongly in numerous dimensions. This can result in varying needs and preferences regarding the UI [5, 6]. Also, different users perceive the same

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situations of AD very differently, e.g. more or less safe [7]. In line with this, previous research encourages individual interactions and human-centered approaches [8].

Therefore, we perform a Systematic Literature Review (SLR) that shows the latest state of research regarding human-centered UI design for AD. This includes the inductive, data-driven derivation of the systematization in the four "W"s (see Figure 1). We developed the four "W"s inductively from all the aspects out of the analyzed works. Additionally, it derives the research intensity per aspect and if it corresponds with its potential. "Potential" refers to the degree, how strongly the aspect can contribute to usability, acceptance, safety, comfort and pleasure for the user [9]. "Comfort" already differs for users: elderly people expect driving support and system feedback, younger people wish to use the travel time in a more useful way [7]. In the last step, it discovers unexploited potentials. The following Research Questions (RQ) guide our analysis:

RQ1. What are the central aspects in human-centered user interface design for AD?
RQ2. What is the research intensity regarding these aspects?
RQ3. Do the intensities correspond to the potential of each aspect?
RQ4. Which potentials in the relations between the aspects are still unexploited?

There are related reviews besides the analyzed research: for automotive UI in general including manual and automated driving, a comprehensive literature review is available [9]. Over the past ten years, only around 22 % of the work focuses on AD, roughly 3 % especially on the regarding UIs [9]. For AD, a review for control transitions is available [8]. It systemizes these transitions in categories but leaves out personalization and human-centered aspects. Thus, we set a focus on individual AD UIs for this SLR, since something comparable is not available yet to the best of our knowledge. Especially, current works lack analyses which user specific aspects to focus on for making UI design contribute to the success of AD. In summary, this article delivers the following results:

to RQ1. *Proposed systematization of human-centered AD UI design in four big "W"s* (see Figure 1)*:* the individual user with all his characteristics ("**W**ho is the user?"), the information shown ("**W**hich information does this user require?"), the chosen channel ("**W**hich representation does this user serve best?") and the time of interaction ("**W**hat time of interaction is best for this user?").
to RQ2. *Research intensity so far per "W":* by far the highest for the channel, around half as high for the user, low for information and very low for time.
to RQ3. *Correspondence between knowledge base and potential for human-centered UI design within each "W":* the greatest gap exists in accounting for the characteristics of the individual user and for personalizing the information provided by the system. Also, for the channel a rather broad research base is available leading to smaller unexploited potentials. For time, very few articles face comparably low potential, resulting in a rather small gap.
to RQ4. *Unexploited potentials in mechanisms between the "W"s:* research lacks a stable framework (i.e. a structure of design principles [10]) to include the individual user in the UI design. Bidirectional relations are possible due to the impact of the UI on certain states of users. Furthermore, the relations between the "W"s are not yet sufficiently incorporated either. For instance, channel or time of interaction could adjust to the information shown.

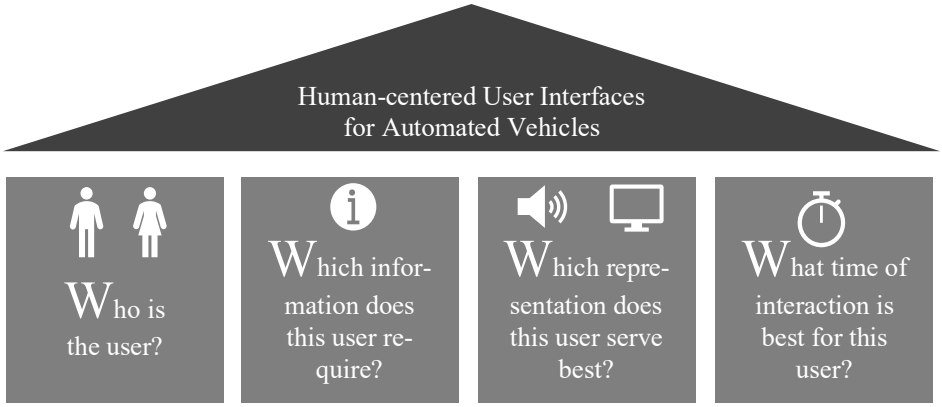

Figure 1: The four big "W"s (aspects) of human-centered UI design for AD.

