Chapter 12
Exploring Challenging Environments: Contextual Research in the Car and the Factory Through an HCI Lens

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Nontraditional environments offer a variety of methodological challenges when exploring cooperation under very specific contextual conditions. We understand contexts as challenging when they exhibit very specific/unique characteristics that need to be explored beyond traditional and already better-understood working/office settings. Moreover, these challenging environments are contexts in which human-human interaction mediated by computing systems and human-machine collaboration is hard to observe. In this paper, we focus on two challenging environments: the highly context-dependent automotive environment and the complex context of a semiconductor factory. Both contexts offer potential in a variety of ways for novel computer-supported cooperative work research, such as driver/codriver cooperation and operator-robot cooperation. In this book chapter, two exemplary contexts "car" and "factory," will be characterized in terms of (1) research challenges posed by the context, (2) performed exploratory studies, and (3) methodological implications for the two exemplary contexts, as well as for CSCW and HCI research practices in general.

12.1 Introduction

Over the past years, the field of human-computer interaction (HCI) and computer-supported cooperative work has moved beyond the desktop and, by going into the field, has started to explore novel forms of interaction in different contexts. Various

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theories and models to motivate context-oriented thinking have been proposed, such as approaches to “situated action,” suggesting that the particular context determines how people behave in specific situations (Suchman 1987). The essence of situated action is that every experience is influenced by, and is constitutive of, the context in which it occurs. An in-depth understanding of context enables application designers to choose what context factors to consider in their applications (Dey 2001).

Since then, the research community became more and more interested in understanding not only the individual interacting with technology but the social context in which technology usage happens (Nardi 1992). Different social science methods (ethnographies, interviews, observations, etc.) and theories (distributed cognition, activity theory, situated action, etc.) entered HCI and CSCW and were used to gain knowledge about various domains. Enhancing the knowledge/understanding of specific contextual situations with deeper insights on user experience (UX) opens up new roads for research and challenges in all design and development phases. Notwithstanding this, however, Roto et al. stated that specific and comprehensive guidance for capturing data about the circumstances that affect user experience in “the wild” is missing (Roto et al. 2011).

By addressing the specific and challenging contexts of a semiconductor factory and a car as HCI research domains, we provide two examples how such contexts can be explored from an HCI perspective in order to enable cooperation between multiple users (as well as users and robotic systems in the factory). In this chapter, we follow an overview on HCI and CSCW approaches in various challenging contexts (e.g., the health sector and airplanes) by presenting the two specific contexts mentioned above. For both contexts, we will present our overall approach and our interpretation of the context with its potential to enable cooperative activities, followed by the research challenges these contexts offer. We will then describe, for both contexts, how we tried to explore them and what findings we could glean. Finally, we will present the specific methodological challenges we derived for both contexts and conclude with how these findings and implications can be of relevance for fellow HCI and CSCW researchers.

12.2 HCI Studies in Challenging Contexts

Several methodological approaches already exist in HCI and CSCW to explore contextual influences on workflows and interaction paradigms, which can build the empirical basis for design implications (Dourish 2006). Beyer and Holtzblatt, for instance, developed the methodological concept of contextual inquiry, which puts designers and engineers directly in the customers’ work context, for gathering rich, in-depth data about working routines (Beyer and Holtzblatt 1998). Similar approaches used in HCI and CSCW are ethnographic studies, which are field research methods that combine several data-gathering methods such as participant observation, formal and informal interviewing, and the analysis of documentary sources (Powdermaker 1966; Wax 1971; Werner and Schoepfle 1987). Ethnography provides detailed insights into people’s behavior, even if they themselves are unaware of it. Using ethnography (Fetterman 1998) has become increasingly prominent within HCI (e.g., Blomberg et al. 1993; Simonsen 1997; Crabtree 1998; Randall et al. 2007). The rapid ethnography method was subsequently developed for product development in order to close the gap between short design cycles and the long, complex nature of ethnographic research (Millen 2000). Originally, ethnography in HCI mainly focused on empirical studies of work routines in the setting for which a novel system should be developed. However, as Crabtree et al. phrase it, "the dominant concern for new approaches is to engage designers instead in a critical dialogue based on cultural interpretations of everyday settings, activities, and artefacts" (Crabtree et al. 2009). This also expresses our concern that we need to find new approaches for nontraditional environments (such as the car and the factory) to gain an understanding of the interplay of tasks, devices, and the (social) context.

As Magnusson et al. claim, there are contextual impact factors, which can only be identified through fieldwork of some kind and which need to be identified before designing a system (Magnusson et al. 2011). They suggest, for the development of mobile devices, to raise the understanding of such contextual constraints by conducting contextual walk-throughs, contextual trials, and key scenarios. They also argue that for a more accessible mobile device design, designers have to consider nonoptimal usage conditions, since mobile situations are very dynamic and change very quickly. Subsequently, usage scenarios for mobile phones should consist of nonoptimal lightning, noisy environment, cold hands (which reduce the touch-sense ability), and the context which requires attention (other people, traffic, etc.).

Two prominent challenging contexts, which have already been intensively investigated through an HCI lens, are the healthcare sector and airplanes. To gain deeper insights in the context of a Danish emergency medical service (EMS), different usability methods were applied to be able to build a set of designs for future EMS work (Kristensen et al. 2006). In total, 13 researchers took part in a 3-day training session, normally conducted with new personnel, to get a step-by-step introduction into the EMS. The interviews helped on the one hand to understand the end users' needs, as well as the use and usability of dictation solutions and electronic nursing documentation systems. On the other, however, researchers had to face similar challenges as in the factory context, such as privacy concerns, a wide variety of practices and contexts of technology usage, as well as the hectic nature of everyday work (Viitanen 2011). In the context of airplanes, one of the most well-known observational studies was conducted by Hutchins and Klausen. Based on the theory of distributed cognition (how information is propagated through a system in the form of representational states of mediating structures), they analyzed airline flight crews performing in a high-fidelity flight simulator (Hutchins and Klausen 1996). It was shown that the expertise of the systems resides as much in the organization of tools in the working environment as in the knowledge and skill of the humans. They also observed patterns of cooperation and coordination of actions within the crew, which could be identified as a structure of propagating and processing of information. On a different level, this structure appears as a system of activity where shared cognition comes forward as a system property. Ballas et al. investigated how to design an interface that supports smooth transition from automated to manual mode to control possibilities for pilots of an aircraft. They found out that intermittent operations of complex tasks in the cockpit are more effective using direct manipulation interface in a variety of dynamic, real-time systems. They showed that, when increasing the cognitive complexity of an interface, it adversely affects the resumption of its use after a period of time (Ballas et al. 1992).

Another challenging context, also explored through an CSCW lens, is that of fire fighting. Ramirez et al. describe how a combination of empirical work and prototyping in real fire fighters' training settings informed the design of the landmark concept to develop an indoor navigation system for fire fighters (Ramirez et al. 2012). Other difficult areas include the context of a paper mill. There, contextual research was conducted in order to understand work activities of production crews and the social and information infrastructure that support them (Auramäki et al. 1996; Robinson et al. 2000) and, subsequently, to inform the design of a collaborative interface. Furthermore, studies at several industrial assembly manufacturing units have been conducted to inform the design of a mobile support system for service technicians (Fallman 2003), ethnographic studies to understand working practices of print facility workers (Martin et al. 2007), and how a combination of ethnographic and human-centered design methods could inform the development of a CSCW system in a power tool organization (D'Souza and Greenstein 2003). More recent studies in the oil and gas industry were conducted to gain insights on the shift team of who is working in and across the industrial environment and the control room (Heyer et al. 2009; Heyer 2010).

Similarly, initial contextual studies have already been conducted in the car context through an HCI and CSCW lens. For instance, the contextual inquiry technique was used by Gellatly et al. to inform future automotive designs by the means of interviews which were conducted with the participants while driving (Gellatly et al. 2010). Another way to obtain naturalistic driving behavior is to make use of video data from vehicles in the field. An often cited example is "The 100-Car Naturalistic Driving Study" (Hanowski et al. 2006). Their goal was to obtain data on driver performance and behavior in the moments leading up to a crash. Therefore, they equipped 100 cars with video cameras over a span of 13 months. Their video analysis helped to understand crash causation and driver behavior. Brown and Laurier (Brown and Laurier 2012) use interactional analysis of video data from 15 naturalistically recorded journeys with GPS to understand the navigational practices deployed by drivers and passengers.

To summarize, challenging contexts beyond the office have already been investigated through an HCI lens by means of (observational) studies in the wild. However, to our knowledge, relatively little light has been shed on the factory and car context, especially in terms of identifying cooperation potential. In most of the cases in factories and in cars, the focus is on the individual user, namely, a single operator or the driver. However, as we will show in this chapter, cooperation happens in both contexts and could be additionally fostered by novel interface technology. In order to do so, we need to have an understanding of interaction paradigms in these contexts, and consequently there is a need for novel methodological approaches which allow us to capture the interplay of entities and factors in these contexts. In the following, we will present the semiconductor factory and the car as challenging contexts for HCI and CSCW research.

