Investigating Car Futures from Different Angles

An Overview of Methods Used to Study Human Factors of Autonomous Driving

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ABSTRACT

The design of self-driving cars is one of the most exciting and ambitious challenges of our days and every day, new research work is published. In order to give an orientation, this article will present an overview of various methods used to study the human side of autonomous driving. Simplifying roughly, you can distinguish between design science-oriented methods (such as Research through Design, Wizard of Oz or driving simulator) and behavioral science methods (such as survey, interview, and observation). We show how these methods are adopted in the context of autonomous driving research and discuss their strengths and weaknesses. Due to the complexity of the topic, we will show that mixed method approaches will be suitable to explore the impact of autonomous driving on different levels: the individual, the social interaction and society.

CCS CONCEPTS

• Human-centered computing → Human computer interaction (HCI); *Empirical studies in HCI*

KEYWORDS

Autonomous Driving, Research Methods, Research Through Design, Wizard of Oz, Driving Simulation, Lead Practices.

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1 Introduction

In various respects, modern societies are mobile societies characterized by high demand on individual mobility demands and highly individualized lifestyles [59,82]. The progress made by partial automation towards fully autonomous driving enables new mobility concepts that affect the individual, the social interaction between the road and the users, as well as mobility behavior on the society level. This shows that the design of autonomous vehicles does not merely pose a purely technical challenge but is a socio-technical one in which human factors must be considered from the outset. The following socio-technical research questions are tackled on the different levels:

At the individual level, new challenges arise regarding the driver-vehicle interaction. A key issue is to understand and design for take-over situations [33,52,88]. Regarding this, three phases in the transition can be distinguished: a scheduled takeover or the initial event causing a takeover, the handover of a control phase and the phase hand back control to the vehicle [48]. Another research topic is to support drivers to make better use of their time in the car when they are no longer equally burdened with the control of the vehicle. Concerning both issues, Mok et al. [52] investigate the activities that are affected by the takeover task when people are disengaged from the driving task such as playing a game, writing emails, etc. There is also another stream of research that deals with the paradigm shift, from driver-centric towards passenger-centric design [36,43,50,66,71]. This raises new questions of what kind of activities passengers want to carry out while traveling in driverless cars and how such activities can be supported by car interior design. Also, the challenge arises, how passengers can interact with the self-driverless car when no taxi-driver exist anymore in order to communicate, for example, the destination, the preferred route, making a stop, or explain the computer what driving style is preferred. For instance, wanting the taxi to hurry up to catch a meeting or to slow down so that one could work in the car in a better way [17].

At the level of social interaction, new questions arise as to how to communicate with other road users [8,9]. The communication will become more complex as it will no longer be based on human road users-to-human road users communication but will include also car-to-infrastructure, as well as autonomous car-to-human road user, e.g. pedestrians, cyclists, etc. Main research themes are about good interaction concepts to communicate other road users that the automated car will turn, slow down or stop, or how to give pedestrians or others a sign to draw their attention to danger. It can also be assumed that in special situations automated cars might be controlled by teleoperators (e.g., to drive slowly around an unsecured construction site, if a sensor fails, etc.). Then new questions arise, namely how to deal with the trialogue of passenger, autonomous car, and teleoperator.

At the societal level, there is also the question of user acceptance on a large scale, as well as questions about the social impact of autonomous cars. The first issue refers to questions about expansion rates and expansion speed of autonomous cars. To answer these questions, several authors adopt technology ac-