The further structure of this paper is as follows: Section 2 describes the research method. Section 3 outlines the results of the analysis and thereby provides detailed insights regarding research questions RQ1 (Section 3.1) and RQ2 (Section 3.2). On this basis, Section 4.1 discusses RQ3 and Section 4.2 RQ4 in greater depth, while Section 4.3 shows limitations. Section 5 concludes and proposes directions for further research.

2 Research Method

This paper is a SLR. We followed established guidelines put forth by Kitchenham [11] and Webster and Watson [12]. Thus, we at first identified the research scope: the paper focuses on 1) human-machine-interaction respectively UI, 2) used in the context of (semi-)AD and 3) on research regarding human-centered questions.

Following the approach of gradually removing and adding synonyms of the demarcations we elaborated a query. To ensure a broad literature base we performed a full text search. Additionally, this SLR excludes other content types than research articles such as work-in-progress or extended abstracts. Furthermore, it considers work published until January 2021 inclusively. The final query is ("human machine interaction" OR "human computer interaction" OR "user interface" OR "human-centered computing") AND ("autonomous driving" OR "automated driving" OR "self-driving" OR "driverless" OR "autonomous vehicle") AND ("human-centered").

In addition to the guidance regarding query formulation by Kitchenham, we also checked all terms of the query for sensitivity. Consequently, we removed synonyms not increasing the hits by at least 5 %. In this way, we avoided a "pollution" of the query with irrelevant terms. For example, in case of "human-centered", possible synonyms such as "user-centered", "personalization" or "customization" showed little impact.

Next, we based our analysis on comprehensive databases rather than individual conference proceedings or journals to ensure an encompassing research base [12]. For the same reason, we did not limit the literature base with respect to research methodology or geographic region. Among the tested databases are Scopus, ScienceDirect, the Institute

of Electrical and Electronics Engineers (IEEE) library and the Association for Computing Machinery (ACM) Digital Library. We limited the quantitative analysis of Section 3.2 to the latter. We did so, since it showed the best fit for the core topic of this article, being the borderline of humans and technology through human-centered UI aspects, personalization and customization. Furthermore, ACM yields notably more hits compared to the other databases supporting a rather broad analysis. For the case of IEEE that could hold true since it has more of an engineering focus. Also, the ACM library comprises most of the relevant journals, conferences and proceedings. The final number of hits in the ACM library was 416 by the end of January 2021. If relevant, we included works from other databases in Section 4.

Then, we screened the 416 papers by analyzing title, abstract and keywords with respect to its fit to the RQs. The inclusion-exclusion criteria are the following [11, 13]: the works need to elaborate on (semi-)automated or autonomous driving for people moving. Also, it must develop either relevant characteristics of the user (driver) or design dimensions of the UI or both. Additionally, possible personalization and customization, as well as research gaps and were of interest. 95 papers out of the hits comply with these criteria. We analyzed these papers in greater depth by reviewing title, abstract, introduction and conclusion. We sorted the hits by relevance using the respective ACM library function for the order of analysis. For each work we either created a new "W" or sub-dimension if necessary or assigned it to one already created by us. The articles we analyzed lastly did not contribute to the inductively developed systematization of the "W"s anymore. This indicates the analysis being broad and not omitting relevant aspects [12].

To address the RQs, we followed a two-step-approach: firstly, we inductively derived relevant aspects and systematized them. (RQ1, Section 3.1). We then determined the research intensity of each aspect within this systematization quantitatively (RQ2, Section 3.2). To do so, we used the numbers of publications focusing on the aspects. We defined as criterion, that the papers need to focus on the regarding "W" or even changes a treatment in the experiment within the "W". Thus, it is not sufficient to mention the participants' average age to be counted as elaborating on individual users, the work would for instance need to show differing needs due to age. Secondly, we compared the state of research with the potential of each "W" qualitatively (RQ3, Section 4.1). This paved the way for finally deriving the currently still unexploited potentials between them (RQ4, Section 4.2).

3 Results

In Section 3.1 we detail the four "W"s as the systematized central aspects of human-centered AD UI design (RQ1). Section 3.2 shows the research intensity per "W" (RQ2).