12.3 The Semiconductor Factory as Challenging Research Setting

The first exemplary nontraditional context we choose for HCI and CSCW research is the context of a semiconductor factory. The overall purpose of a semiconductor factory is to manufacture as many error-free integrated circuits as possible. A fundamental step during manufacturing is the processing of the wafers, which are thin slices of semiconductor material, such as silicon crystal. Wafers are typically combined into groups of 25 or 50 pieces and stored in plastic containers called "lot boxes." Each of these lot boxes has to complete a distinct path through the factory, during which it undergoes different processing steps (e.g., etching, exposure, etc.) performed on various equipment (i.e., the machines for processing the wafers). Many operators working on several different machines have to be coordinated to guarantee an efficient production process. From the point of view of single operators, it is not obvious what other colleagues work on and how the progress of the whole production process proceeds, as it is distributed over several halls and buildings. Understanding the factory as a collaborative socio-technical environment has the potential to develop new supportive interfaces that can enhance human-human cooperation but also human-machine cooperation, with a manufacturing robot. Thus, the overall aim of our research is to thoroughly analyze the semiconductor factory context to be able to redesign existing working routines and, therefore, develop novel contextual interfaces, which support cooperation between different (social) actors (e.g., operators, maintainers, shift leads, but also robots) over different departments, halls, and buildings. In order to gain this understanding, we need to apply and adapt methodologies from HCI and CSCW.

When researching the factory context, the biggest challenge we have to face is its complexity. Even though a semiconductor factory is a very controlled setting in terms of environment factors such as lighting conditions, dust particle control, and ambient noise, the interplay between the different actors and the working procedures is difficult to capture. At the factory with which we cooperate, the operators are relatively flexible in their activities, since they can decide which lot boxes to handle next.[1] This flexibility is often in contradiction to the normally high level of automation in a semiconductor factory. Therefore, a synergetic relationship between human operators and the surrounding technologies should be achieved by the means of "smart automation." A combination of different radio

[1]The company has directed its European subsidiaries towards the development and production of new technologies, which results in short production cycles and a high degree of flexibility within the whole production system, which increases its complexity for external observers.

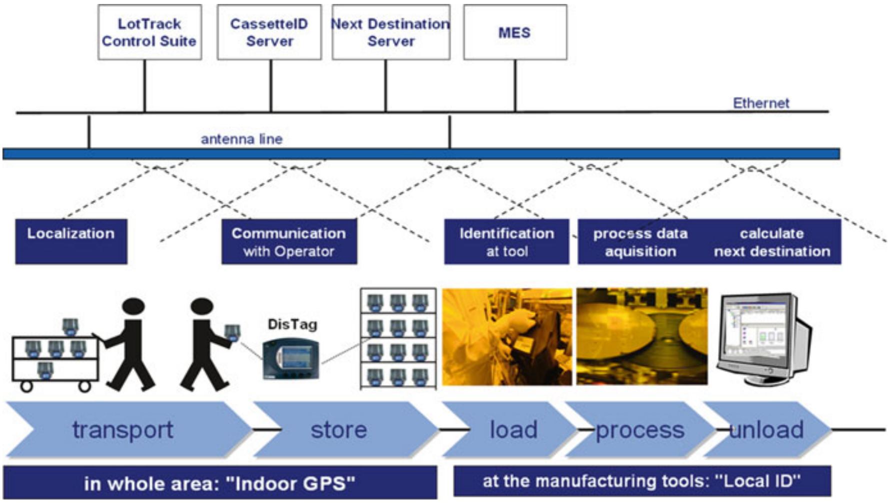

Fig. 12.1 Integration of smart automation technology in the production process in the factory

technologies with ultrasound technologies, innovative hardware (e.g., RFID), and software (e.g., message bus architectures) technologies have already been integrated in the production process to support operator coordination. Figure 12.1 gives an overview of how existing smart automation technologies are already implemented in the production process of the factory with which we cooperate.

Smart automation technology should enable that wafers run through the factory as fast as possible with little idle time, resulting in a maximized equipment load. As Fig. 12.1 shows, the general procedure is always the same in every section. (1) The wafers are stored in lot boxes in groups of 25 or 50 pieces and have to be transported to the right section. (2) They are then stored in the delivery rack where (3) an operator has to load the right equipment with the right wafer. (4) The wafer then gets processed, and (5) finally the equipment needs to be unloaded (afterwards the cycle starts again in the next section). Lot boxes are equipped with so-called DisTags. These DisTags are interfaces placed on each lot box providing several functions: identification, position tracking, announcement of the next production step, and error prevention by recognizing that a lot box was put into wrong equipment. The information provided by DisTags can, therefore, support the operators in their decisions, which tasks have to be conducted next and which processing steps should be applied to a lot box.

These production routines pose general challenges that come with the cleanroom environment. First, the factory is productive 24 h, 7 days a week, and 365 days a year. Second, various different tasks and tools implicate a high complexity. Third, special equipment such as cleanroom suits and cleanroom paper is required, and all electronic equipment (cameras, audio recorders, etc.) has to be carried in extra plastic bags. Exploratory research in the cleanroom is demanding, where work is conducted constantly in an air-conditioned area kept at 21 °C. There is only artificial yellow light, and operators are on their feet for 8 h, observing repetitive tasks. Researchers are also required (as all operators in the cleanroom) to wear the special cleanroom suit (see Fig. 12.3, second row, right corner), which makes it difficult to identify with whom one is speaking to. Acoustic quality is also limited, making it difficult to hear. Special paper and pens have to be used for documentation in the cleanroom, which are much smoother than conventional ones and produce fewer particles by friction while writing on the paper. Writing feels like using a thick ballpoint pen with waterproof ink.

These facts and the risk of industrial spying are the reason why only a few studies of exploratory nature exist in that area. Only a limited number of studies on HCI and user-centered design have been conducted in the context of the cleanroom so far (see, e.g., Lin et al. 2009; Mechtscherjakov et al. 2011). In these studies in which ethnographic and CI approaches were applied, only the working routines of operators were investigated. Other social actors in the cleanroom (e.g., shift leads, maintainers, or robots) were not at all considered. However, it proved to be useful for the requirement analysis phase of cleanroom prototyping to use observational methods to inform the design.

Another challenge is the size of the factory. As mentioned before, wafer production is separated into different processes, with the so-called recipe defining their sequence. In other words, different types of wafers follow a different path through the factory. The main standard processing procedures are conducted in the following different sections: chemical clean, photolithography, plasma/chemical etch, ion implant, and metal deposition/oxidation. Operators in these sections in general have to do the same basic tasks, but are specialized in the different processing steps. However, the sections themselves are again split into different subareas; for example, the lithography section is divided into coating and development, exposure, cluster, and photo-control. Photo-control in turn is a step which can only be performed by more experienced operators. In other words, the work in the factory is distributed over four halls (in total 19.282 m^2 cleanroom space), sections, and subareas, and the overall processing of wafers depends on the single steps performed by operators who are locally distributed over the cleanroom, and, therefore, the information is also distributed over various actors. This fact leads to special research challenges in every section, which again demonstrates the complexity of this research context and the necessity of becoming a domain expert before developing reasonable solutions for interfaces that can sustainably enhance cooperation between actors.

Subsequently, for our point of view, the semiconductor factory itself offers a huge potential for HCI and CSCW research to develop novel systems that foster cooperation between different social actors in the factory (operators, maintainers, shift leads, etc.) over different halls and buildings, such as intelligent guiding systems, feedback statistics which represent how single operator performance impacts the overall factory performance, and many more. However, we have to face several research and design challenges in order to gain sufficient domain understanding to develop useful systems for this difficult context and its actors

(Chamberlain et al. 2012). Therefore, we need to understand the semiconductor factory as a holistic concept, which is set up as a complex interplay between humans, interfaces, and (smart automation) technology.

12.3.1 The Holistic Factory as Cooperation Space

In contrast to offices where employees sit at a desk in front of a single computer, operators within a cleanroom have to move between several kinds of interfaces to gain all the information needed. This leads to the necessity of researching and developing communication interfaces, which accompany operators throughout the cleanroom and contain context-relevant information. From an HCI and CSCW perspective, the factory context can be considered as a triangle, which describes the potential interaction strategies in the cleanroom from an (1) equipment-specific view, (2) a unified interface view, and (3) a user-centered view.