Method	Examples	Strengths	Weaknesses
Research through Design	• Car concept studies [2, 80] • Interior car design [77] • Interactive roads sketch [46] • Car-pedestrian communication [10]	• Explore not-yet-existing realities • Enable to experience possible futures in a physically sensuous way • Inspiring, stimulating creativity, and broaden the perspective	• Depend on the creativity of individual researchers • Can only be realized as a custom-made product and small series • Technical feasibility of design sketches unclear
Wizard of Oz	• Car-pedestrian communication [70] • Making use of a flat rate robo-taxi service [46] • Teleoperated robo-taxi in future [83]	• Timely user feedback • Natural, in situ observation • High flexibility • Cost-efficient	• Later technical implementation unclear • High manual effort, so only useful to a small user sample • Knowing the WoZ behind the scene could bias the user experience
Simulator	• Task performance of car passengers [61] • Driving simulator with a real car experience [4] • Game-based simulator for autonomous driving research [15]	• Controlled, reproducible experiment • Rich user experience compared to thought experiments and interviews • Scalable and cost efficient	• In the wild behavior unclear. • Lack of physical feedback in software-based simulators • Must be supplemented by interviews to capture subjective experience
Survey	• General acceptance of driverless vehicles [49] • Measuring the impact of trust on the acceptance of AVs [9] • Intercultural comparison of autonomous driving perception [34, 73] • Preferences of in-car activities traveling with self-driving cars [18, 60]	• Extensive scientific foundation for creation, implementation, and evaluation. • Standardized surveys are highly comparable • Cost efficient and scalable	• Unsuitable for exploration of new fields of application and uncovering not anticipated phenomena • Underlying, individual patterns of interpretation are not grasped • Speculative when they abstract from real context asking counter-factual questions
Interview	• Perception of car-pedestrian communication [10] • Preferences of in-car activities [77] • Folk visions about shared autonomous vehicles [53] • Natural driver-car interaction [63]	• Studying subjective world views, interpretation schemes, experiences, etc. • Uncover the unexpected • Lightweight and highly flexible	• What people saying is not what they are doing • Possible futures are limited to envision in interviews • Personality and competence of the interviewer influence the situation
Observation	• Analyzing in the wild use of autopilots [8] • Observing pedestrians interacting a "WoZ" car [70] • Observing in-car activities in existing [16, 27, 36] and "WoZ" cars [32] • Study lead practices (e.g. passenger activities in bus, subway or trains [40, 51]) to extrapolate in-car activities in the future [60]	• Studying the sequential structure of interaction • Uncovering appropriation effects and behavioral pattern • Analyzing the socio-material context	• The not-yet-existing practices could not be observed, but only extrapolate from an existing one • Restricted to lead practices and WoZ/Simulator experiments • Not scalable and statically representative

Table 1 Overview of design-oriented and behavioral-oriented methods to investigate car futures

ceptance models such as TAM or UTAUT [41,45,73]. These surveys demonstrate the importance of the perceived usefulness and perceived ease of use as the main adoption drivers. However, in literature, several barriers are also mentioned such as no confidence in the safety or the loss of driving pleasure. Also new questions of social acceptance, e.g. regarding what happens when autonomous vehicles cause an accident, slow down traffic, or take the parking space away from others. The society level also includes the social impacts in terms of environmental issues, changes in traffic behavior (such as rebound effects), the loss of competency in the mass (e.g. what happens in a blackout of the Internet when no one is possible to drive a car manually) as well as economic issues such as job losses in the mobility sector. Here, the impact on the society must take the sum of individual decisions must into account [12]. Due to the complexity of the socio-technical phenomena of automotive driving, a great number of research methods has established in the field [65]. As a result, in particular, newcomers find it difficult to get an overview of the various methods, where they are applied and what their strengths and weaknesses are. Hence, addressing this issue the aim of this workshop paper is to provide a rough orientation by giving a non-exhaustive overview of the variety of research methods.

2 LANDSCAPE OF RESEARCH METHODS

2.1 Research Through Design

Description: *The best way to predict the future is to invent it*, as noted by Alan Key. Singing the same tune, Design Case Studies [74,90,84] and the Research through Design (RtD) approach [24,34,92] argue that what could be designed and what should be designed cannot be reduced to what exists today. In order to study the not-yet-existence, firstly we must create artifacts, to analyze them and observe how they got appropriated by the people.

The RtD approach is particularly important when the subject matter does not present an incremental improvement, but a disruptive innovation as this is the case of autonomous driving. We know from the past that people have a hard time to imagine disruptive futures and therefore it is difficult for them to grasp and articulate their needs and fears. Instead, their ideas are strongly influenced by existing patterns of interpretation and usage practices.

