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The co-evolution of taxi drivers and their in-car navigation systems

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Abstract. The recent market success of in-car navigation systems creates the opportunity to investigate the appropriation of location-aware systems outside laboratory settings. Through ethnographical lenses, we study how this technology changed the practice of a massive community of its early adopters, the taxi drivers of Barcelona (Spain) and, specifically, their exploitation of pervasive geoinformation. The results show co-evolution: taxi drivers adapt to their in-car navigation systems and adapt them to their needs; in particular, there are evidences of an alteration of the learning processes and of technology appropriation to reduce stress rather than to improve efficiency. We argue that these findings can inform the design of next-generation location-based services.

Keywords: Satellite navigation systems, human-computer interaction, co-evolution, qualitative field study

1. Introduction

The recent popularization of in-car navigation systems (Satnav) is due to the maturity of Global Navigation Satellite Systems (GNSS), to the improvements in hardware (e.g. in processing power, screen size and resolution), and to advances in the collection and visualization of geographic information (e.g. in-vehicle sensors, navigable map databases). The resulting devices meet a need of drivers to enhance the safety, comfort and efficiency of their travel. In Japan, where the technology has been available for more than ten years [1], millions of vehicles have got systems installed. Confirming the projections made 10 years earlier [2], a recent market research study stated that one in six (17%) U.S. adults currently own or use a GPS location device or service, and 33% of them use it in their vehicle [3]. This is the first massive adoption of a location-aware system[1], which, however, comes along with poor integration of the technology into the driving practice. For instance, as early as in the late nineties, five years after its introduction, the Japanese transport ministry already identified accidents caused by drivers distracted by their route guidance systems and by problems due to inaccurate mapping information or ambiguous directions. The latter limitations have been widely experienced[2]: only 15% of the participants in a survey thought that the routing instructions generated by their navigation systems were always completely reliable [4].

Some studies have dealt with reducing the problems from a technical issues point of view (see [5] for a review of the challenges), or enhancing the delivery of location and navigation information [6], or a more appropriate visualization [7] within the constraints of mobile devices [8]. These technological and usability investigations reveal discrepancies between the technical

[1] We term "location-awareness system" a system that provides facilities for orientation and localization.
[2] A survey of 7380 members of the British Automobile Association (AA) revealed that 30% of respondents said that their satnav had taken them to places they did not want to go, while 44% disagreed with this statement.

implementation and the social requirements of location aware computing. Ackerman [9] labels such problems as a 'social-technical gap'; a divide between what must be socially supported and what can be technically supported. Specific examples of gaps in the use of location-aware applications are experiences of information uncertainty, of interaction ambiguities, of confusion on the user's intention, or of frustration due to time lost. These gaps pose new design challenges in location-aware computing that are hard to solve. Parts of a dreamt up perfect system must be ignored to provide a working solution with new opportunities for user's engagement with the environment; this trade-off originates a lot of the tension between "technically working" and "organizationally workable" systems in any given implementation [9]. In fact, interface designers will increasingly have to wrestle with this tension to match the capabilities of sensors and the shifting applications requirements [10].

However, the imperfections in terms of bugs and glitches are notorious and yet largely accepted too as a routine part of the 'conveniences' of computers [11]. Users massively buy Satnav devices in spite of their failings. In fact, it seems that drivers develop a new 'Satnav literacy' to respond to a certain 'spatial anxiety' when finding their way through an unfamiliar environment [12]. More precisely, as argued through this paper, Satnav users adapt to their systems and adapt their systems to their needs. This co-evolution has been theorized and argued in several HCI contexts [13, 14, 9], and might be traced in the past, as, for instance, in the Mercator map projection, which simplified navigation calculations, whose introduction was an act of tool adoption and user creation [15].

Our study, based on qualitative observations and interpretations of a field study, shows aspects of how the co-evolution of drivers and in-car navigation systems takes place: the intertwined adaptation of Satnav systems and driver's practice is mainly structured as a transformed ecosystem of artifacts, while drivers use Satnav in unpredicted ways to reduce their anxiety and learn their workspace, the city and its environments; and their use might lead to a potential reduction of the social interactions in the car.

From this observation and understanding of actual use and co-evolution of people interaction with location-aware technologies, and keeping the needed delicate balance with predicting how novel technologies support a real human need, we discuss how the results can be valuable to designers of next generation systems. For instance, exploiting intelligent use to fit better users' needs, if the system is capable of only partial satisfaction. In our study, we describe how users of navigation systems assess the quality of the geoinformation, as we believe there is valuable design knowledge to be learnt from the appropriation of imperfect technologies and how the technologies evolve with users' practices.

After introducing the context of our ethnographic work, we discuss research related to the appropriation of mobile and positioning technologies, and its implications. Then we present our methodology, describe and analyze our observations, comparing them with closely related work and finally draw some implications for the design of future location-aware systems. We conclude with considerations on the results within the research on co-evolution mechanisms.

