**ORIGINAL ARTICLE**

# Anticipatory experience in everyday autonomous driving

Thomas Lindgren [1,2] · Vaike Fors [1] · Sarah Pink [3] · Katalin Osz [1,2]

**Abstract**

In this paper, we discuss how people's user experience (UX) of autonomous driving (AD) cars can be understood as a shifting anticipatory experience, as people experience degrees of AD through evolving advanced driver assistance systems (ADAS) in their everyday context. We draw on our ethnographic studies of five families, who had access to AD research cars with evolving ADAS features in their everyday lives for a duration of 1½ years. Our analysis shows that people gradually adopt AD cars, through a process that involves anticipating if they can trust them, what the ADAS features will do and what the longer-term technological possibilities will be. It also showed that this anticipatory UX occurs within specific socio-technical and environmental circumstances, which could not be captured easily in experimental settings. The implication is that studying anticipation offers us new insights into how people adopt AD in their everyday commute driving.

**Keywords** User experience · Anticipation · Autonomous driving car · Ethnography · Socio-technical · Advanced driver assistance system

## 1 Introduction

In the wake of recent progression towards autonomous driving (AD), through the development of automated driving technologies, referred to as advanced driver assistance systems (ADAS) [1], a growing body of human computer interaction (HCI) research has turned its attention to user experience (UX) to identify the factors which enable people to accept and adopt them. Positive UX and acceptance of AD technology is often seen as the key to success for AD vehicles [2]. Since few

people have experienced everyday life with autonomous cars, UX-related research to date has focused on understanding individual users' relations to the technology in experimental conditions, and people's attitudes towards AD cars [1]. However, the question of how AD cars and related services are experienced and integrated into people's everyday lives has been identified as requiring further research [3–5], in order to address future scenarios at early design stages [6] and develop a better understanding of alternative preferable and desirable technology and service design concepts. In this paper, we outline what can be learned about people's situated experiences and adoption of AD by using the concept of anticipation to investigate how people gradually learn AD in their everyday commuting contexts while engaging with already existing and evolving ADAS technologies, e.g. adaptive cruise control, lane-keeping assistance or self-parking systems.

Our research has demonstrated how people develop new practices of driving over time in their everyday lives with AD technologies rather than through a disruptive overnight change. With this insight in mind, we are concerned with two issues in current UX-related AD research. First, there is a strong emphasis on acceptance (perceived usefulness and ease of use) [7] in UX research. Our concern is that applying only the acceptance perspective will omit the temporal and contextual aspects of the successful adoption of AD

✉ Thomas Lindgren
thomas.lindgren@hh.se; thomas.lindgren@volvocars.com

Vaike Fors
vaike.fors@hh.se

Sarah Pink
sarah.pink@monash.edu

Katalin Osz
katalin.osz@volvocars.com

1   School of Information Technology, Halmstad University, Halmstad, Sweden

2   User Experience Center, Volvo Cars, Gothenburg, Sweden

3   Faculty of Information Technology, Monash University, Melbourne, Australia

technologies. To attend to this we focus on the concept and experience of anticipation. Second, AD research has been limited by a lack of studies undertaken in real-life settings, and ethnographic research in particular is limited by the current absence of AD cars in people's everyday lives. However, already available ADAS technologies are developing fast towards higher levels of autonomy. Therefore, we address this through a longitudinal real-life ethnographic study of evolving ADAS, designed to reveal people's changing anticipation of AD.

AD cars and technologies are commonly envisioned to bring benefits to society and the environment through disruptive change [8–10]. There have been calls for research into temporal and social aspects of user experiences of AD [11] and for studies of expectations and multi-touchpoint experiences related to emerging AD technologies [12]. AD is expected to have high societal impact, where the socio-technical aspects [13] need to be accounted for in order to fully understand its UX. However, what people expect from any technology is not predefined, but is fluid and shifting, and will be defined and surfaced by people's evolving anticipation. The concept of anticipation has been used in HCI research as a form of speculative design practice that situates engagement with technologies in multiple possible futures [14] and explores how people imagine and might engage with device ecosystems [15]. As the basic characteristics of AD are always evolving and never final, we need to investigate the characteristics and origins of the modes through which they are anticipated. The aim of this paper is to examine how different modes of anticipatory UX of AD change through people's use of ADAS technologies in their everyday lives, in order to provide a model of how the socio-technical context relates to anticipatory UX of ADAS and AD. This model is based on an empirical study of five families experiencing evolving levels of ADAS in their everyday context over 1½ years. In the study, we aimed to better understand the social and situational aspects of anticipation and UX in everyday life circumstances, through the research question: How can we understand people's user experience of autonomous driving (AD) cars as an anticipatory experience?

In the next section, we discuss the concept of anticipation in relation to UX. We then draw on related research to discuss the socio-technical dimensions of AD UX and outline our methodology. We discuss empirical examples to demonstrate how situational and socio-technical aspects are part of anticipatory experiences of AD technologies, and outline the implications for further research.

# 2 Related work

In recent years, ADAS technologies have evolved in such a way that has enabled people to experience and anticipate

degrees of AD in their everyday lives. However, UX studies of how people anticipate AD through adopting ADAS into their lives are rare. UX-related research about people's adoption of AD cars tends to be based on evaluating the acceptance of AD according to technology acceptance models [16] in experimental settings or capturing people's attitudes and willingness to adopt and trust AD cars through predefined questionnaires [17–19]. These perspectives often view AD cars as a near future disruptive change rather than seeing the 'here and now' as a guiding source of knowledge. In doing so, they do not account for people's already existing ways of adopting degrees of AD in everyday contexts. However, the reality is that the future of AD cars will not appear as a disruptive change tomorrow. Rather, it will follow slow and incremental steps through development of ADAS technologies towards fully AD vehicles. Moreover, recent research on consumers' perspectives on AD indicates that there are differences in people's attitudes towards future AD cars depending on their driving experience [20], which emphasises the need to study people's understanding in the context of different cultures and their experience of ADAS over time. Related AD research has also shown that pre-experience of ADAS plays an important role in how people anticipate UX of different levels of AD [1]. To address this issue, our work is based on user-centred design (UCD) perspectives and a *holistic* UX understanding of how people experience products contextually [21, 22] and over time.

## 2.1 Anticipatory UX

To understand how people anticipate AD, we add a temporal and exploratory future-focused dimension to existing UX frameworks. UX is defined according to the ISO standard as '[a] person's perceptions and responses that result from the use and/or anticipated use of a product, system or service' [23] and is widely shared within the industry and in UX research [24]. In this definition 'anticipated use of…' is used to refer to how the user imagines the experience before use. However, the relationship to the moment of use has been difficult to define, relate to or even acknowledge as part of the momentary UX [24]. In existing literature, the notion of anticipated user experience (AUX) [25] has been defined as users' anticipation of the future product or service, and how this is influenced by users' imagination, desires, expectations and existing experiences. This product-centred model defines AUX as occurring before the moment of use. However, recent UX research about anticipation has argued for attention to the social and temporal aspects of AUX. This was identified initially through a study of how UX of highly automated cars developed in the context of an online forum of future and current owners of cars with AD features [26]. The study showed how anticipatory experiences can be part of the overall car UX, which rather than being a static state before or

during the moment of use (as portrayed in previous anticipation research concerning UX) evolves before, during and after purchase and as part of a social community of practice. This mode of experience is referred to as *anticipatory* UX, to emphasise that anticipation is an ongoing characteristic of the UX, which we have applied to the experience of using AD features in everyday life contexts. In this paper, we expand the concept of anticipatory UX, to understand everyday life experience and adoption of AD. Here, we understand the adoption of AD in relation to anticipatory behaviour [27] where people 'use' the future in the processes through which they adopt the technology. Anticipation has two mandatory components, both a forward-looking attitude and the use of former experiences to inform action [27]. We need to study how these components interact when people experience ADAS in their everyday settings and over time, when they anticipate AD experiences.