The equipment-specific view is historically the first approach taken in the factory. In a semiconductor factory, there are five major process areas in wafer fabrication: chemical clean, photolithography, plasma/chemical etch, ion implant, and metal deposition/oxidation. Each of these areas consists of different machines with specific interfaces. Even within the areas, the different manufacturers use their own type of interface. This leads to a multitude of different interfaces in the cleanroom. As seen in Fig. 12.2, specific and inconsistent equipment interfaces can be identified within the factory with which we cooperate. From a user perspective, this leads to various problems. Users have to become experts in interacting with different interfaces and various interaction modalities. This leads to a reduction

Fig. 12.2 Equipment interfaces at the factory: the *first row* shows the heterogeneous signal lights of different equipment (depending on the manufacturer); the *second row* shows the heterogeneous interfaces, which can be used to control equipment

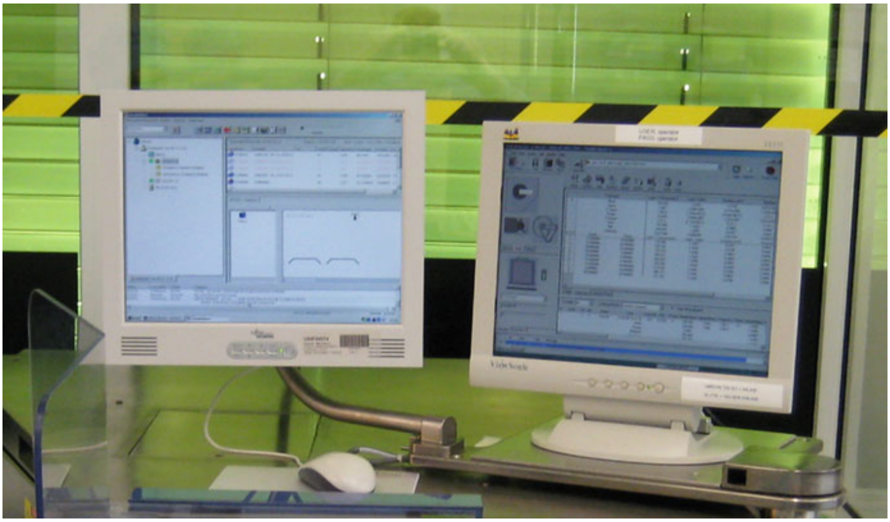

Fig. 12.3 The FabCockpit as unified interface for all kinds of equipment

in overall efficiency. An operator for the most part only knows the superficial commands and is unable to deal with difficulties or exceptions. Thus, specialists for each machine are required. New operators are confronted with a steep learning curve. To take up an analogy from computer science, this would resemble the era of mainframes, where only specialists are able to interact with computers.

The unified interface view is the next step in the development of the factory. The main idea is to unify the different interfaces of the equipment into one consistent interface. At the factory we cooperate with, this approach is partly already implemented. Every machine is coupled with a windows PC showing a program called FabCockpit (see Fig. 12.3). The FabCockpit looks exactly the same way for every machine. This leads to more flexibility, as operators can handle a wide range of machines. Also the ease of learning for new employees is improved. Yet this interface does not differentiate between the individual operators. At any time, all possible information is shown without taking into account either the interaction context or the user. Furthermore, the user only operates optimally on an individual level, not taking the entire factory into account, which is again a source of inefficiency.

The cooperative (but personalized) user-centered view is our future envisioned development for the factory. This view is focused on how a specific user and his working context can be linked with the working context of his/her co-workers (considering different roles, such as operators, maintainers, shift leads, etc.). The displayed information will be tailored for the individual within a specific situation taking contextual influence factors into account. We call this type of interface a "contextual interface," and its deployment in the factory should enhance zero-defect production by means of improved collaboration between the different actors in the factory. However, before we can develop these interfaces, we need to explore the context with suitable adapted methods from HCI and CSCW. In the following, we will present our approach.

12.3.2 Exploring the Factory

To gain insights into the context of the semiconductor factory and to establish a mutual understanding between university researchers and industrial practitioners, we used various observational methods, such as ethnography, contextual inquiry, participatory observation, and cultural probing. Intensive discussions about different styles of "ethnographic" research in HCI can be found elsewhere (e.g., Newman 2009; Dourish 2006) and are not in the focus of this chapter. In general, all methods presented here can be considered as "contextual" and "observational." They follow the most common HCI study design of "formative ethnographies" (Rode 2011), as they were done in order "to understand current practice or current practice surrounding technologies with an eye towards improving or creating new technologies." The different methods were intentionally chosen in order to suit the target group and the exploration aims. Overall, we explored four different main actors in the semiconductor factory:

1. Operators: the workers in the cleanroom who take care of processing the wafers
2. Maintainers: the workers in the cleanroom and the grayroom (i.e., the backstage of the cleanroom which has a higher particle rate allowed in which equipment can be repaired without disturbing the production line)
3. Shift leads: the workers who link production and maintenance work and structure the work of the shift cycles
4. Robots: they take over more and more routine tasks in the cleanroom and therefore change the working conditions for operators and maintainers in the factory. We took the view that they should be considered as acting entities in the cleanroom which, in some sense, collaborate with operators and so constitute a special artifact in the factory context

Table 12.1 shows an overview of the studies with their goals, applied methods, and their rational. As a detailed description of every methodology would extend the scope of this chapter, references to the relevant publications with details are added.

Studies researching the operators were conducted as ethnographies, where researchers actually worked like trainees in the factory to learn about existing systems and working routines in the etching and in the implantation department (Meschtscherjakov et al. 2010, 2011). Maintainers were in parallel studied with a contextual inquiry approach, as maintenance work is too complex to be understood in short-term ethnographic studies (Kluckner et al. 2012, 2013). In many cases, maintainers worked in production before they are skilled enough to change to maintenance work. We then decided to study shift leads, as we identified in our studies with operators and maintainers that shift leads often build the link between

Table 12.1 Factory study overview

Actor	Research goal	Method	Rationale	Reference
Operator	Understanding operators in terms of the interfaces, tools, and systems they use and the main tasks they perform	Three ethnographic studies	Three researchers worked as trainees in the etching, lithography, and implantation sector of the cleanroom. We decided that researchers are introduced to the work-life of an operator the same way as a new employee; however, co-workers were informed that the trainee is a researcher, who should explore the context in order to develop novel production interfaces	Mechtscherjakov et al. (2011)
Maintainers	Understanding maintainers in terms of the interfaces, tools, and systems they use and the main tasks they perform	Contextual inquiry	Two researchers accompanied 23 maintainers and observed and interviewed them in an apprentice/master constellation. As maintenance work is highly complex, and ethnographic approach would not have been the right choice for this group of actors. An inquiry with various maintainers, however, gave us the chance to learn about the reporting tool usage and the communication with other relevant actors in the factory	Kluckner et al. (2012) Kluckner et al. (2013)
Shift leads	Understanding shift leads, in terms of their main tasks and their quality, to link between different actors in the factory	Cultural probing	A creativity card booklet was distributed to 36 shift leads during job training. The booklet was filled in at home and returned by post. Our goal was to learn about the interplay between actors and overall procedures in the factory on a reflective level. Shift leads are the actors in the factory who could best provide an overview like that	Osswald et al. (2012)
Robots	Understanding robots: How are robots and automation technology experienced by the operators? Does experience change over time?	Participatory observation plus short questionnaire	One researcher observed the interaction of the operators with a robotic arm in the etching sector of the factory. Subsequently a short questionnaire on user acceptance aspects of the robots was distributed three times in order to observe a change in perception. As novel robotic systems are the most influential change for working routines in the production. It was relevant to understand on a behavioral and reflective level how the cooperation with these systems looks like	Buchner et al. (2012, 2013a)

operators and maintainers and are crucial for successful cooperation and production, but have very limited technology support for their work (Osswald et al. 2012). Finally, we explored human-robot collaboration in the factory in order to find out how the increasing deployment of robots in the factory is experienced by the operators and to identify possible changes in the cooperation between them (Buchner et al. 2012, 2013a). In the next sections, we will present an overview on our contextual findings followed by the overall methodological implications for the challenging factory context.

12.3.3 Special Context Findings

Besides developing redesigns for specific interactional problems and for specific actors in the cleanroom, our goal is to gain a thorough understanding of the semiconductor factory as a CSCW and HCI research context. This is of major importance for us, as we do not want to be caught in the trap of HCI research projects, which only "result in local solutions to local problems" (Hayes 2011); we want to build a descriptive model of the semiconductor factory from the empirical data gained in all our observational studies as "mosaic bricks" (see Fig. 12.4). We base our context model on the definition of Dey (2001), who coins context as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." To narrow that definition, our understanding of context takes into any contextual information of the semiconductor factory in account, which is relevant for an "interactive task" (meaning a task in which the user has to interact with a computing system in order to achieve a specific work step). The overall context model consists of three main parts: the *user/personal context*, the *application* context, and the *real-world* context. All contextual factors we have identified so far in our observational studies can be mapped on this overall context model for the semiconductor factory (see Fig. 12.4).