A prominent example is the disruptive invention of the car 130 years ago, in which the car was understood as a kind of carriage without a horse and designed accordingly. Traditionally, RtD was a kind of showroom approach [34]. It is mainly based on concept studies, where the design artifacts are analyzed regarding their aesthetics, ergonomics and formal design language. More recent RtD approaches, such as design probing, also attempt to capture the appropriation of artifacts. For this purpose, the artifacts were given to people in a field trial or in a living lab setting. Often, ethnographic methods are used to observe how the people make use of the artifacts, observing how they interpret them, use them, and embed them in their everyday lives.

Examples: Concept studies have a long tradition in the automotive industry. The first concept studies on autonomous driving were still very driver-centered, although they took up various elements to support non-driving activities, such as working [72,85], eating and drinking [72,85], sleeping [25], relaxing [72,75,85], talking together [49,49,53,72], etc. Newer concept studies, such as the one of Rolls-Royce [85], Audi [2], Volvo or Toyota explore more radical passenger-centric concepts in terms of design, e.g. designing the car as first-class driving service [85], as a place for sleep [16], or as a place for work [28].

Because of the limited resources, such kind of design research is much rarer in academia. Instead, research through design usually remains at the conceptual level. For instance, in a co-design study, Stevens et al. [81] let the participants sketch the interior design of future cars using pen and pencil. However, the resulted design was never realized. Mairs [46] create a hybrid photo-sketch of an interactive road to visualize new communication concept among road users. Clamann et al. [11] create a prototypical solution bolt a display in front of a Dodge Sprinter van to display pedestrians advisory information. Krome et al. [35] design mock-ups of exertion interface to explore the design space of in-car activities for commuters. Another example is Hassenzahl et al. [27], who investigate happiness in the car. For this purpose, they sketch *Perfect Commute*– a design that aims for people to experience their home journey in a more relaxed, spontaneous, and especially social way. Yet, *Perfect Commute* was only developed on a conceptual stage but was never implemented and used as a kind of design probe in a field trial.

Strength: RtD allows to explore not-yet-existing realities in terms of design. In particular, as Kant notes: "Thoughts without content are empty, intuitions without concepts are blind". This means our visions of future cars need a form and a materialization to be comprehensible. Regarding this, RtD enables to experience possible futures in a physically sensuous way. Here, futuristic design sketches and concept studies are inspiring and stimulate creativity. However, as said by Kant this constructive work must be accompanied by analytic work to give the design concept a name and a meaning.

Weakness: RtD research cannot be evaluated by the usual scientific standards, such as objectivity, repeatability, and generalizability. In particular, the concept studies are by its very nature subjectively shaped by the ideas, creativity, and competencies of the individual design researchers or design team, respectively. In addition, design studies are relatively complex and expensive, especially fully functional one, so that the approach is usually not scalable. Instead, only a single piece or a small series is often produced. Therefore, long-term user studies are often missing and can only be conducted by a small, statistically non-representative sampling.

2.2 Wizard of Oz

Description: In the design and early evaluation of robots, the use of the Wizard of Oz technique (WoZ) has a long tradition [47,70]. Typically, WoZ experiments are conducted in laboratory settings, where subjects are told that they are interacting with a computer, but instead, the interaction is mediated by a human operator (wizard) [14]. Here, various, not mutually exclusive options exist: (1) WoZ simulate some component(s) of the system, while other parts are implemented by the computer; (2) all input is preprocessed by the computer, only if the task is too complex or has not yet been implemented the WoZ takes over; (3) each interaction with the user is interrupted and interpreted by the WoZ, which then generates an output manually or plays predefined sequences or selects system functions.

Examples: As humans are competent driver, it is quite natural to simulate upcoming autonomous driving technology by a human driver in a WoZ experiment today.