## 2.2 Modes of anticipation

Driving involves interaction between the driver, car and other people to coordinate the future through various modes of anticipation. In order to understand the temporality of anticipation, we draw on Tavory and Eliasoph's [28] theoretical framework, which categorises three basic modes of coordinating futures. First, *protentions*, defined as the moment-by-moment anticipation through which people take instant actions. For instance, how people anticipate when to steer, brake or accelerate the car while driving, in order for them to perform the drive, interact with other road users in traffic and avoid road accidents. The second mode entails the *trajectories*, the narratives or projects of people's future anticipation. All the actions (protentions) of driving are organised along narratives or projects through which the driver performs their journey. However, these will simultaneously be shared, aligned or in conflict with the narratives or actions of other people in the car, in traffic or external to the situation. The anticipated narratives both coordinate the future actions, and put people's actions into narratives of sense making. The third mode refers to *plans* and *temporal landscapes*, which provide the overarching temporal orientation that people experience as inevitable or as a natural future outcome. An example of this is how people assume how much time they need to drive to work. These plans are so natural that we do not even question them, but simply undertake the actions to make it happen. According to Tavory and Eliasoph [28], these different modes of anticipation should not be seen as basic dimensions always coordinated in tandem, but rather as different modes of describing how people coordinate their future. Sometimes, they are driven by higher goals or by just plodding along alone, but often with others. As in the action of driving in traffic, people need to take action according to their own personal narratives or plans, to align or conflict with others in the traffic situation

and to constantly shift and recalibrate their anticipation of their future coordination.

## 2.3 A holistic approach to AD experiences

Driving in traffic involves interaction with other road users, and using ADAS technologies will influence these interactions between people. To understand how people anticipate use of ADAS, we base our theory on Poli's [27] motivational systems, framed by two types of opposition: first, the opposition between my actions and your actions, and second, the opposition between future and past actions. Future actions are referred to as 'in-order-to' structures, and past actions are referred to as 'because' structures. The in-order-to motives are components of the action and shape the action within. In contrast, the because-motives need reflective acts upon already-taken decisions. According to Poli [27], these structures explain why we perceive actions as freely related to in-order-to motives compared with those actions determined according to because-motives. This highlights why we need to understand that anticipation has a role in not only the temporal aspect of past and future but also in how AD affects the social relations of users' actions. From these perspectives, holistic and anticipatory experiences are tied to various places, time and social context. Thus, anticipatory experiences are situational and shared, a form of co-experience [29] where communicated stories about anticipation and expectations become vehicles to condense and remember experiences and communicate them in different situations to specific audiences. The social and the technological relate to each other not as separate entities, but rather as an interwoven network [30], which needs a socio-technical perspective [31] in order to capture the challenges that emerge when new technology is developed and brought into the real world.

To take a holistic approach in understanding anticipation of AD UX, we bring together the concept of anticipatory UX in everyday life with McCarthy and Wright's UX framework [32]. Thus, the temporal dimension of our study acknowledges the emotional, subjective and transformational aspects of experiences. According to McCarthy and Wright [32], technology can be evaluated as being experienced through four interconnected threads of experiences; *the sensual thread* meaning the user's experience connected to the sensory engagement; *the emotional thread:* where value judgements of the positive or negative emotions connected to the experience; *the compositional thread:* as the relationship between the parts and the holistic view of an experience; and finally *the spatio-temporal thread:* how the experience relate to the user's past, future and where the experience takes place. They also define six sense-making processes to be used as to discuss experiences through a temporal lens: *anticipating* (e.g. user expectations from previous experiences), *connecting* (direct response without thinking), *interpreting* (make sense of an

experience in a conscious way), *reflecting* (reflections on experiences), *appropriating* (relating the experience to the past and future) and recounting (telling about the experience to others). This framework explains experience as constructed actively through reflexive and recursive processes of sense-making, and acknowledges that holistic experiences are related to both the place where the experience takes place and the temporal aspects of an experience. Although the temporality of UX is well-known [33], we propose that the anticipatory UX lens, applied in ethnographic studies, enable a new perspective that situates this temporality within real-life circumstances. In the next section, we elaborate this approach.

## 3 Methodology

We used an ethnographic research approach, in order to achieve an in-depth understanding of how participants' everyday lives with ADAS unfolded in natural settings, with a focus on anticipatory UX. Ethnography has often been regarded as 'a toolbox of methods (for extracting data) of theoretical and methodological concerns that give it form and rigour' [34] (p. 64), or just as describing in situ user research settings where more generic implications for design are generated. This view reduces ethnography to a data collection method and misses its potential to provide rich insights about how technology is integrated into social and cultural worlds [34]. Qualitative and design fiction methods have been used to capture people's anticipation of future AD experiences have been used to provide rich and multifaceted insights for design to increase acceptance and adoption of AD cars [35, 36]. However, few studies in HCI research have used an ethnographic approach in real-life settings for studying long-term use of evolving levels of AD [37]. Our approach takes this further by building a long-term relationship of trust with the participants, and gaining a deep engagement with, and understanding of, their interactions with and anticipatory experiences of the evolving AD technologies within their social and cultural context.

### 3.1 Long-term ethnographic study

Through the Swedish governmental founded project Human Expectation and Experience of Autonomous Driving (HEAD), which was linked to the Swedish Autonomous Drive research platform project 'DriveMe', we followed five families, a total of 18 participants (9 parents and 9 children), for over 18 months between December 2017 to June 2019. The DriveMe project involved stakeholders from industry, municipality, road governance and academia, including Volvo Car Group, the Swedish Transport Agency, the Swedish Transport Administration, Lindholmen Science Park, the City of Gothenburg, Chalmers University, Autoliv and Halmstad University (as part through the HEAD project),

and was underpinned by concerns about autonomous driving cars for safer more efficient driving. The DriveMe project therefore provided the context in which we were able to undertake the research reported on in this article. Indeed, our study would have been impossible to fund and deliver as an independent project without the support of these multiple stakeholders. We used an ethnographic approach, involving sustained engagement with the families, during their everyday commuting routines and driving environments. We met the families together and individually to undertake research with them, through qualitative techniques of in-home interviews [38] and drive-along interviews [39], see Fig. 1. The aim was to provide the DriveMe participants with an evolving AD experience up to Society of Automotive Engineering (SAE) AD level 4 [40] throughout the project, and they were told to do so through daily access to a project car which would be continuously developed. We designed these research methods to investigate their everyday perspectives, habits, needs and behaviours and their changing anticipatory experiences towards AD and related services. During the full-time research period, each family was provided by Volvo Cars, with a DriveMe project car (Volvo XC90) with a high level of supervised ADAS functionality corresponding to the SAE AD level 2 definition [40]. Further details of DriveMe are disseminated online by Volvo Cars, for example at: https://www.volvocars.com/au/about/australia/i-roll-enewsletter/2018/february/families-help-volvo-develop-autonomous-drive-cars. At AD level 2, the driver needs to keep their hands on the wheel and attention on the road, although the car can steer and brake for long durations of time depending on the environmental context.

In order to get to know the families and understand their existing experiences and expectations of ADAS technologies, and experience of AD and related future AD services, we first conducted in-home interviews with each family. This involved guided discussions and cooperative mapping exercises to document their everyday driving routes and routines on a map of Gothenburg, and a drawing task to record the things they kept or brought with them in the car, all of which were video-recorded. After 1 year of everyday use of their project car, we conducted 16 drive-along observations and interviews during the morning and afternoon commutes of 8 participants, using a similar research car, but with a higher level of AD functionality close to SAE AD level 3. In this setup, the driver does not need to have their hands on the wheel all the time, but needs to be prepared to take back control from the car at short notice. A predefined AD-route around Gothenburg along the main highways was used as a test-track for the research cars. This offered higher resolution AD map data, real-time weather and traffic information through a cloud connection to the research cars. The drive-along aimed to evaluate expectations and experiences of mixed supervised and unsupervised driving at a higher level than previously in real traffic. Six months
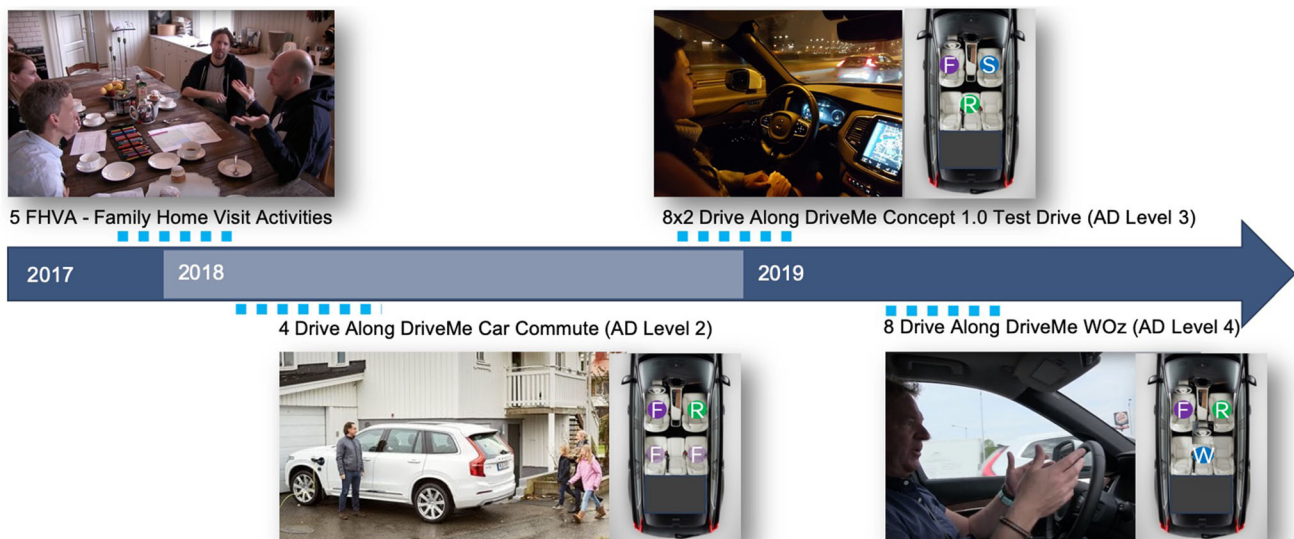
**Fig. 1** DriveMe ethnographic studies