This context model should contribute to the existing understanding of collaboration contexts in HCI and CSCW by identifying and describing all relevant influencing factors prior to developing novel "contextual interfaces" that should foster cooperation between workers. Interface developers should be aware of potential influence factors, which might serve as a key resource for identifying why a new interface is successful or not; the context model thus serves as an empirically grounded design space.

All environmental factors (e.g., lightning conditions, ambient noise, etc.) are mapped to the environmental/physical context that affects the perception of the user (1). Work conventions and the reliability of a user interface are considered as relevant information for the user to perform a job correctly and are, therefore, mapped to the information context (2). Attributes, which characterize our target groups (e.g., computer literacy, basic education, work experience, etc.), are mapped

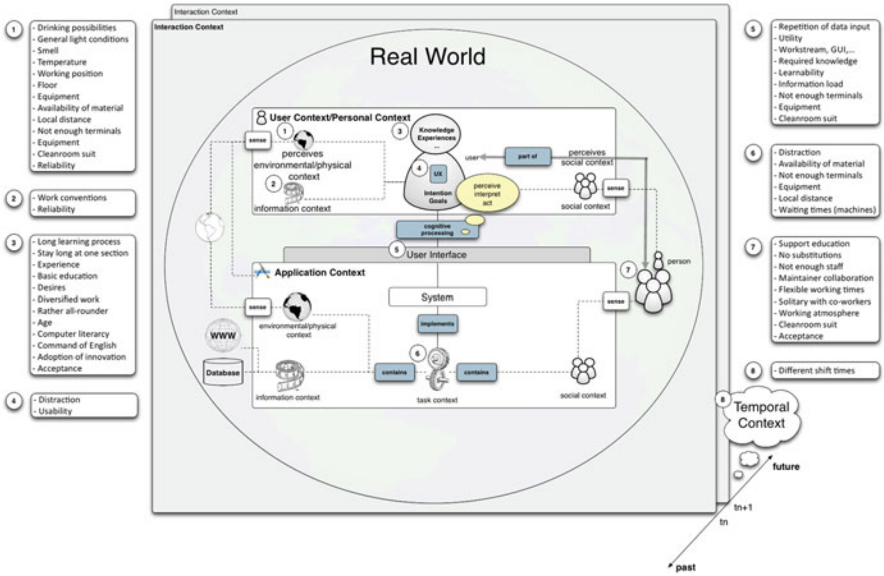

Fig. 12.4 Context model of the semiconductor factory through an HCI lens filled with mosaic bricks form the observational studies

to the personal knowledge and experiences of the user (3). Traditional usability aspects and distraction factors are mapped to the personal experience of the user (UX), as they influence how the user responds to a system (4). However, some of these aspects such as ease of learning, information load, and the heterogeneity of interfaces are also part of the user interface context (5). The architecture behind the interfaces and the core functionality of systems in the factory are mapped to the application context (6). The solidarity with co-workers and the working atmosphere are attributes of the group, which are mapped to the social context of the user and the other actors he/she has to work within the factory (7). Finally, regarding the temporal context, we have to consider the different shift times as well as that the perception and response towards a system might change over time (8).

Clearly, some factors have to be mapped into more than one group, as they have different specifications and influences. For instance, the cleanroom suit influences a series of context parts in this model. First of all, it has an impact on the way the environment is perceived (user/personal context (1)). The cleanroom suit also influences the social context, as it is hard to identify other people (real-world context (7)). Finally, it has an impact on the interaction with the user interface (e.g., reduced tactile feedback, limited field of view, etc., user interface (5)).

In general, the presented semiconductor factory context model does not aim for completeness; it should be considered as an abstraction of an interaction context through an HCI lens. We, thereby, follow the claim of Brooks, who argued that HCI specialists need to develop an appropriate abstraction that “discards irrelevant details while isolating and emphasizing those properties of artifacts and situations that are most significant for design" (Brooks 1991). This abstraction process shapes our thinking of the context, enables better designs of contextual interfaces for future, and eases the communication with our industrial partner.

Furthermore, the descriptive context model is added by relevant phenomena about the context derived from empirical observation, which builds our basic understanding for future HCI work in terms of prototyping and evaluation activities for the semiconductor factory. In the following, three phenomena are presented exemplarily.

1. Novice operators and expert operators perform tasks differently:
   (User/Personal Context)
   Novices are supposed to update equipment states and use tool-tip information offered in the FabCockpit. They are specialists only for selected tools and equipment. Experts train novices on the job, which is only possible in idle times. They consider their tasks as more sophisticated than general operator tasks and do not always trust system recommendations, but add their personal experience to decision-making processes. In other words, experts consider their experience as more effective than when slavishly following system advice.
2. Tasks differ in their complexity:
   (Application Context/Task Context)
   Lot delivery is a traditional task for novice operators, as it can be done correctly without support after approximately 1 week. Loading equipment with pre-assigned lots is also a classical novice operator task. Ambient distraction aspects (e.g., blinking equipment lights and equipment sounds) impact the task performance of novices during approx. the first 6 months.
3. Characteristics of human-human and human-system cooperation:
   (Social Context/User Interface Context)
   Shift groups first try to optimize their in-group performance and in a second step support other shifts. Training on the job is done by expert operators in idle times and is a key success element for overall productivity. Intelligent systems such as the DisTag are not considered to be fully trustworthy (a function of a more general distrust in the IT department). Operators with long experience often prefer established single systems as compared to novel integrated systems (e.g., configuring equipment directly over the equipment interface instead of using the FabCockpit).

Finally, the mapping of factors to the model helped us to identify knowledge gaps. As all our knowledge thus far was gathered through a user's viewpoint, we lacked knowledge on the application context. Knowledge in that area is of importance as it helps us to understand the constraints of prototyping interfaces better. This lack of knowledge needs to be filled by gaining insight in the system architecture of the interfaces, e.g., how the interplay between data basis work and where which information is stored. These are facts, which are important to know as they could affect the simulation of the context (e.g., in terms of timing aspects and information retrieval options) and the interfaces in the lab. Currently, we fill this gap with knowledge-transfer workshops with IT developers of the factory, in which the context model serves as communication basis. These workshops, moreover, give us insights into the historical development of existing systems and tools. Thereby we can close knowledge gaps, we are currently aware of in our semiconductor context model.

12.3.4 Methodological Implications

Our goal was to thoroughly analyze the semiconductor factory context to be able to redesign existing working routines and therefore develop novel contextual interfaces, which support cooperation between different social actors (e.g., operators, maintainers, and shift leads) over different departments, halls, and buildings. On spending time in the context as researchers, we found out that the "wilderness" of the factory is even more challenging than expected from a methodological point of view. Gathering data in the cleanroom turned out to be a challenge, as audio recordings can hardly be understood due to the ambient noise. Taking video footage is not allowed due to confidentiality agreements, and taking notes on cleanroom paper with cleanroom pens takes longer than normal handwriting. However, these are only the "practical" challenges. In the following, we will present our methodological lessons learned for all the studies listed in Table 12.1 above and, subsequently, describe our ideas as to how the next steps of iterative design (namely, evaluation of system and deployment in the cleanroom) could be conducted.

12.3.4.1 Gathering Observational Data in the Cleanroom: Lessons Learned

Several lessons are to be learned in relation to the efficacy of our enquiries. Clearly, we chose methods that we deemed best suited to achieving our exploration goals. However, each study method still involved advantages and disadvantages.

For the *ethnographic studies*, it turned out that the shift cycles are the biggest challenge, as the researchers could not adapt their day and night rhythm according to the shift cycles for just 1 or 2 weeks. However, seeing as many shift cycles as possible turned out to be important, as working routines change between shifts (e.g., the night shift is less stressful than the other shifts due to less work load and less operators in the halls) and as different operators work in different shifts (which implies an information loss, if one shift is missed out). The specific shift cycles our researchers were working in were the morning shift from 6:00 to 14:00 and the afternoon shift from 14:00 to 22:00. Additionally, it took the researchers 2–4 h to write down the notes for each day. Together with the 8-h shift work, this leads to a 10–12 h working day. We quickly recognized that this time schedule had a negative impact on the quality of the notes. First, shift work itself is already very demanding (constant concentration, high cognitive load, and unfamiliar cleanroom conditions), and second, there is too little time to take well-formulated notes. In other words, after a morning shift, the researcher has to write field notes after 8 h of demanding shift work. After an afternoon shift, the researcher was more likely to sleep and write the field notes the next morning.

Thus, in the second ethnography, we decided that researchers only work in the afternoon shift cycle, which was better suited in giving the researchers time for both working in the cleanroom and reflecting on it. In the first and second, ethnography limited themselves to keywords during the study and reworked them with the help of the audio records after every shift and after the completed field phase. This proved to be satisfactory, and the researchers had few if any problems of recall. The third ethnography completely waived field notes and only used the subjective memories combined with the audio files to fill identified knowledge gaps in the context model. The audio recordings, however, proved to be of utmost importance (despite their quality) as the work in production is characterized especially by monotonous and repetitive tasks, which are hard to remember. In order to respect privacy issues, the audio recorder was carried around visibly for everybody.