Baltodano et al. [3] might be the first researchers, who used a WoZ approach to simulate autonomous driving on open public roads. Their purpose was to evaluate the effect of haptic feedback (e. g. providing alerts before the autonomous vehicles' starts, stops, and turns) on the passenger's trust. Sirkin et al. [80] conduct a structured improvisational WoZ study paying credit to the scenario that natural language dialog could turn into the favored mode of interaction between the AV and its occupant. They applied various conversational strategies and in-car dialog. The study did not take place on the road, but in an immersive automobile simulator using computer-generated natural language speech. Sherry et al. [79] conducted a WoZ experiment to explore how passengers prefer to interact with an AV from inside the cabin. They drew attention to the potential value of multimodal sensing and the embodiment of the in-cabin agent. The participants were asked to perform a number of tasks, so they were certainly engaged in affecting the car's operations. Rothenbücher et al. [76] conducted a WoZ experiment, where the windows of a car were darkened so that the driver was not visible to give the impression of a driverless vehicle. The researchers drove around with the car controlled by a WoZ to observe how pedestrians and cyclists react when there is no human driver or when he is not visible.

In a certain way, safety driver of autonomous vehicles can be interpreted as a kind of WoZ, who intervenes only in an emergency situation. The user experience of "fully autonomous" vehicles is further enhanced when the safety driver is replaced by a teleoperator in future [87]. In a similar manner, Krome et al. [35] conducted WoZ like field studies to explore the commuting experience as part of an RtD project. To provide the AV experience, researcher drove the participants to and from work during their usual time. Two cameras were mounted in the car to observe the participants as well as the traffic situation while traveling. One of the insights was that during a large portion of the commutes, the car was not moving at all. On the journey level, commuting presents a dualism of work and home where the commuters' role changes from a private person to a professional. On the long-term level, they uncover that commuting presents an everyday routine that was shaped by the temporal structure of the commuters' daily activities. Meurer et al. [51] explore the driving experiences of passengers in autonomous taxis for about a week. The autonomous driving was simulated by a driver who was not visible by the passengers.

Strength: One advantage of WoZ experiments can be implemented with relatively little effort, getting timely feedback from users and offer a high degree of flexibility in the exploration of various forms of interaction. WoZ also makes it possible to explore futures, that are not technically possible today. Compared to simulations, Rothenbücher et al. [76] stress that one of the advantages of WoZ is to allow in situ observation of behavior in a natural environment, rather than a lab. In addition, it is usually more affordable and may enable more systematically constrained experiments by eliminating the limitations of an automated system. Furthermore, it enables less constrained experiments through the use of improvisation.

Weakness: The main disadvantage is that there is no guarantee whether a WoZ simulation can ever be implemented technically in a similar way. Furthermore, a bias in the user experience can occur, when the experience of the experimental setting is stronger than the simulation of a real-life scenario. That can happen when the users react in the WoZ experiment as if the car is controlled by a person and not a machine. However, these accounts should become observable in the concrete situation. By using manual control, WoZ experiments are also not scalable, so that they can usually only be performed with a small user sample.

2.3 Driving Simulators

Description: Driving Simulators have a great affinity to WoZ as both simulate a not-yet-existing future. The basic difference can be simplified as follows: In a WoZ experiment, the environment is real, but the computational driving is simulated. With the driving simulator, it is exactly the other way around: the environment is simulated while the computational driving is real.

A large part of the driving simulators is used for the early quality assurance of autonomous systems. In driving simulators, tests are already carried out in virtual test environments before the first test vehicles are ready for testing in the real world. The simulation is based on in-the-loop models and software. The driving simulators can be designed very differently (from high- to low fidelity driving simulators) to test previously identified test cases. The further the development progresses, the more real-world components can be added for testing on the different test benches, like driving simulators or test grounds. In order to check the action and reaction of the system driver - vehicle - environment (to close the loop), simulation models are also used for these test executions. Simulation models are images of reality in software and aim to simplify the complexity of the real world.

In particular, there are "simulators" of non-existing vehicles, such as spaceships because of fun. Nevertheless, there are several racing simulators which are very realistic. Moreover, compared to the simulators from the training sector, such simulators are quite cost-effective and easy to adapt.