later, we undertook 8 further drive-along observations and interviews (accompanying eight participants during their daily commute) with another Volvo XC90 research car able to simulate an AD system at SAE AD level 4, at which major parts of the drive could be achieved without the need for the participant to have their hands on the wheel or eyes on the road. This exercise was undertaken to evaluate fully unsupervised driving in real traffic. Each drive lasted from 30 to 90 min in a real traffic environment on the participants' everyday routes. The setup of following the participants through their everyday experiences of evolving level of AD functionality from before the study to the SAE AD level 4 simulation laid the ground for us to understand how their initial anticipation of autonomous driving technologies evolved and how they thought it would fit into their everyday life.

### 3.2 Participants

The DriveMe families were selected out of more than 1000 volunteers who signed up to an open application for families to participate in the project. The five families (18 participants) were selected through a screening process once they had fulfilled the basic requirements of being able to do their everyday car commute along parts of the predefined AD prepared route around Gothenburg. The sample was not intended to be statistically representative of the wider demographic of Gothenburg, but was designed to include both traditional and non-traditional families (with four families with two different sex parents and children, one same sex family with two men as parents and one single parent family headed by a father). However, it was not divided by age, gender and social class. It was a purposive sample designed to recruit households with families who were already interested in

autonomous driving technologies, living in or close to Gothenburg and using their car for everyday commuting. The final set of five families was informed of the full study and the research procedures and gave their informed consent to participate according to conventional research ethics standards. Each family was given a new Volvo XC90 on a lease contract, which they paid for, to be used for their everyday commute. The cars were equipped with driving support functions according to SAE AD level 2, which is also available for regular Volvo car customers as standard equipment for selected new Volvo models at that time. Eleven participants had driving licences during the project and attended an ADAS and AD education provided by Volvo Cars in order to be able to drive and evaluate higher levels of autonomy at specific organised driving evaluations with the research cars. The families were trained and encouraged to use and try out the ADAS functions as often as possible in their everyday use. In this article, we report on the experiences of all five families who participated in the study.

### 3.3 Drive-along study of partly unsupervised SAE AD level 3

The aim of the SAE AD level 3 drive-along study was to research human experiences and expectations of partly unsupervised AD functionality in natural traffic contexts. The week-long series of drive-alongs was designed so that researchers could accompany members of the DriveMe families in their morning and afternoon car commutes, on their way to work and back. The Volvo XC90 research cars used in this drive-along study were very similar to the participants' DriveMe project cars, but had been programmed to enable some unsupervised hands-off driving functionality of AD level 3 (see differences in Fig. 2). This made it familiar and

easy for the participants to sit in and drive the AD level 3 research car, but also to sense small differences between how the cars performed in real traffic. They were asked to drive their regular route at their preferred time to and back from work. They could take extra driving time on the predefined AD-route around Gothenburg where the hands-off wheel driving could be enabled. All participants used were familiar with the AD-route and used parts of it for their daily commute to or from work.

During the drive-alongs, there was one research participant in the driver's seat, one safety driver (Volvo AD system development engineer) at the front and a UX researcher in the back seat (see Fig. 2). The research car offered the AD-mode to be activated on the AD-route if some preconditions were met. Drivers activated the AD-mode by pressing two buttons on the wheel. Drivers could override by braking or steering at any given time, but for safety reasons, the gas pedal could not be pressed because this would lead to the AD-mode being deactivated. In AD-mode, releasing hands off the wheel allowed the drivers to experience some AD functions (automatic speed limit adaptation, automatically changing lanes and taking sharp curves). The speed for the function was set to maximum 70 km/h and at some parts of the route it was reduced to 60 km/h according to the speed limit. The car needed to be below 70 km/h and above 20 km/h to provide AD function. The car detected the driver's eye movement and warned to keep attention on the road if the driver's attention dropped and they took their eyes off the road. The car warned by sound and pop-up text on the HMI for action needed to be taken by the participant. The preconditions for hands-off wheel driving were not only defined by the car's sensory data

about the surrounding traffic and road conditions but also through an external signal from a traffic information centre about the weather conditions, road works or accidents along the route. Parts of the route had geofenced (AD prohibited) zones, and the participant was informed through a distance countdown graph about when to take over control of the steering wheel up to 1 km ahead of the restricted sections. If the driver did not take over control, then the car would slowly decrease speed and stop.

The UX research aspect of the study was designed to explore the following areas: handover and lane changing experience; desired future technology updates and overall understanding of how the AD functions would fit into already existing everyday driving and commuting routines. By combining this with ethnography, our aim was to extend ethnography's temporal scope and ground expectations in everyday commuting routines and driving environments. Although the interview was focused on predefined areas, researchers let participants' curiosity to guide and lead the drive-along session by letting them ask as many questions as possible during the ride-along. This way, insights were based on what participants did not understand, wanted to know or were curious about. The questions were formulated in relation to the participants' anticipation, speculation and expectations towards automated functions. This was often triggered by the unfolding traffic situation as well as by how the car behaved during the commute. The role of the safety driver was to monitor and assist the AD-system performance limitations and to explain or prepare the participant for upcoming events where the car suddenly needed assistance for manual steering

| | DriveMe Project Car SAE AD Level 2 | DriveMe Concept 1.0 SAE AD Level 3 | DriveMe WOz SAE AD Level 4 |
|---|---|---|---|
| F = Family Participant R = Researcher S = Safety Driver W = WOz Driver | | | |
| Supervision | • Hands on driving • Eyes on road | • Partly hands off driving • Eyes on road with Driver monitoring reminder | • Hands off driving • Eyes off road |
| AD Features | • Adaptive cruise control with steering aid | + Speed/Curve limit adaptation + Lane Change (manual conf.) + Route planning + Countdown to hand over | + Full AD on almost all roads |
| User Interface | • Production UI | • Production UI • AD UI concept A with steering wheel paddles | • AD UI concept B with buttons on steering wheel |
| Preconditions for use | • Visible lane markings and no sharp curves or roundabouts • Hands on wheel detection | • Only available along AD route around Gothenburg • Traffic cloud info | • No narrow streets with limited visibility |

Fig. 2 DriveMe research car setups

or braking. The drive-along was video-recorded by the UX researcher in the rear seat.

## 3.4 Drive-along study of unsupervised SAE AD level 4

The aim of the SAE AD level 4 drive-along study was to research and understand human experiences and expectations of almost fully unsupervised AD functionality in a natural traffic context and to explore users' anticipation of future fully autonomous related Mobility as a Service (MaaS). This study was undertaken 6 months after the AD level 3 drive-along. The study was designed to provide the participants with an AD level 4 experience during their commute to work or back home from work. In this study, we used Wizard of Oz (WOz) Volvo XC90 research cars [41], which also looked very similar to the participants own DriveMe project cars, enabling them to quickly become familiar with the research car. Wizard of Oz is an approach where a fully working technical system is simulated, but is handled by a human operator, a wizard. In order to simulate an AD level 4 experience in real traffic, these cars had a WOz driver in the rear seat able to drive the cars, steering, accelerating or braking without exposing the control setup to the participants (see Fig. 2). The participants were told beforehand that they were about to experience a higher level of AD functionality as part of their everyday commute route. As the WOz car and the interface were very similar to their own AD level 2 car, they were only given a short introduction on how to use the AD level 4 system, and we did not tell them at this point that AD level 4 was simulated by the WOz driver. In addition, they were offered to drive a bit longer if they wished. In this study, they were not restricted to enabling AD-mode on the specified route, except at the beginning or the end of their routes. The route was calculated by the built-in navigation system. In order to simulate the AD level 4 experience, the participants started each drive by entering the selected destination into the navigation system and starting the drive manually. Once in AD-mode, the WOz driver drove according to the route guidance. The WOz driver controlled the car in the sections of the route where road conditions made it appropriate for the WOz driver to safely control the car, due to the limited visibility from the rear seat. The WOz driver triggered a vehicle pop-up message to hand over control to the participants. The WOz method therefore enabled participants to experience a very high level of AD functionality in real traffic environments within their own everyday driving routes. The user interface in the car was similar to the AD level 3 research car in the previous drive-along study but had a cleaner instrument cluster layout with less information when driving in AD-mode. The car appeared fully autonomous in AD-mode, undertaking lane changes and navigation, adapting to speed limits, merging in traffic and managing sharp curves or roundabouts. Participants were told they did not need to hold the steering wheel or pay attention to traffic when in AD-mode. Engaging and disengaging AD-mode was similar to the previous level 3 drive-along, but the two AD-buttons were in front of the steering wheel instead of behind.