For future ethnographic studies, we plan to take into account the differences between the shift cycles (i.e., the different working routines for the operators and for the researchers). The ethnographic observations of the usage of our novel contextual interfaces in the actual cleanroom will be performed during the morning, afternoon, and night shift, whereas note-taking will be replaced completely by an audio diary, which will be transcribed and interpreted after the complete study.

Regarding the *contextual inquiry* with maintainers, it has to be mentioned that the work of maintainers is very different, depending on the department for which he/she is responsible and the functionality problems that can arise from different equipment types. Thus, it is difficult to explore "general" maintenance activities as these vary a lot between departments. Even for the departments in which we spent more time and accompanied several maintainers, a four-day contextual inquiry was not sufficient to come across all standard maintenance activities, and only a limited number of acute troubleshooting/fault repair activities could be observed. Moreover, maintainers are expert employees, important for keeping the 24/7/365 "zero-defect" production running; in other words, maintainers should not be distracted in their work and are only interviewed in idle times (which are very limited due to the requested standard maintenance activities). Subsequently, we did not get the chance to accompany maintainers with the highest skill level. We were, however, able to follow beginners and process managers, who have to use the same tools for reporting their work as maintainers. Our picture of all maintenance activities cannot be considered as 100 % thorough but provides a "good enough" insight into their usage of existing reporting tools (which are very similar over the different departments). We also conducted a reflection workshop with maintainers, managers, and process mangers, which allowed us to close knowledge gaps with experiences from different working groups. For future contextual inquiries with maintainers, we will more precisely specify the department of interest with our industry partner and, based on an expert interview with an experienced maintainer, define which main tasks need to be observed to gain a thorough understanding of the work routines.

Regarding the *cultural probing study* with shift leads, we learned a lot about the material we used. We intentionally developed a booklet with a large variety of probes and topics so every participating shift lead could find at least one topic of interest to fill in. However, we learned that not all of our probes could be filled in by every shift lead to the same degree, as not all of them have exactly the same work routines. Some shift leads are not working in production, but in the quality assurance or the laboratory. When we reported the results back to the shift leads, we got the feedback that the rather low response rate (only one third of the booklets were actually filled in and returned) can be explained by the fact that filling in the booklets at home was considered as an extension of the working day and that the very open format made it difficult to answer the questions. The shift leads preferred a short questionnaire (which we developed based on the probing results) in order to quantify the probing results. However, clearly this questionnaire could not have been developed without the probes, and we, as researchers, were satisfied with the quality of the data.

Regarding the *participatory observation* (i.e., the operators were aware that they are observed during their work) of operators interacting with the robots in the cleanroom, we learned about the necessity to have a technician accompanying us. Only with the additional comments and explanations of the technician was it possible for us to interpret the behavior of the operators (without disturbing them during their work) and also to understand the actions of the robot. However, the disadvantage was that operators felt even more observed during the work, as both a researcher and a company person "monitored" how they interacted with the robot. During the participatory observation, it became obvious that operators were not willing to discuss their real attitude about the increasing amount of robotic systems in the cleanroom (potentially due to the fact that they were afraid to be replaced by robots at some point). Therefore, we developed a supplementary questionnaire out of the observational data. The operators were willing to fill in this short questionnaire (with closed questions) that guaranteed them 100 % anonymity as it was directly sent back to the researchers and was not collected by the company. For future studies on robots in the cleanroom, we plan to keep this two-step approach of qualitative and quantitative data gathering. Currently, we are in discussions with the work council to collect video-data on how the operators interact with the robots over a longer period of time in order to have more observational data that can be quantified by the means of video annotation to explore usability issues of the operators when interacting with the robotic systems.

12.3.4.2 Evaluation of Cleanroom Redesigns: Field vs. Lab Trials

In addition to the methodological lessons learned from our requirement studies in the cleanroom, we had to make methodological considerations of how to evaluate novel contextual interfaces in terms of their ability to increase the cooperation between the various social actors in the factory. Clearly, natural interaction with our prototypes, such as an intelligent guiding system for the operators called "Operator

Guide" (Meschtscherjakov et al. 2010) and a mobile maintainer interface, which communicates the repair states of machines back to the operators, can only be evaluated in the "wild" and over a longer period of time to make ecologically valid statements. As it is understood by Rogers (2011), "in-the-wild" studies involve deploying new technologies in real-world situations and studying how they are actually used in this context, taking the fact into account that the physical and social context will have a critical effect on the usage. We aim to evaluate all our novel contextual interfaces at some point by the means of observational studies in the factory (taking into account the lessons learned, such as the need for expert discussions before the observation and the company of a technician to discuss behavior observations in parallel). A first "in-the-wild" study was already conducted to explore the actual usage of the Operator Guide and showed us unexpected usages and interpretations of the display (see Strasser et al. 2012).

However, we also want to evaluate the basic interaction concept and its iterations before we really enter the factory again (above all in order not to harm zero defect). Similarly, this poses a research challenge in itself, how to evaluate a semiconductor factory interface, without a factory. For basic concept evaluations, substitution tasks can be a reasonable approach (Osswald et al. 2012b), e.g., repetitive tasks, such as stapling chairs combined with cognitive tasks such as solving number puzzles can be used to "simulate" the working routines of an operator. However, substitution tasks can only help us to identify severe usability problems but cannot tell us anything about how the system supports actual operator tasks. Therefore, we needed to find a way to simulate the cleanroom in our laboratory. We reassembled equipment out of shelves (see Fig. 12.5/left) and

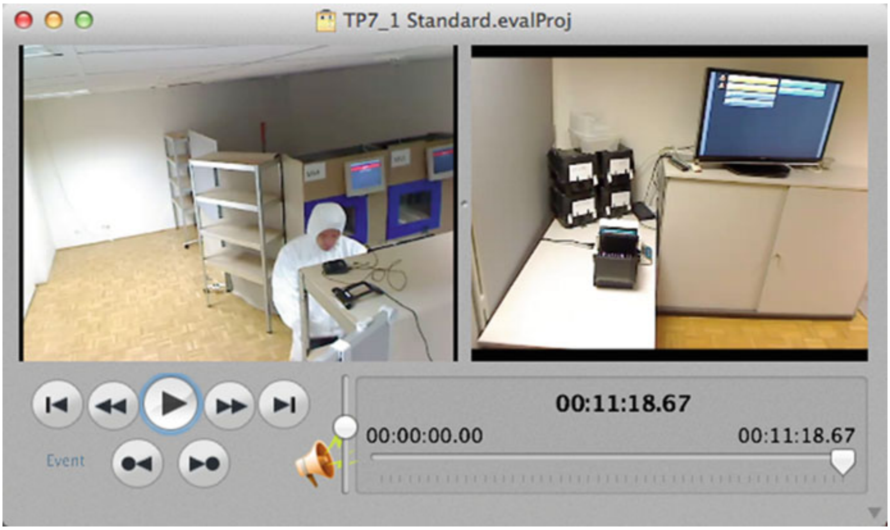

Fig. 12.5 Snapshot of the wizarding tool, which was used for the first lab-based cleanroom study; study participant loading equipment, reassembled out of shelves (*left*); cleanroom prompts and the Operator Guide display (*right*)

used real lot boxes as prompts. In combination with a self-developed Contextual Interaction Framework (based on the OSGi framework) for wizarding system states and logging performance data, we can simulate the working routines in the cleanroom (Zachhuber et al. 2012). Thereby, we built our own "HCI-semiconductor experience laboratory," which allows us to study redesigns before going back into the factory. By means of this system, we already successfully evaluated the Operator Guide in a laboratory setting (Strasser et al. 2012). However, another challenge that needed to be solved was the recruitment of representative study participants.

In the ideal case, study participants for our interface prototypes are trained cleanroom operators. However, as the cleanroom is not located at the same town of our research laboratory, it is difficult to recruit participants with this professional background. Thus, we developed the so-called proxy-operator concept as a methodological innovation for our interaction studies. Our understanding of proxy operators is a meso-level choice between people with no cleanroom experience at all (microlevel) and people who already have working experience in the cleanroom (macro-level).

In other words, the possible levels for interaction study participants could be summarized as follows:

1. Microlevel: Study setup uses elements of the cleanroom
2. Meso-level: Participants get introduced into the topic before every study
3. Meso-level: Panel participants (meaning a pool of participants who take part in several cleanroom studies over several years) take part in a cleanroom training before taking part in our studies
4. Macro-level: Participants who actually worked in the cleanroom before

We decided on the 3rd level and recruited a stock of 40 panel participants. Before their first study, participants got a training session about the tasks and behavior rules in the cleanroom. In every subsequent study they take part in, they have to fill in a questionnaire about their knowledge of the cleanroom and get an adapted training session before they take part in the study. Our long-term goal is to analyze this questionnaire material in order to assess the success of our proxy-operator concept. However, we are aware of the high degree of confounding variables in the approach due to the artificial setting in the laboratory, and therefore the results and its ecological validity need to be validated in comparative "in-the-wild" studies.