Examples: Driving simulators have been used in autonomous driving research since the very early days [18]. In particular, driving simulators allow researchers to test certain scenarios and evaluate user behavior under controlled conditions. Pollmann et al. [67], for instance, used a physical driving simulator that enabled them to change the interior design. In three different interior configurations, they studied the participants' performance during concentration-demanding tasks while getting driven under controlled condition. Benz et al. [4] present a vehicle-in-the-loop (VIL) approach, where a real car is used that is operated on a mapped test track. The simulated environment can be mapped using a head-mounted display or visualization of a simulated environment mapped onto the test track. Dosovitskiy et al. [18] have built *CARLA*, a simulator for autonomous driving research. It was implemented as an open-source layer over the game engine *Unreal Engine 4*. In contrast to racing simulators, *CARLA* focusses on realistic urban traffic, including urban layouts, a multitude of vehicle models, buildings, pedestrians, street signs, etc.

Strength: (Mass-consumer) Simulators are relatively inexpensive, so that they, as Dosovitskiy et al. [18] noted, democratize research in autonomous urban driving. Furthermore, simulators could be used to evaluate critical situations, such as taking over situations under stress in a safe environment. Simulators also allow to conduct controlled, reproducible experiments as the initial state of the simulation as well as the behavior of the test users can be logged.

Weakness: A weakness is the limited ecological validity. In particular, it is unclear, to what extent a simulator solution will work under real-world condition. Furthermore, simulators throw only little light into the area of appropriation, behavioral change, the establishment of new forms of mobility routines, etc. In addition, the subjective experiences and preferences of people must be collected by additionally means, e.g. by interviews. Thus, simulators are less suitable for exploring questions of social interaction and social acceptance.

2.4 Surveys

Description: Surveys are a common instrument in empirical social research with an extensive theoretical foundation, starting with scale development, questionnaire design, implementation, and evaluation.

In business, descriptive surveys are often carried out to determine, for example, attitudes, preferences, and knowledge of potential customers. Due to the economic power of market research institutes and consulting firms such as Gardner or PwC, the strength of such surveys lies in their actuality and a large number of participants. However, such surveys often lack a theoretical foundation and the methodology used, the recruitment of participants, the questionnaire design, etc. is not quite as transparent described as is the case with scientific studies.

In the scientific field, surveys are mostly used to test theories and hypotheses. An essential goal of research is to discover and empirically verify universal laws derived from theoretical considerations. To this end, standardized measuring instruments must be developed, which are then adapted to the respective application.

Surveys are also an established part of usability tests, e.g. to evaluate the general user satisfaction (e.g. [7]), the user experience (e.g. [26]) or to get formative feedback on usability problems (e.g. [39,68]). To our knowledge, however, there are no specially developed, standardized measuring instruments for autonomous driving (e.g. for recording motion thickness or perceived quality of time).

Examples: One main field of application of surveys is the research of user acceptance of autonomous driving. Many of the work is directly related to or indirectly refers to the socio-psychological theory of planned behavior [1]. This theory was adopted by Davis as the theoretical foundation to develop the TAM [15] a universal technology acceptance model. This model is again the foundation of many acceptance studies in the field of autonomous driving. For instance, Nordhoff et al. develop and implement a conceptual model based on the unified theory of acceptance and use of technology (UTAUT) to analyze the acceptance of driverless vehicles [54]. They found respondents consider AV easy to use and convenient and expect a ride in an AV as joyful [55]. Zmud et al. [93] use Osswald's Car Technology Acceptance Model (CTAM [57]) to understand people's intention to use AVs, concluding among their respondents were 14% AV enthusiasts, 18% AV rejecters and a large majority that consider it somewhat likely or somewhat unlikely to use AVs.

A significant amount of studies used surveys to explore trust in and user acceptance of AV. Therefrom, many studies researched quantitatively through online surveys. Using TAM as a baseline, survey results of Choi and Ji show that perceived usefulness and trust are major important determinants of intention to use AVs with system transparency, technical competence, and situation management having a positive effect on trust [10]. Payre et al. [64], for instance, study the a priori intention of French drivers' to use a fully automated car by conducting an online questionnaire. Their research revealed that about 70 % of the participants responded positively to the possibility of utilizing fully automated cars. Surveys are also used for intercultural comparison to uncover difference and similarities among different countries, how people perceive autonomous driving [37,78]. Schoettle and Sivak [78], for instance, asked people in the U.S., U.K., and Australia, showing that in all countries there was a positive initial opinion of autonomous driving and the survey's participants had high expectations about its benefits, but most of were highly concerned regarding security issues and the loss of driving control. Rödel et al. [73] examine the effect of different autonomy levels towards user acceptance and user experience. The former included the perceived ease of use of the system, attitude towards using the system and behavioral intention to use it. The latter checked trust and fun. According to the study, both decrease with the rising level of a car's autonomy. Pakusch et al. [58,62,61,60] adopt utility theories to conduct surveys that study the impact of driverless cars on the future mode of transport choices. Regarding this, they also took rebound effects into account to consider the unintended effect to promote individualized motoring instead of promoting more sustainable alternatives [61,60].