Our UX study examined the experience of the following unsupervised autonomous driving of SAE level 4 features: handover experience, automatic lane changing, traffic merging and automatic route selection. We also explored participants' desired future AD technology updates, and an overall understanding of how this level or even a totally fully autonomous SAE level 5 vehicle would fit into their everyday driving and commuting routines. We used the same ethnographic setup in order to make the participants fully immerse in, experience, imagine and reflect on unsupervised driving and future evolution of AD. While ensuring our key questions were covered, our discussions with participants were often inspired by suddenly occurring traffic events or participants' personal reflections. At the end of the drive-along, it was revealed that the car was mainly driven by the WOz driver when in AD-mode. The drive-along was video-recorded by the UX researcher in the front passenger seat.

## 3.5 Analysis process

The drive-along interviews with the five families generated a total of 30 h of video recordings. We undertook a two-step thematic analysis of the drive-along materials [42]. First, the major parts of the video recordings were transcribed, and quotes related to participants' anticipation or anticipatory experiences were identified and coded into Atlas.ti. Second, the codes were grouped into categories related to the contextual source of the participants' anticipations. Based on Tavory and Eliasoph's [28] theoretical framework of the temporal modes of human anticipation, defined as *protentions* (instant), *trajectories* or *plans*, we modified it and the codes were grouped into different temporal phases of anticipation, as the instant, near and far future anticipations of AD. Through this methodology, rich insights emerged about anticipation of the AD driving experiences, the temporal aspect in the participants' anticipations over time between the drive-along and the effects of the socio-technical context. We structured our findings into a model of how anticipatory experiences emerge and change, which we describe in the next section. Following the methods of future-oriented ethnography [43], we emphasise examples and quotations of those participants who articulated their experiences and feelings in ways that represent the findings from across the sample.

## 4 Results

Here, we present our findings mainly based on the analysis of the AD level 3 and level 4 drive-alongs (see Fig. 1), although we were familiar with all the DriveMe families from the

beginning of the DriveMe project, through in-home interviews with all five of the families and initial drive-alongs done with four of the families (with sometimes more than one family participant in the car) in their AD level 2 project car on their everyday commute.

## 4.1 Initial and external AD anticipations of the DriveMe project

In the initial phase of using the DriveMe project cars with AD level 2, participants quickly learned to use the ADAS functions in the car for their everyday needs and context. All of the families were engaged in evaluating the system limitations and values in their everyday use and shared their experiences and anticipation of the AD technology development with the family and friends actively throughout the whole project. In the beginning of the DriveMe project, the participants were told that the aim was to develop their DriveMe vehicles throughout a number of iterations to reach an AD level 4 experience at the end of the project. This created high anticipation for the final AD experience from both the participants and other stakeholders in the project. During the project, issues with the technical development of the AD technology and restrictions from the Swedish road administration regarding driving permits for testing a high level of AD on public roads limited the possibility for quick iterations. This in turn restricted the participants' anticipation during the project, but through the drive-alongs with the two different research cars with AD level 3 and 4 possibilities, we were able to simulate these experiences. Our results are based on the qualitative analysis of the drive-along interviews and observations of the participants' commute drive with these different research cars. We categorised the participants' different anticipatory experiences both into where they came from as *situational sources* of anticipation and in what timespan they related to as *temporal modes* of anticipation. We visualise the results through these categories in a model of anticipatory experiences (see Fig. 3).

While our research findings are derived from the analysis described above, which is based on the materials from all five families, we have selected one of the DriveMe families as a key example through which to demonstrate the points we wish to make. Lotta and Lars, a married couple with two grown-up sons, have been selected for this purpose because in their interview, they clearly articulated feelings that resonated strongly throughout the whole sample and therefore enable us to evoke the human experiences we wish to discuss more plausibly, by situating them within a family context. We complement this with additional quotations from the other families as to demonstrate how their comments resonated with those of the other families. Lotta and Lars' sons were in the process of moving out of the family home, but at the dinner table, they often mentioned being engaged in the discussions of AD. Lars

was the person in the family who was very interested in cars and AD technology, and he would take time to sit in the car and read the instruction manual thoroughly to learn about all the functions. He liked to be an active driver and to find a smooth flow in traffic, but he could also enjoy the freedom to relax more when using ADAS functions. Lotta on the other hand was not so interested in cars and technology but was very curious to find out what AD technologies could do for her to make driving more joyful, social and safe.

## 4.2 Situational sources of anticipation

Our analysis of the sources of participants' different anticipation and anticipatory experiences identified four main categories: *Social, Environment, Technology and Individual* (see Fig. 3). In this section, we outline the findings relating to these, giving examples from selected participants to demonstrate how these emerged from the ethnography.

### 4.2.1 Social

The *social* source of anticipation became evident when the participants spontaneously talked about how they had learnt or discussed about AD via different social channels. An example was the anticipation of AD technology development and future values, which was frequently discussed within the families and with friends or colleagues. They also referred to anticipation based on different kinds of media information, regulatory authorities or internal company information from people involved in the project. The impact of sudden AD-related accidents in media has been shown in other research [44], which could be seen in our study, for instance, when Lars described how he thought the DriveMe project might not allow them to try out higher levels of AD, due to an AD-related accident in the USA:

> Lars: And then there was the accident in the US, which I assumed was the main reason why we couldn't continue the project as planned.
> Safety driver: It's one important reason
> Lars: That's what we thought when she [DriveMe project contact] called us directly after the accident, before it was in the news. Then I said to Lotta [his wife] 'Damn, I think that's the end of it...' It was a very tragic accident, but it wasn't the cars' fault. The car was totally not convicted for it. There's quite a lot about it in the media, not just about these kinds of cars, but also trucks and buses. And there are some buses that are self-driving now, as I understand it ...in some areas?

Another example is how Anna (the mother of one family) started to really believe and anticipate how she might sleep in an AD car going from Gothenburg to Stockholm for work,
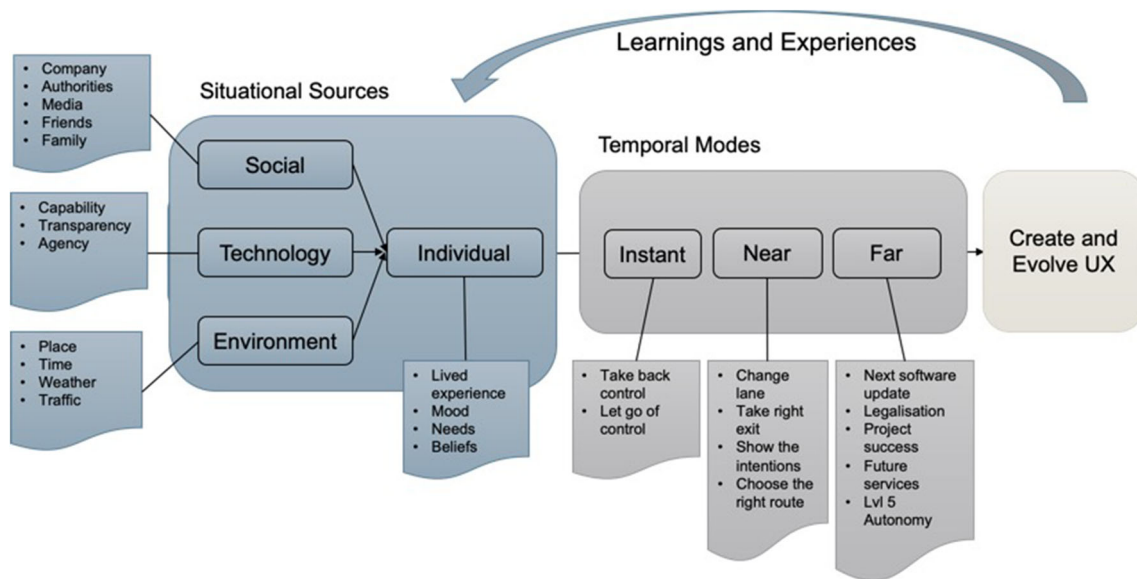
**Fig. 3** Anticipatory experiences

once she had experienced AD level 4 in the WOz car and reflected on her past experience from the Volvo concept AD level 5 car demonstration (360C design mock-up and Virtual Reality simulator) https://www.volvocars.com/intl/cars/concepts/360c:

> Anna: When we tried the 360C [AD Concept car] I started to think about taking the car instead of the plane. That would have been nice and you don't need to take the train and get your own time. Better taking the car than flying. Now we are already here.