12.3.4.3 Integration into the Factory Software Architecture and Production Schedule

Another challenge for HCI and CSCW research in the factory is the integration in the production schedule and the existing software architecture of the factory (the manufacturing execution system (MES)). In phases of high-order volumes of wafers, novel systems clearly cannot be deployed in the cleanroom as this could negatively impact the "zero-defect" production rate. Due to the constantly high-order volume, novel systems can only be deployed during summer or Christmas time, when fewer operators are working in the cleanroom and fewer orders are taken by the company. However, the grayroom offers us a potential environment for "semi-wild" studies. The grayroom provides similar conditions as the cleanroom and is also used by the company to test novel equipment before being integrated in the production line. In other words, our novel contextual interfaces could be studied in the grayroom even under controlled experimental conditions with actual operators or maintainers without disturbing the "zero-defect" production. Another difficulty for us is that the company alone makes the decision as to whether one of our interface prototypes is robust enough to be rolled out in the factory, and we are obligated to follow their schedule. However, as soon as a system is deployed, valuable logging data is collected by the manufacturing execution system, which provides insights in how our systems change productivity in terms of quantitative data. Nevertheless, traditional usability testing or controlled experiments in the cleanroom will hardly ever be possible in this specific context. Therefore, we will explore the actual usage of the systems again by observational studies, such as ethnographies or contextual inquiries.

12.4 The Car as Challenging Research Setting

In addition to the factory, we have chosen the car as a challenging environment for HCI and CSCW researchers. Driving a car can be dangerous, and the driver must not be distracted – that is why collaborative aspects from other domains might bring fruitful ideas into the automotive context. So far advanced driver assistance systems (ADAS) are mainly technology driven and arguably fail to make use of social interaction in the car, and between different drivers. ADAS help us to keep within the lane (e.g., lane departure warning system) or even to change it (e.g., Lane change assistance); they assist us in dangerous satiations (e.g., blind spot detection, collision avoidance system), or they monitor our status (e.g., driver drowsiness detection). In addition, however, HCI research has recently started investigating the collaborative nature of driving (Forlizzi et al. 2010; Esbjörnsson et al. 2007; Inbar and Tractinsky 2011). Drivers are in a steady negotiation process with other car drivers, and traffic behavior is a social interaction (Juhlin 1999). Understanding the car as a collaborative social space has the potential to develop new ADAS, which support driver-driver collaboration, as well as driver-passenger collaboration. We need to understand ADAS as social embedded systems in order to increase acceptance and user experience. For exploring and understanding the automotive context in this sense, we need to apply and adapt HCI and CSCW methodologies.

When researching the car, apart from safe driving simulators with traditional HCI and CSCW methods such as ethnographies, researchers have to carefully reflect upon the dangers the research itself can have for the driving situation. Driving a car can be dangerous not only for the driver but also for passengers, the researcher included. Moreover, the research itself could potentially heighten risk for all parties. Car accidents can also be expensive. Questions such as "Who will pay for repair costs?" need to be discussed. Basically, the liability of the people involved needs to be specified. In addition, there might be regional legal differences that need to be considered. What makes interventions in the car dangerous, especially for the driver, is the fact that a driver always has a primary task: to drive the car safely from one place to another. Interventions in the car have to take into account that they compete with the primary driving task. This task is usually not interruptible.

At the same time, the car offers some methodological affordances. Cameras can be very easily mounted, and electricity for those and for potential systems can be pulled from the car itself. But again, the legal regulations/restrictions of the study location need to be considered. Also, power supply is often very instable in cars (e.g., the power supply is interrupted when the ignition is turned on or off). When mounting observation systems into the car, it has to be carefully checked that these are secured in a way that they become loose or detached when taking a sharp turn or when the car breaks. Similarly, they cannot be positioned in a way that they distract or impair the sight of the driver or act in the form of a safety hazard (e.g., obstruct the airbag).

In addition to safety and legal aspects, the effect of the presence of a researcher needs to be considered. It might be that we, as researchers, want to be present in the car during a study to take notes and interact with the driver or the passengers. In such cases, we also need to understand how the car in many ways offers a very limited space. In such limited spaces, we do not just affect the study from the official role researchers have. Researchers in the automotive domain can be seen as explainers, facilitators, encouragers, or mainly as technical support as discussed by Johnson et al. (2012). However, we can also affect the social space within the car during a ride. In order to reduce researcher participation, many studies use remote techniques such as video ethnography (e.g., Brown and Laurier 2012) to gain insights without being physically in the car.

In addition to these challenges, the car is typically a moving object. From a researcher's point of view, this can cause some practical problems, such as shakiness, constantly changing lighting conditions that may affect video and audio recordings, difficulties with note-taking, etc. When conducting studies in natural conditions (i.e., noncontrolled settings; journeys which would have taken even without the study), timing could also be challenging. When a researcher is present in the car, questions arise such as how will the researcher determine when and where the trip should start and end, how will the researcher get to the starting point in time and then back again, whether or not the start and end of the video recordings of a remote study should be automatic or done by the participant, and what should happen if the deployed prototype or the video system fails.

Another challenge of automotive studies is recruiting (appropriate) participants. If not investigating specific user groups, such as taxi drivers or other professional drivers, this can be tricky, as drivers are generally a very heterogeneous group. Researchers thus often use convenience samples that are reused several times, but do not represent the true characteristics of drivers. It is further not unusual to recruit students or people from the local area with specific characteristics (e.g., own a driving license for at least 3 years). Nevertheless, automotive studies often recruit from specific user groups who use their cars for business purposes such as commuters (Ben-Elia and Ettema 2011), taxi drivers (Phithakkitnukoon et al. 2010), and policemen (Hampton and Langham 2005). Thus, the pool of potential participants can be limited or untrained. Recruiting new drivers or older adults might be easier (since these are larger groups), but safety issues have to be handled since beginners have more cognitive overhead in operating the car, and older drivers are more likely to have restricted vision and longer reaction times. Some researchers have addressed this issue by conducting their studies with user groups that are easier to access, while still aiming at a generalization of their results (Esbjörnsson et al. 2007).

These challenges and opportunities make the car a challenging collaborative place to be studied in situ – where the action actually happens. This is why we need to tailor existing HCI and CSCW methods to this very specific context and develop new methods in order to understand user experience in the car. So far, we have been focusing – like most other research in automotive user interface design – on the driver. However, the car offers more than just driver interfaces. To fully understand the car as a design space, we need to look beyond the driver (e.g., the role of children in the car (Hoffman et al. 2013)). We need to see the car in a holistic way where collaboration and negotiation routinely happens. Inside the car, the driver often collaborates with passengers in operating the navigation system or handling the entertainment system. Outside the car, drivers are cooperating with each other to ensure a safe and smooth traffic. If this collaboration fails, accidents may occur.

12.4.1 The Holistic Car

In order to make technology in the car more controllable and to reduce workload and stress, while simultaneously enhancing user experience in the car, we have to understand the car in a holistic way (see Fig. 12.6). We need to understand how contextual influences are related to different user experience dimensions and how they influence the car design space. Additionally, we need to address both

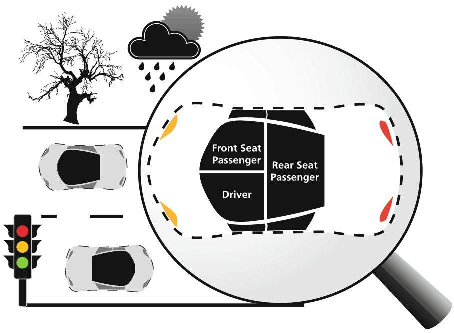

Fig. 12.6 The holistic car consists of three interconnected areas: the driver, the front seat passenger, and the rear seat passenger. These areas are again highly linked to the context they are currently in, shaped, for example, by other traffic participants and environmental characteristics

passengers and users outside of the vehicle. We need to understand the social nature of the car by identifying collaborative behavior inside the car as well as between drivers. To address the car more holistically, we propose two things.