With regard to the economic value of time, Fraunhofer IAO and Horváth & Partners [21] use a web survey to ask people about their willingness to pay for added values in highly automated cars. Pfleging et al. [66] use this instrument to query what activities people prefer during a highly automated ride.

Strength: The strength of surveys is that they are based on an extensive scientific foundation. Furthermore, standardized surveys are highly comparable, so that meta-analyses can also be carried out (e.g., to determine changes in settings over time or cultural differences). Questionnaires and surveys allow you to gather information about a large audience, up to representativeness. Furthermore, standardized questionnaires are well validated and easy to reuse. This makes surveys quite cost efficient and scalable.

Weakness: Surveys are usually unsuitable to explore new fields of application and uncovering not anticipated, emergent phenomena as they are normal in the development and diffusion of new technology. Due to their standardization and the fact that they can only query conscious knowledge, underlying particularities and individual patterns of interpretation are typically not grasped by surveys. Abstracting from the specific situation, they also neglect the affordances of socio-material context and the situated motivation of the people. Surveys work well to study the existing, but the non-existent can only be captured poorly and mostly rather speculatively.

For instance, Lee et al. [42] criticize survey studies on autonomous driving for being based on hypothetical scenarios and simulations. According to the authors, the circumstances of the real road such as weather conditions were not displayed adequately. Hence, they did not consider various factors from real-life situations, which could cause distrust or built trust. In addition, the work criticized that such studies only considered people's first encounter with an autonomous driving instead of an ongoing, routine experience such as daily commuting. In addition, these studies were limited to participants' a priori attitudes and did not consider that (dis)trust was established over time and by repeated experiences.

2.5 Interviews

Description: Interviews are used, among other things, as part of ethnographic studies and are interested in subjective experiences to understand how people make sense of the world form their perspective [31]. In contrast, usability study interviews are typically used before a test usage to let users describe their expectation about the system and afterward to ask them about their experiences.

There are various interview types ranging from very informal to very formal: In-depth interviews [29], for instance, can be used to explore personal narratives about mobility biographies, attitudes towards general technology trends such as artificial intelligence, or narratives and design fictions that also express the hopes and fears of common people. Most often, semi-structured interviews are used to explore specific, but complex topics such as planning the daily mobility or describing how to make use of trains to use travel time efficiently.

Examples: In almost every user study interview are used. Here, we restrict ourselves to a few examples that show how this method can be used in very different contexts. Rothenburg et al. [76], for instance, interview pedestrians involved in their in-the-wild WoZ experiment after their interaction with the car. The interviews were based on open-ended survey questions and were analyzed by a thematic-coding methodology. Stevens et al. [81] conduct semi-structured interviews to understand the time management and mobility behavior of people. In addition, they used inspiration cards to foster reflection, creativity and to empower the participants to envision purposeful time use within the car. Pakusch et al. [63] use interviews to better understand motivations, preferences, and fears that are associated with shared autonomous vehicles. In particular, the aim was to capture the "folk visions" about autonomous driving and to explore the various reasons to use autonomous taxis and how this might affect existing mobility behavior.

Conducting qualitative, semi-structured interviews inside their parked vehicles, Ramm et al. [69] explore driver-car interaction. Applying a theme analysis methodology, they identify from descriptions ten different characteristics for driver-car interaction naturalness including physical and tactile qualities such as mechanical feedback (e.g., the sound of the engine at stop-start systems). From these finding, they extrapolate how interaction with (semi- or fully) autonomous cars could feel more natural in the future.