Lars' experience of the accident and Anna's experience of an AD concept car represent a common example of how the participants' external sources of anticipation—which emerge through social discussions (within or outside family) and media channels—instantly affected and coordinated the anticipatory experiences of AD-related futures for the participants.

### 4.2.2 Technology

*Technology* as source of participants' anticipation often referred to the learned capabilities of the current level of technology, for instance through participants' everyday use of the project cars with AD level 2 capabilities. During the drive-alongs with level 3 or 4 of autonomy, participants' own level 2 cars often became reference points in their new anticipated experience. For instance, Christian (father in one of the DriveMe families) tried to anticipate the level 3 research car's capability based on his own experience and the AD-system transparency:

> Christian: That's the thing with PA [Level 2 ADAS], I felt that with this car as well. I'm not sure…does it see

that there are cars on the side? Here I see it does but it [the car] is driving really close [to other cars] and I guess the car feels it's a good gap, but I don't. It's too close. Does it sense the car over there [pointing to the car in the right lane] or can it drive into it [the other car]?
> Safety driver: It should sense the car. I'm pretty sure it does because it's so close.
> Christian: When you drive in and out of the parking space it feels and senses everything. Are they the same sensors?
> Safety driver: No, not in this car. It's not the same actually.

The participants also gave the AD system and the car agency in order to refer to its, sometimes irrational, behaviour or anticipate its capabilities. For instance, Lotta discussed the level 4 research car as if it were a person:

> Lotta: Look how it finds the way to work! Now it's interesting to see which road it takes.
> UX Researcher: And when it thinks you need to take over. […the car is turning]
> Lotta: It this when it turns…now there wasn't a car [pointing to the inside lane]. You haven't felt that before, or could it really take the turn that well. Or will it then stop driving very soon…or?!?
> UX Researcher: Yes…
> Lotta: It's a bit messy here. It's very narrow.
> UX Researcher: We'll see…
> Lotta: I don't want it to hit any obstacles [Lotta prepared to take the wheel][...car is turning]. It's good!

These two quotes represent two common examples of how both participants' past real-life experiences of the ADAS

technology and their future beliefs and sense making of ADAS technology shape their anticipation of future AD actions and developments.

### 4.2.3 Environment

The *Environment* was a dominant source for the participants' anticipation of their experience of the AD system. As participants drove along their everyday routes home or from work, they referred to their anticipation of AD experience in relation to what could or usually happened in the traffic at the specific spot. For instance, Alex (father in one of the DriveMe families) explained what normally happened with his level 2 car where the lane split into two:

> Alex: Now it will be interesting to see how it handles this. Here it is 50/50 if the PA [AD level 2] gets freaked out because this lane gets very wide soon
> [...Car wants to change lanes to the right]
> Alex: That was clever! It would have been more interesting to see how it handles that lane..[referring to the lane that split]

The time of the day or the weather also played a role in how participants anticipated their experience of the AD system. For instance, when Lotta anticipated the level 3 research car's intermittent performance in the early wet morning of the day of her drive-along, she explained the experience based on her former experience:

> Safety driver: Do you notice the difference of the time of day for the PA [the level 2 driving support system]
> Lotta: It's worse in the morning vs afternoon even though the road's wet at both times. Maybe it's got something to do with the salt.
> Safety driver: Is it dark both times
> Lotta: Yes
> Safety driver: The problem is the glare from the road

These two examples of environmental sources for anticipation are just two instances of many, which demonstrate the strong influence that the environmental aspects of place, weather, time of day or traffic intensity had on the participants' anticipatory experience of AD.

### 4.2.4 Individual

Finally, the *Individual* source refers to how participants' anticipation emerged from their own beliefs, needs, mood or lived experiences. It connects the other sources of anticipation via the lived experiences of the social, environmental or technological elements. For example, when asking Lars during the AD level 4

drive-along about what he anticipated in the future with shared AD cars, he replied by referring to his own needs for freedom:

> Lars: I think there will be a choice between private or shared rides. [Lars explains his own experience from shared car service in France]. I would mostly go by myself...I'm used to being able to get where I want when I want. Of course we still could, it's a matter of cost. Today you already pay a lot by having your own car. There are options like Sunfleet but I don't use them. I think I value my own car too much to do that

When anticipating and speculating around the various ways that automation would become meaningful, participants often reflected on how AD would synchronise with different ways of driving. For example, Anna (the mother of one DriveMe family) identified the AD function as something that might be particularly 'limiting' or 'beneficial' depending on the purpose and context of the drive and destination. AD functions in what she calls 'stress driving' situations—when she was in a hurry, for instance taking the children to sports practice—will be largely limiting because she will lose the opportunity to take 'shortcuts'. As she explained, shortcuts help her to save time by taking alternative routes or speeding up on more deserted streets and areas. But if the car followed all rules, she said she would lose the ability to make shortcuts. On the contrary, she identified the AD function to be particularly suitable on two occasions: longer-term travels and morning drop-offs. Twice a week, she uses Sunfleet (car sharing service) with her colleagues to drive long distances for work to see clients in another region. These are the longer-term drives, what she calls 'cruises', where the AD function would work particularly well for her. Her husband Sasko drives the DriveMe research car in the mornings. Anna either cycles to work to the city centre or takes public transport when the bicycle roads are too slippery. She says she would take the car more often if she did not have to think about parking, which gets particularly difficult in the city centre, where her office is located. As these examples demonstrate, for the participants, all the external sources of anticipation tended to be combined and integrated with their individual beliefs and goals in coordinating their own futures.

### 4.3 Temporal modes of anticipation

All the situational sources of anticipation noted above generate anticipatory experiences and actions related to different time spans. The results of the analysis of the different anticipatory experiences from the AD levels 3 and 4 drive-along interviews were then also categorised into three different time spans, ranging from the most instant anticipation, through near future anticipation to the furthest future anticipation. In Fig. 3, we describe these experiences through the actions they were afforded

by. In this section, we outline these and demonstrate them with selected specific examples.

### 4.3.1 Instant anticipation

The first category entails *instant anticipation*, which affects the immediate actions and experiences. Examples of anticipation in this category were related to when the participants took the action of letting go of the steering wheel in AD-mode or when they instantly anticipated a need to take back control due to the AD research cars' behaviour in the traffic situation or through a prompt in the information display. As for the beginning of the AD level 3 drive-along, participants initially hesitated to let go of the steering wheel in AD-mode at familiar curves where they normally had experienced limitations in their own level 2 project car, but during the drive-along once they learned the research car's capability, they did so. They also experienced situations the other way around. For example, at the beginning of his drive of the level 3 research car, Lars was very relaxed, and took his hands off the wheel at a comfortable speed in standing queue in the left lane. Suddenly, a car merged into the standing lane and the AD car automatically braked:

Lars: I often sit like this with my hands... Ooops!
Safety driver: It thought the car was too close.

Then just a hundred metres later, a very similar situation happened when a taxi tried to merge into the queue in the left lane, but ended up standing still partly occupying part of the lane ahead. The research car's sensors seemed to totally miss the taxi and continued at the same speed and position in lane. Lars sensed the taxi was too close and anticipated intuitively that the research car had not sensed the taxi and that he needed to take back control of the steering wheel to manually steer around it:

Lars: Was that good?
Safety driver: That was not good…
UX Researcher: It should have seen that?
Safety driver: Yes it should…
Lars: I felt like it was a bit too close.