2. Context

Empirical evidences of co-evolution/adaptation of systems to needs and of users' practice to systems are difficult to collect because of the challenge to properly observe subjects in real life situations. As the use of computers in taxis has been common in some countries for a few years

[16] the study of taxi drivers is relevant. In the second half of 2007, we took the opportunity of the market success of Satnav systems to observe how positioning technologies integrate into the existing practice and how this practice affects the technology use. Our aim is to provide evidences of the importance of the context and the situations in the use of the systems. We analyzed the co-evolution in three different aspects:

1. Acquisition: why and how this new technology gets integrated with other artifacts and how, over time, it modifies their use;
2. Expectation gap: why the integration into the practice does not match the initial expectations;
3. Evolution of the appropriation: despite the gaps, how the practice evolves in relation a) to the awareness of, and reactions to, the limitations and imperfections of the system; b) to the driver's knowledge of the environment; c) to the access to geoinformation both from the system and other artifacts.

The collection of contextual evidences through ethnographic techniques was carried out within a community of taxi drivers in Barcelona, Spain, with 10,400 licensed cars. This community forms a massive population of early adopters of in-car navigation systems that also rely on more traditional elements, such as mobile phones and paper maps, to support their work. The study of this community is very relevant because it provides evidences of location-based systems impact and implications, outside the laboratories. We believe that this approach is necessary to inform the design process with considerations on the evolution of the appropriation of the technology.

3. Method

Our research approach is based on ethnographic methods often used in ubiquitous computing [17, 18]. Other scholars have dealt with the use of navigation systems, but mainly relying on quantitative data collected from surveys [19], sensor data [20] or experimental settings [21]. These approaches do not fully appreciate the scope and implications of the practice evolution when using novel technology. We were inspired by Chrisman [22], who argues that the study of technology removed from its construction or its use neglects the active role users play in the co-evolution process. Our design intended to provide an interpretation of user practices and situated activities, but without imposing our previous understanding onto the situation. We did not mean to be exhaustive; we focused on how taxi drivers use the systems, but did not examine how the systems work (e.g. interfaces, mobile antennas, software and hardware).

We collected empirical evidences from 12 taxi drivers (11 males, 1 female, respecting the male/female ratio within the community) with a working experience ranging from 6 months to 20 years (2 with less than one year; 3, 4 and 3 between one and five, five and ten, and ten and twenty respectively). They owned their navigation system for at least 6 months. We stopped collecting data when no significant new information or evidences emerged with additional subjects: after 10 taxi drivers our categories, described later, were already filled with data to the point of saturation [23]. Of course, more empirical data could provide further emerging ideas outside the scope and questions of this research.

We conducted semi-structured interviews in Spanish (we translated some excerpts for this paper) at the Barcelona airport parking lot for taxis (Figure 1). It provided a good setting to get in touch with taxi drivers, because they often must wait there for over 30 minutes, spending their time chatting, playing (e.g. chess, scrabble, golf), cleaning their cars, drinking refreshments and eating.

The interview covered the three different aspects of the co-evolution indicated earlier with questions on the reasons and expectations for the acquisition, the particular evolution of use (e.g. how the practice was before and after its use), the context of use with successes, failures and the acquisition of the knowledge on the city. It is well known that informants are often selective in what they describe and discuss, and we needed to go beyond the interviews: we collected additional insights from observation of driver work settings (e.g. artifacts used and their evolution, context of use in the wayfinding process) and behaviors (e.g. engagement with different types of geoinformation such as streets, numbers, instructions, points of interest) while driving. Acting as customers, we requested rides from and to a railway station, a major hotel and an address at one of the many very narrow streets in the Gracia neighborhood in Barcelona. Each informant took part in one session, lasting from 45 minutes to 1 hour, divided in two halves, the first collecting insights in the parking lot, which triggered a semi-structured interview; followed by a ride.

Figure 1. Taxi waiting area at the Barcelona airport. Usual drivers' activities include fixing or cleaning the taxi, sleeping, reading, eating and playing.

We collected rich data consisting of photos of work settings (e.g., to record the ecosystem of artifacts discussed later), videos of taxi rides (e.g., to capture key moments of access to geoinformation) and written field notes from the interviews. After each session we analyzed and compacted the data. Our analysis consisted in a careful reading of the different materials and in highlighting parts that were related to the aspects of the co-evolution we wanted to focus on. We organized the relevant parts into common themes, and coded the documents using the emerging themes.

The findings have been extracted within a framework for observation of the co-evolution that focuses first on the contextual ingredients that support their practice, then how this context evolves during the navigation and its situated activities, and finally, how it impacts their knowledge of the city and in return how the knowledge impacts on the use of the navigation systems. We summarize the findings extracted around these themes in the following section.

4. Findings

Satnav systems relieve car drivers of the need to closely observe the environment, to look out for road signs or landmarks, to orient themselves with respect to where they are located, or to memorize a chosen route for future reference. In this section we see how this takes place in the practice of the taxi driver community.