Strength: The main strength of interviews is their ability to capture subjective worlds of experiences, interpret schemes, needs, and attitudes. Regarding future cars, these issues are still in flux and quite diffuse. Here the major strength of interviews, especially open-ended one, is to deal better with such kind of vagueness and tentativeness as for instance standardized surveys can. Moreover, open-ended interviews open up the possibility to uncover the unexpected. This is particularly important if one takes the role of the user as co-creator and expert for one's own mobility practices seriously. A further strength of interviews is their high flexibility and lightness so that they are used in almost all studies.

Weakness: Interviews are insufficient when the subject matter is subconscious such as tacit knowledge, the flow of action, or when past experiences are forgotten or remembered wrongly. Interviews must also take the intention-behavior gap into account, as what someone says is not what someone will actually do. In addition, preferences and patterns of interpretation articulated in interviews are shaped by previous experiences, while future developments are usually intangible and difficult to assess. Furthermore, interviews always depend strongly on the competence and neutrality of the interviewer, as well as on the interview guidelines, which are usually defined in advance. Compared to standardized surveys, (open-ended) interviews are difficult to compare by its very nature and usually not representative in a statistical sense.

2.6 Observations

Description: Observations aim to capture the social world as an ongoing accomplishment of the concerted activities of daily life, where action produces and reacts to the affordances of the situation at the same time.

This production of social reality is only partially conscious so that interviews could capture this reality to a limited extent. This is also one of the reasons for the often observed behavioral-intention gap, i.e. that people behave differently in everyday life than they indicate in interviews, surveys or eye-tracking studies [6,38].

The ethnomethodological CSCW research has a long tradition to observe actions in situ to reconstruct this *Vollzugswirklichkeit* [5] by analyzing the sequential structure of the interaction of the actors. With the practice-turn in HCI [91], there is also greater attention to the materiality and agency of things. In other words, it will be examined more closely how an action is shaped by the material design and symbolic meaning of things. Here, the action is not determined by the things, but rather the things have to be appropriated by the people [83], in which the self-will and long tradition of the people and the things are equally picked up and being integrated.

Regarding autonomous driving, the challenge is how to observe the not-yet-existing. In principle, two strategies can be identified here: On the one hand, one can create future situations and environments prototypically in which one can observe the behavior of people and try to uncover where the first shoots of new practices began to emerge. This strategy can be found, for example, in the use of simulators and WoZ experiments. While it is useful how people make use of existing competencies and needs, usually there is no time left in such kind of research that the participants can develop new practices. With regard to this, living lab approaches take a different approach, in which a qualitative sampling of individuals is equipped with advanced technologies and observed over a longer period (and often in an iterative process of co-design and appropriation), how people make use of the technology and adapt their routines to new possibilities.

The other strategy is to go to places where future practices are already lived today or where practices exist that are assumed to exist in a similar way for other user groups and under slightly similar conditions. In relation to Hippel's lead user approach [86], the second strategy can be called the *lead practice* approach, where researchers search for places where people already practice future development today in certain respects. For instance, studying where people are already interacting with autonomous vehicles today or visiting places where people are using semi-autonomous cars in everyday life and how this has changed their mobility routines. Regarding the paradigm shift from driver-centric toward passenger-centric design, another research strategy would be to study people who act as passengers today. Conclusion by analogy, we can learn by how mobility routines of passengers might look in future, how passengers interact with the transportation mode and what (emotional) relationship passenger have to the transport mode, etc.

Examples: Observations are made in almost all Wizard of Oz and simulator experiments. However, these observations are methodically evaluated to different degrees. For example, Pollmann et al. [67] observe the test persons quantitatively based on EEG recording and behavioral performance measures but do not carry out qualitative observation. In contrast, Rothenbucher et al. [76] capture how people interacting with the car on video and use this data afterward to uncover behavioral patterns and responses. In a similar way, Krome et al. [35] use two cameras as part of their WoZ-like experiment to observe the commuters in the car as well as the surrounding traffic.