Another example was when Miguel (father in one of the families) described how he wanted the AD level 3 car to be more transparent in how it perceived the traffic situation and decided to act, for him to be able to anticipate if he could trust it or not.

Miguel: In the beginning, I need to know how the car thinks, for now. I don't want to wait to see how it breaks. I want to see immediately what the car sees, what's happening, at what distance it starts breaking and so on.

These examples represent how instant actions were coordinated according to how the participants anticipated their next move, regarding if they would engage physically in the driving task or not, depending on the socio-technical context and their former experiences.

### 4.3.2 Near future anticipation

The second category entails *near future anticipation* of the next events during a drive-along, e.g. changing lanes, taking a turn or exit, route selection or determining other road users' intentions. For example, Alex anticipated the best lane for a smooth traffic flow passing a bus stop in relation to if other road users in the faster left lane would find his car too slow:

Alex: Now I know the bus needs to go in there [pointing at a local bus at the bus stop along the road]
Safety driver: You could change to the left lane if you want ...now
Safety driver: Then you would be able to see if it wants to change back to the right lane...it's an example of what it could do.
Alex: We'll see about that, I normally drive in that lane where traffic is faster, but then you don't want someone driving 70 km/h in that lane.

The way that driving actions are coordinated according to a higher goal or task becomes apparent in the example above, since Alex wanted to achieve both a smooth ride without unnecessary braking and also fit into the local traffic behaviour. This example shows how Alex's near future anticipation of the traffic situation (based on this specific place along the route and the anticipated social behaviour of other road users) directed his actions (or in this case non-action) in order to optimise the outcome of the situation.

### 4.3.3 Far future anticipation

The third category entailed *far future anticipation*—of events such as the next update of the AD-system—changes in AD legislation, the DriveMe project progress, potential future AD services or how full AD level 5 would be experienced. This became apparent in how the participants talked about the pace of AD development and how it shifted depending on the experience in each drive-along. In the beginning of the project, all participants were very positive and anticipated that AD development and its usefulness in their everyday lives would be fast-paced. However, during the project, living with their DriveMe research cars limited AD functionality, experiencing the level 3 research car's limitations and the slow progress of authorities to provide AD driving permits, they felt that an AD future was increasingly distant. Experiencing some level of AD functionality in their everyday life made the participants also to better

understand and reflect of not only technical challenges for AD but also the social aspects of AD compared with the beginning of the project. For example, when Lars discussed how he thought the constant ongoing construction work near his work, combined with people's irrational driving behaviour when navigating the mess it created would be complicated for AD cars to cope with:

UX Researcher: What do you think are the main obstacles?
Lars: That this technology isn't available to everyone, so others will keep driving themselves... and if you need to mix the self-driving cars with ordinary people, with all their faults and mistakes… and strange ways of driving, stressed by the afternoon traffic, blocking each other. It's going to be very much like that. [...] I have wondered what it would be like in a mix, with some AD cars and the rest human drivers … It needs enough space to be able to get in. Otherwise it won't be able to enter [the flow of traffic] at the right time.

Another example of the far future anticipations is when Sasko during his AD level 3 drive-along reflected on the need for personalisation, but also the difficulties for artificial intelligence to learn your way of driving:

Sasko: To some extent you learn how it works and then it's a bit tricky if it changes the way it behaves. Theoretical you could end up in endless loop where it continues to learn and I make corrections just because it has learnt something and then it learns something else. Spontaneous it doesn't feel like a good idea. You maybe don't want to go with yourself.

Lars' and Sasko's examples show how their experiences of being part of the DriveMe project and driving with ADAS technology in their everyday commute made them re-coordinate their future anticipation of AD technology development and integration. At the beginning of the project, they both anticipated that the AD technology would develop and integrate in people's everyday lives more rapidly and easily. Although, like Lars and Sasko, other participants' anticipation of a fully AD future declined during the project; almost all participants wished to continue their participation in the development of AD functionality and services after the DriveMe project.

## 4.4 Learning through anticipatory actions

The situational sources of anticipation identified above affect and were affected by how the participants anticipated their instant, near or future experiences in the drive-alongs. This relationship between the situational sources and temporal modes was construed by how anticipatory actions and experiences fed back through a learning process, thus influencing

new situational sources to occur that in turn create new anticipatory modes, thus creating an ongoing iteration of creating anticipations, actions and context (see Fig. 3). For instance, when we asked Lars how he knew if it was him or the car that was in charge of driving:

UX Researcher: How do you sense the AD-mode?
Lars: Yes you feel it, but I don't understand it. You feel it through the steering wheel by holding it slightly. It also gets a bit more sensitive. You also watch the steering wheel icon, unconsciously
UX Researcher: What about mode confusion?
Lars: Yes, it happens, but it works seamlessly. I don't think about it. I have even learned to recognise when it starts to remind me to hold the wheel, so I know when to grab the wheel before it beeps

He anticipated the car's ability to drive and handle the situation by lightly holding the steering wheel; thus, he sensed the car's agency as communicated through the haptic feedback in the steering wheel. He also learnt the interval when the car started to remind him about holding the steering wheel. However, without the contextual aspects of the place, time of the day and the weather, the feedback through the steering wheel would not be enough for him to subconsciously feel who was in control in a specific moment. Riding with his wife Lotta, he also learned how people are different and how they have different needs, which made him anticipate that future AD functionality needs personalisation options:

Lars: I think I would like personalisation, Lotta [his wife] might just be satisfied with it as it is, but I think I could make it a bit better if it drives like me. [Laugh] People drive very differently

It also became apparent how sensitive the UX is due to the situational anticipatory experiences and how the different time spans of anticipation interact. Minor changes of any social or environmental sources to anticipation could quickly change the UX of the AD technology from one moment to another. In Lotta's first early morning drive-along with the AD level 3 research car, she had a really bad driving experience. The drive started before dawn; the morning rush hour and the rainy weather made it difficult for the research car sensors to detect the lane markings. This made the car behave in an uncertain way about both providing AD drive offer or keep driving steady in the lane, when in AD-mode. As Lotta anticipated and recognised this behaviour from her AD level 2 project car, she tried to hold the steering wheel firmly in AD-mode, which made the research car uncertain if she was about to take back control or not, e.g. the car was programmed to take sharp curves at higher speeds with hands on the steering wheel than without, which in her situation increased the feeling of losing

control. This initiated a loop of increasing uncertainty between Lotta and the AD car, which also was anticipated by the safety driver, who took a role as a driving instructor for Lotta to help out. However, even if the driving experience of the morning drive was horrible, Lotta still wanted the project to be successful and anticipated the car's behaviour could be diagnosed as being due to the bad weather conditions, based on her past experience from her own AD level 2 project car:

> UX Researcher: Do you feel it has a different will?
> Lotta: No it's just as bad at reading the lane markings [Laugh] Or was I rude now?
> UX Researcher: You don't need to be kind
> Lotta: It's probably the 'morning problem'

Lotta's afternoon drive-along with the same AD level 3 car and with the same people in the car was totally different. The light conditions were brighter and the traffic was less intense; the AD level 3 car was reading the lanes easier and provided AD offer more frequently and more stable in AD-mode. Lotta sensed the difference quickly and let go of the steering wheel more often. This also made the AD car driving more comfortable and confident in the driving responsibility, as the car was programmed to take curves at lower speeds if it sensed through the steering wheel that the driver did not have the hands on it, prepared to take back control immediately. Also, if too much force were applied to the steering wheel, the AD car would lose the lane tracking and suddenly give back the control to the driver. Lotta started quickly to be more relaxed, as the sharp curves were taken at a reduced speed compared with when she had her hands on the steering wheel, and the car could follow the lane without getting input from her, which in this case increased the feeling of control. Lotta found it hard to blame the car for the bad morning experience and thought it might have to do with her own inexperience.

> UX Researcher: Do you feel any difference between now and the morning drive?
> Lotta: Yes it feels more stable and maybe I wasn't really used to it as well
> UX Researcher: It had more problems then as well
> Safety driver: It's almost dry now
> Lotta: It feels like it's going smoothly

Although she quickly anticipated the research car would be more competent in the afternoon drive, she still anticipated the moments in which she should resume control, due to factors including car behaviour, traffic behaviour, location and time of day.

To summarise our findings, in Fig. 3, we show how the different sources of anticipation refer not only to participants' experiences or anticipations of the AD technologies themselves but how social and environmental sources also play a major role in how anticipation feeds into their lived experiences.