3.1 The four Big "W"s

The user

To enable customization and human-centricity for AD UIs, users with their differing preferences and needs are the central reference point [14, 15]. Thus, we start our analysis there. The driver can vary in several dimensions having implications for the interaction:

demographics, *predispositions*, *personal conditions* and *level of awareness*. This paper sorts these dimensions ascending by changeability. Changeability is the degree of dynamism and speed of alteration over time for a specific user.

The less changeable dimensions are *demographics* including age and gender [16, 17]. People in certain ages differ in terms of trust and acceptance towards AD [18]. Moreover, elderly people can have limitations in perception of a certain communication modality for instance due to hearing impairments [16]. Also, the user can differ in gender and with it in its emotional perceptions of interaction with technology [17].

The next still rather static dimensions are *predispositions*. They consist of experience [19] and prior knowledge [20] in (automated) driving, personality traits such as risk perception [19], cultural background [21], affections such as the desire for joy of manual driving [22] and trust in automation [14, 23]. Furthermore, there are physiological predispositions such as impaired eyesight [24].

More changeable is the *personal condition* of the user. It consists of psychological and physiological aspects. The former comprise comfort and anxiety, the cortical load and nervousness [5, 25]. The latter refer to heart rate, eye movement pattern, galvanic skin response and reactions such as motion sickness [25, 26].

The most changeable dimension of the driver is his *level of awareness* [27].The user can be aware of the surrounding (traffic) situation, but also of the current driving mode [28]. The UI could adapt to the introduced user characteristics. For this adaptation however, it is important to know the user in detail. The first of the four "W"s results:

Who is the user?

The information

The aspect of the information offered by the UI has the sub-dimensions of *amount*, *selection* and *prioritization* [27, 29]. The amount describes how much information the UI displays at a certain time [29]. The selection describes which information the user could need, for instance system uncertainty information for trust calibration [4, 30]. When it comes to prioritization, considerations such as safety and relevance of warnings over other information are factors for higher prioritization [29]. In addition, users have individual priorities regarding the traffic situation and which other participants are most important [31]. Hence the information need is specific for a user and it thus has to be determined for each user. Thus, the second "W"s results:

Which information does this user require?

The representation

Based on the analysis of an individual user and the information he or she requires, a resulting question is how the system should communicate it. Several ways of doing so are available: *auditory* [32, 33], *visual* [26, 29], *haptic* [34, 35] and less frequently treated in research deictic gestures [36], gaze (direction) [37] and olfactory [23].

For each channel, additional design dimensions of the *presentation* are available: anthropomorphism by using (partly) human-like avatars [38], the degree of abstraction [39] and assertiveness [40]. Consequently, the third "W" follows:

Which representation does this user serve best?

The time

Concerning timing-aspects in UI design, it is the choice to communicate information before, during or after an action [41]. This relation to the real world happening is an important design dimension. In addition, the interface can give information either over a period of time or just at (a) certain point(s) in time [42]. Such aspects are important to ensure the user is not absorbed by a driving maneuver, can process the information and is notified immediately for safety-related cases. Hence the fourth big "W" arises:

What time of interaction is best for this user?

Table [1] summarizes the "W"s with sub-dimensions as well as the relevant works.

Table 1: AD UI "W"s with their sub-dimensions and relevant sources

The "W"s of AD UI	Sub-Dimension	Relevant works
"Who is the user?"	Demographics	[16–18, 43]
	Predisposition	[3, 6, 43–47, 14, 15, 19–22, 24, 31]
	Personal conditions	[5, 22, 50–55, 25, 26, 31, 41, 43, 44, 48, 49]
	Level of awareness	[2, 21, 60, 26–28, 43, 56–59]
"Which information does this user require?"	Amount	[15, 29]
	Selection	[3, 4, 62–68, 14, 15, 23, 27, 29–31, 61]
	Prioritization	[29, 31]
"Which representation does this user serve best?"	Auditory	[27, 32, 69–78, 33, 40, 44, 53–55, 62, 65]
	Visual	[2, 4, 52, 53, 60–64, 66, 68, 72, 14, 75–84, 22, 85–93, 26, 27, 29, 31, 37, 46]
	Haptic	[4, 6, 84, 94–97, 34–36, 53, 62, 70, 72, 78]
	Presentation	[5, 38–40, 58, 96, 98]
"What time of interaction is best for this user?"	Relation to real world happening	[14, 41, 42, 99]
	Period/point	[42]