In a more lead practice manner, Brown and Laurier [9] collect and analyze videos from YouTube that shows uncut footage of driving under the control of an assisted or autonomous driving system. They discarded news reports and commercial clips to focus on 'naturalistic' observations of using the autopilot in the wild. In addition to many clips, where drivers holding their phone while driving, among others they could observe several overtaking maneuvers in the wild. With regard to the self-driving car-pedestrian interaction, we can also draw a conclusion by analogy by existing studies, such as the video data analysis of existing car-pedestrian in urban traffic [32].

Another source of information is to draw a conclusion from existing ethnographic studies about in-car activities such as how people are doing office work [40], doing mobile phone communication [30], or taking care of children [19]. In addition, we can also draw a conclusion for observing commuters in other transportation modes such as subway [22], buses [77] or trains [44,56]. Pfleging et al. [66], for instance, is one of the few who use such a *lead practice approach* explicitly to extrapolate possible futures of passenger-centric car design from these observations.

Strength: Observation is the means of choice if one wants to analyze the *Vollzugwirklichkeit* of social action, i.e. to study the sequential structure of interaction in a natural setting. Furthermore, observations are particularly suitable to uncover the effects of technology and behavioral patterns using new technology – even if these effects and patterns are not conscious of the people. Observations are also better suited to take the socio-material context into account, for instance analyzing the affordances of a particular car-interior design and how this shapes people's preferences and behavior.

Weakness: The not-yet-existing cannot be observed. Hence the approach is restricted by the existence of lead practice from which conclusions by analogy can be drawn and by the prototypical realization of a future situation, where experiments with people could be observed. In addition, the approach is not scalable, so only a limit sample of people could be observed.

3 DISCUSSION

The overview shows that there is no *one size fits all* method, but a pluralism of methods in research on autonomous driving. Therefore, it is important that researchers have a rough overview of the different methods, their scope, strengths, and weaknesses in order to select the right set of methods based on their research interests or to get some inspiration for future works.

Addressing design issues and their impact on people, researchers should draw on methods from design science research and combine them with interpretative, qualitative methods. As outlined, design case studies help to broaden the perspective, giving theoretical concepts a sensual expression and physical materialization.

Another source of knowledge is to draw a conclusion from existing mobility practices and routines that are similar to the one that is envisioned by experts or users. Traditional ethnographic methods such as observation, field studies, and interviews are quite helpful to uncover mobility practices and analyze them in minute detail. Furthermore, Wizard of Oz experiments help to simulate possible futures in order to observe the reaction of the participants. In terms of methodology, this has strong affinities to breaching experiments [23] as conducted in sociology and later adapted by HCI research [13,84].

At the level of individual behavior and situational interaction, in-the-wild experiments can be supplemented by lab experiments using driving simulators as a quite cost-efficient and very well controllable method. Subjective attitudes and personal views of autonomous driving are best studied with the help of interviews.

In the case of specific questions (e.g., which activities are preferred while driving), semi-structured, problem-centered interviews [89] are the best option. If, on the other hand, the focus is on mobility socialization, basic interpretation schemes, diffuse fears, and future hopes, open-ended in-depth interviews or biographical interviews [20] are more appropriate.

When it comes to researching social acceptance among the general public, surveys are an appropriate method. The same is true when general opinions among the population should be studied. Although individual differences and the specific contexts of the people are not revealed, surveys provide a good overview of the attitudes and preferences of the average consumer. Furthermore, surveys are useful when correlations should be discovered or causal relationships to be tested. For instance, proving that the acceptance, e.g., depends on the perceived benefit and correlates with the age.

As researching autonomous driving means researching the not-yet-existing, the choice of the right method has to weigh up scientific rigorousness, research practicability, and openness towards novelty. As in all design research investigating possible futures, there is a trade-off between creativity and degree of innovation on the one hand and generalizability and reliability of the empirical findings on the other. By its very nature, inventing the future is explorative, speculative, and vague.

Due to the strengths and weaknesses of the different methods, mixed method approaches should be the preferred way. Studying the subject matter from a different angle and triangulate the results allows getting a complete picture of the possible futures of autonomous driving and its impact on the individual and society.

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