## 5 Discussion

Above, we have analysed the situatedness of anticipation of automated driving in relation to the *compositional* and *spatio-temporal* threads of experiences [32] and we have captured examples of all of the six sense-making processes through our theoretical and temporal lens that describe human instant and future actions as part of intentional trajectories [28], always entangled in ever-changing compositional and motivational contexts [27]. Through our long-term study, we found that the participants' different sources of anticipation for their future experiences played an important role in how they instantly reacted in the drive-along traffic situations, how they experienced the research car's ability to follow the correct route and how they anticipated their futures with AD cars, AD development integration and related AD legislation. Thus, the ongoing learning iteration between context, actions and anticipatory experiences turns our attention toward the complexities of appropriating automated driving technologies that reach far beyond more simplistic models of acceptance as a matter of how people perceive ease of use and usability [16]. Instead, our results indicate how appropriation of automated driving technologies includes a processual and ongoing interplay between the social, technological and environmental context and the temporal modes of anticipation people experience and act on when learning to drive in different autonomous modes.

### 5.1 Understanding the temporal process of anticipatory UX

Compared with other empirical studies of AD experiences undertaken in lab settings or with a short time span, our approach to studying evolving automated technology used in people's everyday lives has provided new knowledge about how people integrate an AD into their lives step by step within a specific socio-technical context. Participants learned to ride with AD through a gradual learning process whereby they anticipated that their need for displays and information communicated from the car would decrease gradually. Many UX studies discuss AD in terms of user acceptance, adoption and uptake [17]. However, our initial observations suggest that acceptance will gradually be established and that interfaces that support adoption and provide a glimpse of or transparency relating to the car's way of 'thinking' and decision-making will play a key role in assistive and cooperative driving, such as when Lars explained (above) how he sensed the car's ability to drive through by lightly holding the steering wheel.

Drawing on Poli's [27] theory of motivational systems, we found and outlined how people's situated anticipatory experiences of AD is a combination of the *because* structures, based on the participants' past actions and former experiences of the AD technology and socio-technical AD-related aspects, together with their *in-order-to* motives, based on the goal of their drive or needs and beliefs in the AD technology. As an

example, we saw how the participants continuously hoped for improvements in the technology and sometimes pushed the AD systems to the limit, even though they already had experienced the limitations of the system in the same context. This explains the sometimes irrational actions of AD use, which show how the question is not simply if the person trusts the system, but rather if the person wants to trust the system in a specific situation. This is because there is an in-order-to motive, which drives the actions. Poli's [27] *because of* structures explain the loop of learnings, which informs the sources of anticipation in combination with the person's individual needs and motives which are driven by the in-order-to structures.

In order to understand the different temporal mode of anticipation, we built our model on Tavory and Eliasoph's [28] framework, where we identified the different anticipatory time spans from instant to far future. By identifying how participants' anticipation of AD plays out on a wide temporal spectra simultaneously on different modes, we could better understand how and why instant actions are related to higher level modes of near future or even far future anticipation. These modes are different but closely nested, which explains how people anticipate future experience AD technologies on different timespans, and why these anticipations became shaped through participants' experiences of their everyday use of a lower AD level system. As an example, when their ADAS experience was bad in some situations during the AD level 3 drive-along, it affected their far future anticipation of AD development. In contrast, as soon as their real-life experience of AD improved according to their reference points, as in the AD level 4 drive-along, they quickly adapted and increased their anticipatory experiences of the far future AD developments. Anticipation of different time spans is related and nested with each other. This makes them difficult to separate but shows why we need to investigate and attend to all these different anticipatory temporal modes in order to fully understand how anticipation could change.

Through our research into how AD is experienced and appropriated in everyday life contexts, we have demonstrated how the socio-technical elements and the situatedness of AD are part of a temporal process in which anticipatory modes and actions are key. Our contribution brings new understanding of the temporality of socio-technical sources of anticipation, as a process involving how people use these sources in their anticipation of AD in different time spans. This is visualised as a model in Fig. 3, in order to show the different and complex aspects of how anticipatory UX of AD technologies evolve in people's everyday lives.

## 5.2 Implications for studying anticipatory UX

Our study responds to the identified need for more HCI research into the temporal processes through which UX emerges in relation to the social and material contexts [11]. We made the socio-technical sources of participants' anticipation of AD

technologies visible and showed how important these are for the immediate UX of AD, what people expect next and how this continuously changes. It also showed how small changes in these sources could totally change the UX. When participants experience AD technologies over time in their own contexts and routines, research shows that the social, technical and environmental sources of their anticipation impact on their UX of the evolving AD experiences [26]. The results presented above reinforce this point and stress the importance of attending to social and environmental aspects in empirical studies that inform UX design. As Poli [27] explains, anticipation has a role in not only the temporal aspects of past and future but also in social relations between users. AD technologies are in an ongoing process of design and development, in relation to technology design, regulation, policy and human experience. Thus, we argue that studying and understanding people's anticipatory experiences of ADAS will provide a more holistic understanding of how UX designers should design and evolve AD design in order to encourage easier and faster adoption of AD into everyday life. Designers need to learn from today's users of ADAS and their changing anticipation of future AD developments. Asking people predefined questions when they have no experience of ADAS in their everyday life is of limited value in informing the design of iterative solutions for people who are using evolving levels of automation. As we found anticipation ongoing, it opens for an understanding of the particular relevance of iterative design methods when it comes to the development of ADAS systems. Our model also demonstrates the importance of acknowledging the social and environmental (not only the technical) aspects of how anticipation evolves, aspects that have been neglected in previous research [1].

## 5.3 Limitations

The study is based on a small sample of people living in the same city area who all joined the DriveMe project voluntarily due to their positive interest in AD technology. Limitations relating to participants' interest in autonomous driving technologies when applying to be part of the DriveMe project are possible, but difficult to measure, since this interest may also have had the benefit of making their anticipatory experiences more apparent. Simultaneously, we stress that this sample was made possible by the DriveMe experiment, and has presented a unique opportunity to study AD as it becomes integrated into everyday life over time. It is impossible to know how the participants would have experienced a future AD car where the safety driver and researcher were not present, because such a situation is not yet possible. Our aim was to study the phenomenon of socio-technical aspects and peoples' evolving anticipatory experiences of AD cars and technology, rather than quantify the aspects of anticipatory experiences of AD or verify a model for it. The ethnographic approach of following this small group of people for a long period in their

everyday lives enabled us to study the socio-technical aspects in detail, although it limits the possibility for generalisation or transferability. Our selected methodology fulfilled our objective to study these aspects as they emerge and become visible. It demonstrates a remaining need to study socio-technical aspects further, to better understand how AD technologies integrate into real everyday life practices and circumstances.

# 6 Conclusion

We followed five families in a long-term ethnographic project in order to study their evolving anticipation and experiences of AD technologies. The participants had access to project cars with high levels of ADAS, according to the definition of SAE AD level 2 for their everyday use. During the project, we performed drive-along studies with two research cars equipped with higher levels of simulated automation at SAE AD level 3 and SAE AD level 4. We used tailored ethnographic methods to first get to know the families and build trust, through in-home interviews and then through drive-along interviews. We identified how the participants gradually adapted to the AD technologies, through a process involving anticipation of different time spans, from instant letting go of the steering wheel, to understanding what the AD car will do next, and imagining what longer-term AD technology possibilities will provide.

Our theoretical framework [28] was helpful for investigating how anticipatory experiences of AD technologies occurred and changed over time within specific socio-technical and environmental circumstances, in which participants' lived experiences of their everyday commute and social context played a major role. Through this theoretical lens, we were able to understand and visualise the temporal process of the socio-technical sources of anticipation and how it informs the different time spans of anticipatory UX into a model (Fig. 3). Situational everyday experiences became learnings into the sources of an ever-changing process of anticipation. Even minor changes in any of these sources of anticipation shifted the UX of the AD technology from one moment to another.

Our study responds to the identified need for more HCI research that attends to the temporal and social-technical contexts of UX. Studying how anticipation is created and affects UX provided us with new insights into how and why people adopt AD technologies. This has implications for how to take a holistic perspective when designing AD technologies for smooth adoption. Designing for people's anticipatory experiences of AD should provide them with a technology that evolves with their learning, shows transparency of system capabilities and provides them possibilities to adopt technology into their everyday lives.