First, we need to understand the interior. The car can be said to consist of three interrelated spaces: the driver's area, the front seat passenger area, and the back seat area. The last two areas, we suggest, have not yet been sufficiently researched from an HCI and CSCW perspective. Front seat passengers traditionally can be regarded as copilots. They help the driver in navigation tasks, and they can support the driver in operating navigation devices or the entertainment systems. They may even act as an additional pair of eyes in the primary task of driving. Passengers in the back seat are less likely to do so, for obvious reasons. Nonetheless, they interact with the driver to a certain extent. They might use smartphones to access information needed by the driver, or they may want the driver to perform certain tasks for them (e.g., switch the radio station). Collaboration and negotiation outside the car is done constantly and often implicitly. When the car in front of me brakes, I have to brake too. Indicator lights signal an intention. Horns call attention. These actions are highly collaborative. Thus, social systems, which are formed within the car and with its surrounding (e.g., other cars, other road users, surrounding infrastructure), cannot be left out when trying to understand how technology is used in the vehicle and how it should be designed in the future.

Second, we claim that, especially when focusing on contextual and cooperative user experiences, automotive interfaces have to be researched in the context, in which they will be used. While this also applies to other areas of HCI, context in the highly mobile automotive area is more unstable and dynamic than in other HCI domains due to the high speed with which vehicles are moving and the diversity of situations they are used in. In situ studies are the only way of allowing an investigation of how things happening around the car influence what happens in the car. At a first glance, it appears obvious that a vehicle is a very enclosed and private space that hosts interactions within. We are, nevertheless, convinced that the borders between interaction within the vehicle and interaction with the exterior are highly blurred. While simulator experiments have a high value when, for example, trying out prototypes of new interaction modalities, they often miss aspects of contextual influences as well as surprising and unexpected events.

Automotive research "in-the-wild" not only allows us to understand the influence of what we call "environmental" context but also the pre- and post-usage experiences that shape their goals and expectations towards technology. In one of our studies, for example, we came to a new understanding of the concept of distraction in the vehicle. Usually, efforts are taken to reduce distraction (from the road); however, we discovered distraction has a more ambivalent status and is often linked to events outside the immediate trip (e.g., angry discussions with the girlfriend). This richness of contextual aspects cannot be sufficiently represented in simulator experiments. Although context can also be prototyped in simulators, the diversity of situations is so high that sufficient representation in a simulator cannot be achieved. In conclusion, an in-depth understanding of users' experiences can only be achieved in the original context they evolve in (Law et al. 2008).

12.4.2 Exploring the Car

In order to grasp the car as a holistic space, we so far have conducted seven contextual studies in the car. They contribute to a broader understanding of the car as an interaction design space (see Table 12.2 for an overview). These seven studies focused on the driver, the front seat passenger, the rear seat passengers, and the interaction in between these spaces. For the studies, we used different methods with different degrees of researcher participation and technological support.

Studies researching the driver and driver-related tasks as well as driver user interfaces include three studies: a contextual inquiry with the focus on interaction with multifunctional rotary knobs (Neureiter et al. 2011), an ethnographic study experiencing drivers in traffic jams, and an adaption of the experience sampling method to gain insights on the relation between context and user experience factors (Meschtscherjakov et al. 2012). We conducted two studies focusing on front seat passengers: an ethnographic study observing the interaction between drivers and front seat passengers (Gridling et al. 2013) as well as a cultural probing study at the gas station to inform the design of the future front seat passenger design space. The rear seat space as third area was researched in two studies: a cultural probing studies utilizing a variety of probing materials to get inspiration for future interfaces in the backseat area of the car with a special focus on children as well as an exploratory study where we deployed and tested three prototypical games for children sitting in the back seat.

12.4.3 Special Context Findings

The in situ studies provided us with a huge amount of scientific findings, some of which are well known; others of which offered some deep insights into the nature of cooperative experiences in the car for drivers and passengers. The various studies provided us with inspiration for new ideas and novel prototypes. In this section, we present the most significant findings from our studies.

1. Primary tasks in the vehicle

Most research in the automotive domain still applies Geiser's distinction of tasks in the vehicle into primary, secondary, and tertiary tasks (Geiser 1985). Within our studies, we found a transition from the traditional sense of primary tasks (i.e., controlling a vehicle) to a more value-sensitive definition of primary tasks (e.g., staying in contact, having a good family time). While driving a vehicle should be the main focus of the driver, we as researchers have to be aware that it may not be the first priority for the person behind the wheel – at least not consciously. As our studies showed, drivers are often not aware of risky situations when being distracted from driving. In their mind, so-called secondary tasks (e.g., entering a destination into the navigation system, making a phone call, changing the radio station)

Table 12.2 Car study overview

Space	Research goal	Method	Rationality	Reference
Driver	Understand how driver uses central multifunctional systems and which contextual influences exist	Contextual inquiry (CI)	Participating in trips helped us to gain a first sense of drivers' tasks and contextual influences; a one-on-one observation and context-dependent inquiring was chosen to focus on the driver	Neureiter et al. (2011)
Driver	Investigate users' behavior and technology usage in rush hour traffic	Ethnographic study	Rush hour was a particularly interesting field identified in the CI, showing a highly diverse usage of technology and improvement potential; we used a video-supported ethnographic study to be part of peoples' daily commute	
Driver and passengers	Investigate the drivers' experiences and their relation to contextual parameters	Experience sampling method	The experiences and contextual influences that the CI had brought up were investigated in more detail collecting quantitative data more widespread; this was possible without researcher participation through experience samples	Meschtscher-jakov et al. (2012)
Front seat	Investigate how an interactive system could support or substitute front seat passenger assistance	Ethnographic study	Finding that passengers are a main source of support and distraction, we collected assistance situations and the context in which they happened, as well as related aspects of user experience by taking part in trips with two or more passengers; we utilized a traditional ethnography (without technological equipment) to live the experience without distracting natural behavior	Gridling et al. (2013)
Front seat	Investigate front seat passenger experience with their space in the car to deduce design ideas for future interfaces in that area	Cultural probing	Based on the findings in the ethnographic study, we wanted front seat passengers to probe their view on their space, seeing how they could imagine interfaces in this space to be like; cultural probes were distributed at gas stations to get a broad range of inspirations	Osswald et al. (2013)
Rear seat	Identify technology usage on potentials for future technology in the rear seat	Cultural probing	The advantage that no researcher has to be present in a probing study was necessary to help us open the rear seat space for research. Including families as example user group, we investigated their use of the rear seat and related technology with a variety of different probing materials	Wilfinger et al. (2011)
Rear seat	Design mini games that make sitting still in the rear seat a fun activity	Explorative design study	Applying findings from the probing study; kids should be given tools for diversion that improve the situation of everyone in the car; game prototypes helped us exploring the concept of sitting still while traveling	

becomes the primary task in terms of conscious relevance. Steering, accelerating, and breaking are often unconscious activities. This can be dangerous when the interaction with technologies in the car becomes too distracting. Acknowledging that modern vehicles are more than tools to get from one point to the other but tools to help users pursue their goals will support a less function-oriented design of technology in the vehicle.

2. Passenger-to-passenger interaction

Technology in the vehicle, to date, is very driver-centered. We believe that this is due to the high amount of trips with only the driver in the vehicle. Nevertheless, our experience sampling study showed an average of 1.52 people in the vehicle per trip, making the potential effect of passengers in the vehicle significant. Especially in the ethnographic study on front seat passengers, we found that they are a major source of assistance as well as distraction. We have investigated how front seat passengers do actually assist drivers (e.g., cleaning a steamed-up window) in a collaborative and cooperative way. Front seat passenger wants to be more involved in the driving task itself (e.g., monitoring the speed of the car or assisting with the navigation device). We have found that the balance between sharing information and being in control is crucial for a positive collaboration experience. Similarly, the rear seat cultural probing unveiled the positive and negative effects that the condition of passengers can have on everyone in the car. We, therefore, see the driver as administrator, being the most important user of the facilities in the car. The driver, for example, needs to be able to control technology usage in the rear seat while maintaining the driving task. The passengers, on the other hand, have a high amount of free resources they can use to assist the driver but which are also a source of boredom. We, therefore, see the necessity to include all passengers in the car into the driving task, based on their abilities and interests.

3. Context awareness

Context awareness has been a central concept in the efforts to improve in-car interfaces (see, for example, Bellotti et al. (2005)). Most approaches nevertheless aim at reducing cognitive workload by making systems context-aware, leading to less distraction and an increase in safety. While this is valuable, our results indicate that this approach does not go far enough. As in other areas of HCI, user experiences are very context-driven. In the vehicle, where contexts are highly dynamic, context-aware interfaces therefore also have to include the effect of changing context on UX. Driving through an unknown area in the dark, for example, can have a negative effect on perceived safety and cause anxiety. A navigation system should be aware of ambient lighting when guiding a driver through an unfamiliar part of the town during the night. Trip destinations and purposes have a major influence on how people perceive their trip. The studies conducted showed only a small fraction of possible contextual influences, but what we see is that strong efforts have to be taken in understanding the overall effect of context on the driver beyond distraction and workload. In a current study, we aim at investigating the effect of short-term pre-trip experiences on the perception of a trip in the vehicle.