3.2 Research intensity per "W"

Out of the analyzed papers, 38 treat the user or a dimension he or she can vary in. 72 paper treat the UI in its different dimensions of information, channel and time. Hence, these 72 paper at least touch one of the other three "W"s. We show this combined number of paper treating information, channel and time, since these "W"s can rather be assigned to the UI itself and not primarily to the user. Consequently, almost double as many publications treat the interface than being concerned with the person of the driver. Figure 2 depicts the number of papers treating the "W"s and their sub-dimensions.

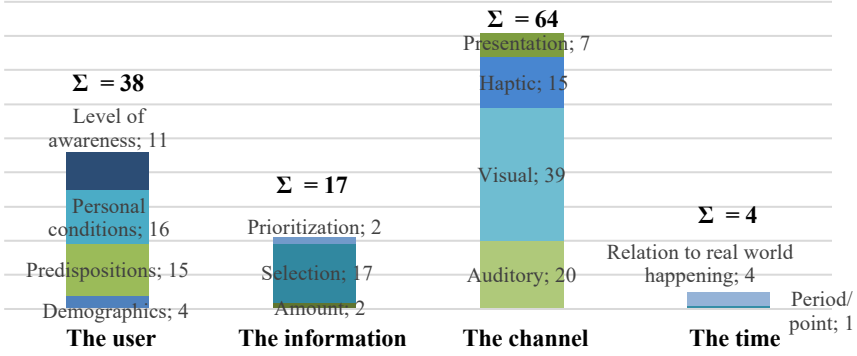

Figure 2: Number of papers treating the four "W"s and their sub-dimensions in detail indicating the research intensity. Papers do not add up due to allowed double counting.

Furthermore, within the field of the UI, 17 papers address the information (second "W"), 64 the communication channel (third "W") and four the factor time (fourth "W"). Consequently, research treats the communication channel almost four times as often as the information to be communicated, while widely disregarding the time.

Obviously, one paper can deal with more than one "W". 19 out of the 95 paper address the user as well as dimensions of the UI. Consequently, around 80 % of the papers only treat the user or the UI in depth without striving to identify a mechanism between both. Additionally, only roughly 13 % of the paper treat the UI dimensions information and communication channel, while only roughly 1 % also treats time.

4 Discussion

4.1 Correspondence of research intensity and potential

Due the definition of potential as a possibility not exploited yet, it is within this understanding that it is hard to quantify. Thus, in the following we focus on qualitative argumentation based on indicators pointing towards untapped potentials.

Who is the user?

At first, we outline the specifics of the user and the potential for customization. These specifics have the sub-dimensions demographics, predispositions, personal conditions and level of awareness. Starting off with demographics, 75 % of elderly people refuse AD due to high distrust and uncertainty [18]. Besides, these drivers require the system to detect cases of emergency and react accordingly, when the regarding person cannot solve the situation by itself [43]. Furthermore, age can come with physical impairments. These can also be the reason for elderly people to feel less safe during AD [7].

As a second demographic dimension the gender of users can have impact on the needs regarding UIs. This can for instance be due to a higher desire for the expression of power, freedom and self-control of men resulting in rejecting AD emotionally [17].

In terms of predispositions, the cultural background has influence on the behavior such as gaze patterns and perceptions. For instance, Japanese users rather focus on salient

foreground objects. In contrast, Americans rather perceive prominent background features [21]. As a more dynamic predisposition the skill level regarding (automated) driving of users influence performance and perceived usability, usefulness and satisfaction [20]. Besides, the desire for joy in AD differs for users. They depend on the wish for control or also to engage in non-driving-task-related activities [22]. Moreover, risk and trust are not generalizable but lie in the users' perception [3]. Also, the impact of information, their amounts and visualizations on trust varies [14, 19].

The first sort of the rather dynamic personal conditions is the psychological one. A central one of these are comfort or anxiety, which varies between users [25]. Furthermore, anger can lead to a certain driving behavior such as higher speed and slower lane changes [54]. Additionally, the degree of cortical demand and activation resulting from a certain scenario is a central psychological condition [5].