## Compliance with ethical standards

## References

1. Rödel C, Stadler S, Meschtscherjakov A, Tscheligi M (2014) Towards autonomous cars: the effect of autonomy levels on acceptance and user experience. Paper presented at the Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Seattle, WA, USA

2. Distler V, Lallemand C, Bellet T (2018) Acceptability and acceptance of autonomous mobility on demand: the impact of an immersive experience. Paper presented at the Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, Montreal QC, Canada

3. Immonen M, Sintonen S, Koivuniemi J (2018) The value of human interaction in service channels. Comput Hum Behav 78(1):316–325. https://doi.org/10.1016/j.chb.2017.10.005

4. Ryghaug M, Toftaker M (2014) A transformative practice? Meaning, competence, and material aspects of driving electric cars in Norway. Nat Cult 9(2):146–163. https://doi.org/10.3167/nc.2014.090203

5. Svangren MK, Skov MB, Kjeldskov J (2017) The connected car: an empirical study of electric cars as mobile digital devices. In: MobileHCI '17: Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services, Vienna, Austria. ACM, pp 1–12. https://doi.org/10.1145/3098279.3098535

6. Strömberg H, Pettersson I, Andersson J, Rydström A, Dey D, Klingegård M, Forlizzi J (2018) Designing for social experiences with and within autonomous vehicles-exploring methodological directions. Des Sci 4. https://doi.org/10.1017/dsj.2018.9

7. Hornbæk K, Hertzum M (2017) Technology acceptance and user experience: a review of the experiential component in HCI. ACM Trans Comput Hum Interact 24(5):1–30. https://doi.org/10.1145/3127358

8. Bonneau V, Yi H, Probst L, Pedersen B, Lonkeu O (2017) Autonomous cars: a big opportunity for European industry. Digital Transformation Monitor

9. Howard D, Dai D (2014) Public perceptions of self-driving cars: The case of Berkeley, California. In: Transportation research board 93rd annual meeting, 2014. vol 4502, pp 1–16

10. Piao J, McDonald M, Hounsell N, Graindorge M, Graindorge T, Malhene N (2016) Public views towards implementation of automated vehicles in urban areas. Transport Res Procedia 14:2168–2177

11. Bargas-Avila JA, Hornbæk K (2011) Old wine in new bottles or novel challenges? A critical analysis of empirical studies of user experience. In: CHI 2011, Vancouver. ACM, pp 2689–2698. https://doi.org/10.1145/1978942.1979336

12. Pettersson I, Lachner F, Frison A-K, Riener A, Butz A (2018) A Bermuda triangle?: a review of method application and triangulation in user experience evaluation. Paper presented at the Proceedings of the 2018 CHI conference on human factors in computing systems, Montreal QC, Canada

13. Emery F, Marek J (1962) Some socio-technical aspects of automation. Hum Relat 15(1):17–25

14. Cuciurean-Zapan M (2017) Situated: reconsidering context in the creation and interpretation of design fictions. Ethnographic Praxis in Industry Conference Proceedings 2017 (1):112–126. https://doi.org/10.1111/1559-8918.2017.01142

15. D'Arcey JT, Haines JK, Churchill E (2019) Understanding embodied state using speculative artifacts. Paper presented at the proceedings of the 2019 on designing interactive systems conference, San Diego, CA, USA

16. Davis FD (1985) A technology acceptance model for empirically testing new end-user information systems: theory and results. Massachusetts Institute of Technology, Cambridge

17. Gkartzonikas C, Gkritza K (2019) What have we learned? A review of stated preference and choice studies on autonomous vehicles. Transport Res C Emerg Technol 98:323–337. https://doi.org/10.1016/j.trc.2018.12.003

18. Panagiotopoulos I, Dimitrakopoulos G (2018) An empirical investigation on consumers' intentions towards autonomous driving. Transport Res C Emerg Technol 95:773–784. https://doi.org/10.1016/j.trc.2018.08.013

19. Leicht T, Chtourou A, Ben Youssef K (2018) Consumer innovativeness and intentioned autonomous car adoption. J High Technol Manag Res 29(1):1–11. https://doi.org/10.1016/j.hitech.2018.04.001

20. Cho E, Jung Y (2018) Consumers' understanding of autonomous driving. Inf Technol People 31(5):1035–1046

21. Forlizzi J, Battarbee K (2004) Understanding experience in interactive systems. In: DIS '04: proceedings of the 5th conference on designing interactive systems: processes, practices, methods, and techniques, Cambridge, MA, USA, 2004. ACM, pp 261-268. https://doi.org/10.1145/1013115.1013152

22. Hassenzahl M, Tractinsky N (2006) User experience - a research agenda. Behav Inform Technol 25(2):91–97. https://doi.org/10.1080/01449290500330331

23. ISO (2010) Ergonomics of human-system interaction. Part 210: human-centred design for interactive systems (ISO 9241-210: 2010). International Organization for Standardization, Switzerland

24. Law EL-C, Roto V, Hassenzahl M, Vermeeren APOS, Kort J (2009) Understanding, scoping and defining user experience: a survey approach. In: CHI '09: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Boston, MA, USA. ACM, pp 719–728. https://doi.org/10.1145/1518701.1518813

25. Yogasara T, Popovic V, Kraal BJ, Chamorro-Koc M (2011) General characteristics of anticipated user experience (AUX) with interactive products. In: Roozenburg N, Chen L-L, Stappers PJ (eds) Proceedings of IASDR2011: The 4th World Conference on Design Research: Diversity and Unity, Delft, The Netherlands. IASDR, pp 1–11

26. Lindgren T, Fors V, Pink S, Bergquist M (2019) Experiencing the future car: anticipatory UX as a social and digital phenomenon. Scand J Inf Syst 31(1):3–30

27. Poli R (2017) Introduction to anticipation studies, vol 1. Springer

28. Tavory I, Eliasoph N (2013) Coordinating futures: toward a theory of anticipation. Am J Sociol 118(4):908–942. https://doi.org/10.1086/668646

29. Battarbee K, Koskinen I (2008) Co-experience: product experience as social interaction. In: Product Experience. pp 461–476. https://doi.org/10.1016/B978-008045089-6.50022-8

30. Hansen TR (2006) Strings of experiments: looking at the design process as a set of socio-technical experiments. Paper presented at the proceedings of the ninth conference on participatory design: expanding boundaries in design - volume 1, Trento, Italy

31. Bannon L (2011) Reimagining HCI: toward a more human-centred perspective. Interactions 18(4):50–57. https://doi.org/10.1145/1978822.1978833

32. McCarthy J, Wright P (2004) Technology as experience. Interactions 11(5):42–43

33. Kujala S, Roto V, Väänänen-Vainio-Mattila K, Karapanos E, Sinnelä A (2011) UX curve: a method for evaluating long-term user experience. Interact Comput 23(5):473–483. https://doi.org/10.1016/j.intcom.2011.06.005

34. Dourish P, Bell G (2011) Divining a digital future: mess and mythology in ubiquitous computing. Mit Press

35. Pettersson I, Karlsson ICM (2015) Setting the stage for autonomous cars: a pilot study of future autonomous driving experiences. IET Intell Transp Syst 9(7):694–701

36. Pettersson I (2017) Travelling from fascination to new meanings: understanding user expectations through a case study of autonomous cars. Int J Des 11(2)

37. Lee J, Kim N, Imm C, Kim B, Yi K, Kim J (2016) A question of trust: an ethnographic study of automated cars on real roads. Paper presented at the proceedings of the 8th international conference on automotive user interfaces and interactive vehicular applications, Ann Arbor, MI, USA

38. Mitchell V, Mackley KL, Pink S, Escobar-Tello C, Wilson GT, Bhamra T (2015) Situating digital interventions: mixed methods for HCI research in the home†. Interact Comput 27(1):3–12. https://doi.org/10.1093/iwc/iwu034

39. Pink S, Fors V, Glöss M (2018) The contingent futures of the mobile present: automation as possibility. Mobilities:1–17. https://doi.org/10.1080/17450101.2018.1436672

40. International S (2018) Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles J3016_201806. Surface Vehicle Recommended Practice. SAE Int. https://doi.org/10.4271/J3016_201806

41. Osz K, Raats K, Fors V, Pink S, Lindgren T. (2018) Combining WOz testing and ride along video ethnographies: advancing methodologies for autonomous driving car development for mixed traffic environments. In: OzCHI conference, December 5-7, 2018, Melbourne, Australia

42. Braun V, Clarke V (2006) Using thematic analysis in psychology. Qual Res Psychol 3(2):77–101. https://doi.org/10.1191/1478088706qp063oa

43. Salazar JF, Pink S, Irving A, Sjöberg J (2017) Anthropologies and futures: researching emerging and uncertain worlds. Bloomsbury Publishing

44. Bissell D (2018) Automation interrupted: how autonomous vehicle accidents transform the material politics of automation. Polit Geogr 65:57–66. https://doi.org/10.1016/j.polgeo.2018.05.003