4. Driving as a chain of plastic episodes

Based on the results of our studies, we propose a new perspective on interaction with automotive user interfaces, based on the "plastic" metaphor introduced by Rattenbury et al. (2008). Researching mobile computers, they refer to "plastic" as a term describing technology which allows users to fill opportunistic gaps, making the plastic time slots shrink and expand until interrupted. Interaction with in-vehicle systems have mainly been seen as continuous, having a constant level of distraction from the road. We found users to be highly flexible in how they interact with technology, routinely judging whether it is safe to interact with technology in a certain moment or not. Granted that these judgments were not always correct, it still shows the high potential of technology to support users in adopting a safer usage behavior based on "plastic" episodes, which allow a higher distraction from the road than others. Alt and colleagues (Alt et al. 2010), for example, propose to use contextual information to enable micro-entertainment in cars. They suggest anticipating how long a car has to wait in front of a red traffic light and fill this plastic time with entertainment snippets.

5. Smartphones on wheels

Many people are nowadays experienced with smooth interaction on smartphones and tablets. Multi-touch gestures and the immediate feedback of the device and high-resolution screens have, however, exaggerated expectations for these technologies. In the distraction study, we witnessed the negative effect on user experience of a resistive touch screen (no multi-touch, slow reaction time) when people expected the seamless interaction of a touch screen as used in most smartphones. In addition, people are used to being connected all the time via their smartphones to their social peers. They expect to be able to use text messages, Twitter, and Facebook, etc., all the time. They expect this connectedness also in their cars. Since production cycles for cars are significantly longer than for mobile phones, industry has to struggle with outdated technology in their cars. To enhance user experience beyond usability, these expectations have to be considered.

6. Make driving and riding more fun

Finally, we propose that both driving a car and riding in a car could be made more fun without making it more dangerous. Our explorative design study on making sitting still in a car for children more fun revealed significant potential. We experienced that sitting still could be actually fun when fostered through a playful design. This approach is not only true for children and/or the rear seat but for the whole car. We envision making driving safe or eco-friendly more fun and also enhancing passenger experiences. The driver's working place as well as the design space for front seat passengers and rear seat passengers offers huge potentials for future contextual "in-the-wild" studies.

12.4.4 Methodological Implications

Beside our empirical mosaic findings on the car context, we also recognized a number of methodological implications from our automotive "in-the-wild" studies. In this section, we summarize these implications and answer issues raised in Sect. 12.4.2.

12.4.4.1 Use the Automotive Context

In general, we found experiences in the vehicle to be a study topic that participants can easily relate to. People feel comfortable in sharing experiences with their car; it is something they use often, and it is easy to have an opinion or a good story about it. The same is true when communicating the study topics to the participants. Similarly, words that describe parts of cars, trips, and context (e.g., traffic) are often used in everyday language, making it easy for participants to express themselves. We also found the car to be a good space to work with children, since it is a familiar area (especially when the family car is used).

When studying interactions in the car, we found it to be beneficial to make use of what is imminent to making trips with a car. As with other researchers (Kern and Schmidt 2007), we, for example, found the break when filling up gas at the gas station to be an ideal moment for a survey, an interview, or the start of a probing study. We also found that other aspects of a trip might be utilized as new methods to research the automotive context. For example, when people take a trip (especially abroad), they may write a postcard to their family and friends at home. We suggest using this tradition for research purposes. In one of our probing studies, we asked participants to write a postcard "home" and express their experiences during this trip in relation to the car. When recruiting participants for automotive "in-the-wild" studies, we suggest being provocative and innovative. Gas station or garages are places where many car drivers can be easily observed or interviewed. Car retailers and online car sharing platforms also provide a pool of potential participants.

Although the car is restricted in some areas such as space, it also offers an infrastructure for studies "in-the-wild" that support research. The car itself provides a high amount of data that can be used for studies and prototypes. Speed, GPS, or throttle position provides rich input for interactive systems while allowing the recording of user behavior. Bringing cooperative technology into the car, however, is especially challenging, given potential drain on power and the possibility of, for instance, blown fuses. These potential breakdowns require at least an extra study assistant to be present, raising the effort that has to be invested.

In our studies, we found low-tech study materials, such as postcards and notebooks to be valuable. Cup holders are a well-suited place to store this kind of study material. Giving users the possibility to take the materials with them, nevertheless, did not prevent users from forgetting about the studies. We do not have any proof that this is a more severe problem in the car than in other spaces, but we certainly became aware of the need to remind participants of their study tasks.

12.4.4.2 Complexity of Automotive Studies

The car is a space eminently suitable for researcher involvement. The placement and position of participants in studies is very stable; it is, therefore, easy to conduct observations. Nevertheless, having a researcher taking part in trips requires some effort. On most occasions, researchers have to join at the beginning of the trip, travel with the participants, and, afterwards, make their return on their own. Research in the vehicle with participating researchers, therefore, creates a negative ratio of time in the study situation to time needed to travel there and back – an issue that technology-supported studies can solve. Unfortunately, the usage of recording equipment is challenging since lighting conditions rapidly change in the vehicle and the recording of sound is interfered by the ambient noise.

As well as the rapidly changing contextual factors influence research "in-the-wild"; interaction in the vehicle is also very season-dependent. Results of our rear seat probing study, for example, would have been different in the winter compared to the summer, where long vacation trips are made during hot weather. Both long-term and short-term contextual changes make conducting automotive "in-the-wild" studies a complex task – especially when researching the influence of context-dependent factors such as weather or traffic density.

Safety is a major concern in vehicles, making them a sensitive research environment. The main threat is that participating in any kind of study activity distracts the drivers from the road. One suggestion is to use spare time during driving when prompting drivers (e.g., during a traffic jam or in front of a red traffic light). Another possibility would be to use audible input and output for asking questions and gathering answers. Additionally, study equipment has to be secured and cannot be used if it causes a threat in case of a technology failure or obstructs safety measures (e.g., emergency braking). Researchers have to make sure that their equipment must not be the source of distraction or danger. It must be safely attached to the car and no equipment can be unsecured. Participants should be able to use the prototypes extensively prior to the ride.

Nevertheless, even when a high amount of countermeasures are taken, we are always alert to the possibility that we are creating difficulties in the automotive domain. Choosing the car as "wilderness" for research activities can be challenging, when safety has to be addressed without muting creative ideas that do not conform to current interface norms (Greenberg and Buxton 2008). Regarding liability and ethics, we suggest that participants should be made aware of the fact that safety is the most important aspect during an automotive in situ study and that all regulations must be complied with during the study, although an element of risk always remains. Researchers should be aware of this fact.

12.5 Conclusions

In this chapter, we presented two difficult and challenging research settings for HCI and CSCW, namely, a semiconductor factory and a car. We explained the general challenges which both contexts pose for exploratory research through an HCI and CSCW lens, such as environmental constraints (e.g., cleanroom conditions in the factory and limited space in the car). Then we presented our view on both contexts as cooperation spaces and how we tried to approach them with various different research policies. We used a set of different requirement methods (ethnography, contextual inquiry, cultural probing, and a participatory observation) in both contexts to gain an understanding of the different actors, their interplay and needs for cooperation, and the environmental conditions. Based on this contextual analysis, we derived empirical mosaic bricks with which we could describe both contexts in a holistic manner. These descriptive context models for the factory and the car should contribute to the existing understanding of collaboration contexts in HCI and CSCW by identifying and describing relevant factors prior to developing novel "contextual interfaces" that should foster cooperation in these contexts.

Moreover, we presented other salient issues in these challenging contexts, namely, the methodological lessons learned from the exploratory studies, as well as the challenges studies of future contextual interfaces will pose. This includes aspects such as lab-based studies within a "simulated" factory or car context and the integration of our work into the production cycle of the factory. Our implications have an influence on traditional contextual design and evaluation assumptions in HCI and CSCW. We suggest potential solutions that might also be used for other challenging domains, such as air planes, healthcare settings, public spaces, etc. We experience constraints in these contexts not only as a challenge but also as an opportunity to develop new interaction designs. Sometimes limitations can inspire through their challenging nature. The vision here is to better understand how to make use of the beneficial constraints for interaction design and how to cope with hindrances (Fuchsberger et al. 2014).

However, in these challenging contexts, close collaboration between HCI researchers and our industrial partners was crucial as they were the "context-holders." By this we mean that they provided us with knowledge about the context as well as access to it. For example, to study the factory context, a researcher needs to gain access to the cleanroom and actual operators. In the automotive context, it is crucial that a researcher gains access to the newest technologies in order to study them. We argue that the importance of a close collaboration between context-holders and researchers is important in most challenging contexts and the resulting collaboration could be beneficial for both partners. We explored two contexts, which have received only little attention from an HCI and CSCW perspective to date, with a view to the redesign of systems to optimize working routines for different actors. In other words, even if these observational studies in the wilderness of a semiconductor factory and a car denote a huge effort for both parties, its outcome justifies its effort.

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