Furthermore, there are physiological conditions. Since these phenomena are rather expression of relevant psychological states it does not seem suitable to adjust the UI to them. Instead, they can predict or measure psychological states of the user, for instance heart rate, eye movement patterns and galvanic skin responses can be used [25, 26].

The level of awareness in several regards is the last sub-dimension of the user. The most important one is the situation awareness [56]. Another important type is the current AD system mode. This describes the transparency for the user which functions are running [29]. Accordingly, in case of high transparency the user knows which part of the driving task he or she has to perform or if the need to take over will arise soon.

Taken together, UI design could view every user as a bundle of manifestations in these sub-dimensions. This can be the basis for personalizing the UI. So, for elderly people it can mitigate aversions and fears by explaining situation and operation. Additionally, for impairments the UI can customize communication channel and time. For the personal skill level, it could give more or less detailed feedback. A similar mechanism seems applicable for different trust levels. Moreover, it could mitigate anxious feelings or nervousness by showing more information. This could include the traffic situation or system reliability. The awareness comes with a huge potential for customization due to a strong interrelationship with the interface [26]. If the user has low situation awareness, the interface could act more intrusively and vice versa. During low mode awareness, the UI could provide more information regarding the current AD tasks. In other digital domains (e.g. electronic devices or software engineering) such personalization is state of the art, where it is not even safety-critical as in AD [100, 101].

Putting these potentials in context with the current state of research gives a differentiated picture: there are some contributions available, focusing on one or very few narrow characteristics assessing influence on the UI design. Despite that, research lacks a framework taking the user and all his characteristics as basis for adjustments of UI design. Deriving the requirements from the different characteristics and balancing them in case of conflicts is an unexploited but promising potential. Already the quantitative analysis in Section 3.2 showed the research effort being roughly half as strong for the user compared to the UI. Hence, the qualitative analysis can confirm this by outlining the knowledge in this "W" as rather fragmentary. Research regularly starts with designing interfaces without firstly analyzing the user as the addressee in depth. In line with this, a former work outlines the potential to personalize shown system information to individual needs regarding system transparency to foster trust in AD [31].

Which information does this user require?

The dimension of information has the three sub-dimensions of amount, selection and prioritization [29]. The amount of information offered by the UI has impact on the mental workload since the user needs to process it. In the ability of processing information human users can vary, leading to potentially different requirements in this regard [15].

The selection which information to communicate to the user is the next central decision for personalizing UIs. For instance, the trust of the user in a specific situation is inversely correlated with his desire for feedback. Generally, the feedback about objects in the driving environment are central for him. It is individual, which objects are the most important ones [31]. Additionally, users prefer the current or planned route or explanation for the upcoming actions of the system over no information [14].

Furthermore, this design dimension comprises the balancing of information related to the (AD) task and non-driving-task-related information. On the one hand, the user requires information about system state and operations. On the other, being involved in activities besides driving is one of the main advantages of AD [67].

The transparency regarding system reliability plays a special role in terms of selection. It can foster the current trust but also increase the mental workload of the user [15, 62, 64]. Trust, mental workload and changes of these can vary for different users.

The last sub-dimension of information refers to the prioritization of the same. In this context, users rate other traffic participants relatively high, especially vulnerable ones like pedestrians. Also, priority rises for objects being closer to the own vehicle. Still, these preferences differ for different users [31]. Surely, the entire dimension of information is quite dynamic and also depends on the current driving situation [14].

All the sub-dimensions of this "W" regarding information have great potential for personalization. The amount can follow the individual capacity to process it. Also, it can mind the need for information depending on the general attitude and trust towards automation. Riegler et al. raise a similar potential by investigating personalized information for AD UIs [102]. Furthermore, the degrees of nervousness, anxiety, comfort or awareness could be a viable basis to customize the amount of shown information.

The selection primarily can consider the desire of the specific user for system transparency and reliability information. In the following, the UI can use remaining mental capacity for non-driving-task-related information. Based on the level of prior knowledge about AD systems the UI could explain the activities more or less. In terms of prioritization the UI design has potential to adjust to the users' requirements to understand driving situation and mode. For a user with lower needs in this respect, the UI can prioritize non-driving-task-related information. In contrast, for a user rather sceptic about AD trust calibration should have a higher priority.

Bringing the named potentials in the "W" of information in relation to the available literature base yields the following result: the information is a central aspect of the UI design. However, rather limited knowledge base is available. Especially, only two papers out of the 95 relevant ones address each amount and prioritization. In terms of the selection narrowly for the case of system transparency several contributions are available. Still, as for the other sub-dimensions, no mechanism or framework is available systematically incorporating the user and his or her characteristics as the basis. That would be necessary to derive the information needed in the right amount and order. This further

supports what the quantitative analysis in the preceding Section suggested: a rather low number and share of paper treats the information. For instance, the communication channel has roughly four times as many relevant papers. The qualitative analysis indicates similar: previous research does not focus on the information shown by the UI, its personalization and the impact on user experience.

Which representation does this user serve best?

The "W" of representation has the sub-dimensions of auditory, visual and haptic channels as well as different kinds of presentation [72]. Auditory communications are for instance sound or talking to a voice assistant. Such sounds then have effects on the user and his states such as (situation) awareness [32]. The same holds true for voice assistants, where more assertive ones are more capable of grabbing the users' attention. This results in faster reaction when taking over the driving task again [40].

The next sub-dimension of the communication channel is the visual one. The most common form of this channel are displays, while research also treats ambient lights, augmented reality (AR), transparent cockpits or direction of the users' gaze [37, 63, 64, 66, 79]. Displaying information at the right place can improve take-over-times and productivity for non-driving-task-related tasks [68]. Additionally, the user can differ in mental states such as anger requiring different communication to lower frustration [52].

The third sub-dimension of communication is the haptic or tactile one. The most common form is vibration, but there are also touch displays or gestures [34, 94, 96]. Gesture input decreases in interaction performance when cognitive load is high [78].

The last sub-dimension of the communication is the presentation. This comprises anthropomorphism of the UI, degree of abstraction and talkativeness [38, 39]. Designing interfaces more anthropomorphic can result in higher trust, better sense of control and higher joy [38]. An example of this are conversational agents replacing traditional touch surfaces for instance [38]. The need for this varies between users.

All these sub-dimensions have potential to adjust to users. For instance, the UI can make use of different interaction modalities or degrees of anthropomorphism. In line with Pretto et al., such personalization can foster comfort, safety and acceptance [103].

The quantitative analysis in the preceding Section shows not only a focus on the UI compared to the user in general. It also showed within the UI the focus on the channel compared to information and time, having more relevant paper than all other "W"s combined. That implies a rather comprehensive knowledge base in this area. The qualitative analysis in this chapter confirms this showing relevant contributions connecting the user with the communication channel [15, 31].

What time of interaction is best for this user?

This work details the time dimension in relation to the real-world happening, (in advance, simultaneous or afterwards) [14] and in time span or (a) point(s) in time [42].

The upside of informing the user in advance can consist in preparing him for the potentially upcoming take-over. This can happen by giving information regarding the possibly needed action [99] or traffic situation [14].

In terms of time, the potential of customization consists in considering the time a specific user needs to prepare for an action. Therefore, it differs how early he needs the

information. For the specific case of front collision warnings Hasenjäger et al. outline a similar potential [104]. Furthermore, if the user needs an information only once or several times can depend on his prior experience. Other factors can be his degree of comfort or the situation and mode awareness. In a situation rather easy to handle, the interface could approach the user while leaving him alone in a complex one.

The quantitative analysis in Section 3.2 showed that only very few works of the analyzed 95 deal with the interaction time. Compared to the other "W"s this indicates a low research intensity. The closer look into these four works in this chapter underpins this result, showing that research regarding the interaction time is yet rather rudimentary. Especially, no actual work is performed regarding personalization. So, regarding safety-relevant interactions such as take-over-requests it has the potential to consider the user's individual lead time. Still, compared to the other "W"s time has fewer sub-dimensions and possible design options lowering the potential for human-centered design.

4.2 Unexploited potentials of the "W"s

The previous Section 4.1 shows the potential personalization of UI design for AD. In the next step, we derive what the mechanisms between the different "W"s could be.

The user itself as the central addressee of the UI is less in focus of research than the UI. Consequently, he mostly is not the starting point for its development. Based on the user as a bundle of characteristics, needs and preferences, a human-centered approach could emerge. Based on the analyzed works, all of the three "W"s concerning the UI depend on the individual user. Consequently, the UI dimensions of information, channel and time have potentials to adjust to his personal characteristics and states [31, 41, 52, 58]. In addition, the choice of one or more channels impact the states of users such as cognitive load [105]. Thus, bidirectional interactions are present.

Related work mentions many different dimensions the users can vary in (see Section 3.1). However, only few works strive to convert them into implications regarding the UI design. As the quantitative analysis showed, only 20 % of the papers analyzed treat at least one dimension of the user and the UI. All the rest solely focuses on one of both.

The contribution by Akash, Jain and Misu is one of the few examples trying to derive such a mechanism: based on human current trust and workload the UI adjusts the shown system transparency information [15]. Another one is the contribution by Von Sawitzky et. al: the authors suggest an UI that adjusts the displayed information to the experience of the driver. Additionally, the driver can choose from different visualizations [14].

Still, a research work treating (sub-)dimensions of both the user and the interface does not necessarily mean that it derives a connecting mechanism. Regularly, articles leave discovering the relationship between the dimension of the user and the interface to future research [6, 26, 60]. Also, they often do not investigate the effect on usability, acceptance, safety and pleasure, but rather focuses on a single influenced factor [2].

Not only between the user and the interface the articles rarely discover dependencies. Also, within the three "W"s of the interface, no strong research focus lies on the mechanisms between them. For the case of information and communication channel, only around 13 % of the analyzed articles treat both. Despite that, the information can influence the preferred way to communicate it: in case of reliability information users prefer a single modality and perceive the visual channel as the least annoying one [62]. More

generally, for important driving-task information such as vehicle status or possible control transitions a steady display seems the most feasible modality [29]. For take-over-requests, instructing the user in advance how to intervene can reduce lead times [106]. Besides, reaction times are shorter for auditory or tactile interaction compared to visual ones [107]. Thus, interrelations between the "W"s have impact. To properly design the "W" regarding communication channel, the design process should firstly analyze user and needed information. Otherwise, it risks a "jump-to-the-solution" problem.

Furthermore, the time-wise design depends on the information to be displayed. Information regarding maneuvers or the AD functions do not help the driver being shown simultaneously to the real-world happening. Such information only generate value being shown to the user in advance since than time is available to process it [14].

Additionally, the UI can not only adjust to the user at a given time. It could also improve its personalization over time by adjusting to the users' habits. Hasenjäger et al. discuss a similar potential [104]. So, the UI can also change with the user for gained experience. For instance, while the user familiarizes with the system, system transparency declines in importance [108]. The interaction with the functions is safety relevant. Thus, such changing UIs still need to fulfill standards of safety and reliability.

In summary, several potentials seem unexploited: human-centered approaches within the different "W"s, mechanisms between the four "W" and also future-facing possibilities of growing with the user. Future research can enable great enhancements regarding user experience and acceptance by designing based on individual needs. Such a framework would enable researchers and designers to directly address individual UI personalization without starting from the scratch be deriving requirements every time.

4.3 Limitations

Firstly, as typical for SLRs it derives the results by analyzing a subset of the available literature and thus cannot claim completeness. Secondly, for the quantitative analysis it measures the research intensity per "W" by the number of relevant articles. This can be unprecise, since few papers could broadly investigate an aspect. Thirdly, databases of other research fields possibly treat relevant aspects connected to the ones analyzed here.

5 Conclusion

We analyzed the so far performed research in human-centered UI design for AD. By doing so, we identified the main aspects, their research intensity, their potential for usability and acceptance and to which degree this potential is already exploited. Thus, we emphasize research to focus on the individual user as basis for UI design regarding information, channel and time. The greatest yet unexploited potentials are in accounting for individual users with their characteristics and in personalizing the information shown by the UI. Furthermore, research lacks a holistic framework to answer the "W"s starting with the individual user and basing the following "W"s on the preceding ones. This framework should as well comprise mutual influences between the "W"s of the UI. Future research could also analyze users' social context. Implementing such a framework in practical UI development could even foster the diffusion of AD in automotive markets.

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