4.1. The Satnav system as complementing and modifying an ecosystem of artifacts

The artifact model has been used in the ethnographically inspired Contextual Design methodology [24], abstractly representing the physical objects supporting work, along with their

usage, purpose and information content. We started with the model as an observation framework, and we enhanced it to a discovered ecosystem of artifacts that we discuss in terms of the types of tools, how their respective use relates to each other, and when and why drivers access their geoinformation.

The navigation system completes an array of artifacts providing layers of geoinformation to support the job (Figure 2). Based on our observations, we categorize some as detecting real-time information sources such as the Satnav system, dispatched radio, electronic booking system, mobile phone and radio. Another category provides less dynamic information of the city: newspapers supplying daily events and activities; scribbled list of "unofficial" points of interest requested by customers (e.g., strip clubs), and above all the street and map directory of Barcelona *Guia Urbana de Barcelona* (*Guia*), generally kept at easy reach, on the seat near the driver's, above the dashboard or in the interior storage compartment. The purpose and context of use of these artifacts are described in more detail in Table 1.

Artifact	**Purpose**	**Context and situation of use**
Satellite navigation system	Inform on the whereabouts; provide directions to destination (e.g. street number, hotel, place); keep track of speed radars.	At the start of the ride to locate the neighborhood and/or in proximity to destination to precisely locate a street number[3]
Guia Urbana de Barcelona, the street and map directory of Barcelona which is a thick and dense book with all the streets and points of interest	Locate the destination, find references, and locate points of interest and hotels.	At the start of the ride to locate the neighborhood and/or in proximity to destination to precisely locate a street number
Dispatched radio	Receive jobs from the call center.	When looking for customers and when navigating to accept future rides. In rare situations when the driver gets lost to get advice; for professional questions (e.g. asking on special rates for some destinations); in the rare cases of emergency (attempt robbery).
Electronic booking system	Receive jobs from the call center	When looking for customers and when navigating to accept future rides.
Mobile phone	The mobile phone often available is seen as a social link to family and friends, and is very rarely used as a tool to support their work. One driver told me that he used it a few times to check if a table was available at a restaurant for clients (particularly foreigners). This is a service given as added value, but he "normally should not do it".	Used for social contacts with friends and relatives and also for administrative duties (e.g. calling the bank). Mainly used during breaks and waiting period or in the rare situations when the driver gets lost and there is not a source of information within the car that can help. Drivers express a level of respect for their passengers in their behavior: trying to make

[3] Satellite navigation systems have two main modes. In the passive mode the system mainly provides a sense of orientation and situation awareness. The active navigation system is started by a destination being entered, and the system may provide routing advice, turn by turn guidance and traffic information.

		few or no calls on their mobile phones
Newspaper	Provide updated information on the city	During breaks
FM Radio	Provide entertainment and updated information on the city (e.g. news, debates)	Depending on the driver, the radio can be used with some respect towards a passenger by keeping the radio volume low
Handwritten notes	Store information on informal destinations of the city that are not present in the *Guia* and in the navigation system	To keep track of specific destinations and opening hours. On customer request

Table 1. The ecosystem of artifacts that taxi drivers use for navigation, social interactions and updating knowledge

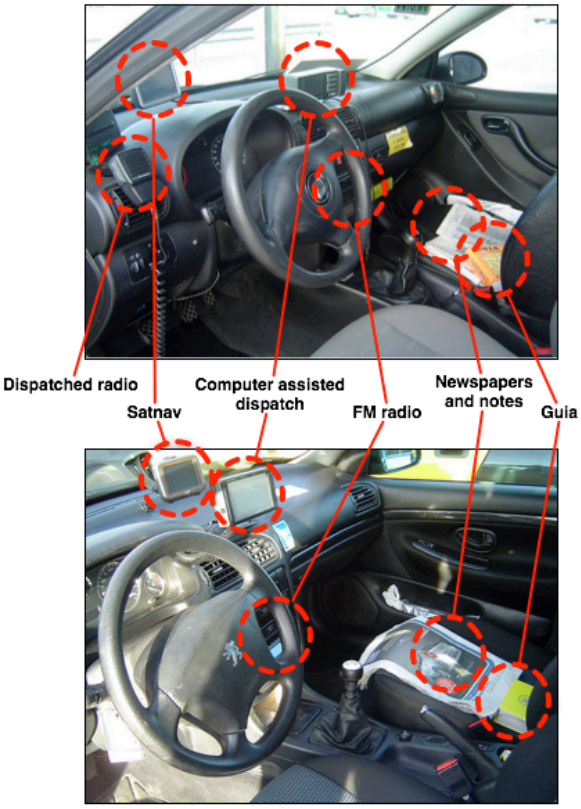

Figure 2. The ecosystem of artifacts for navigation and updating knowledge: Dispatched radio, computer-assisted dispatch, FM radio, satellite navigation system, newspaper, paper notes and the *Guia*. Mobile phones are kept in the pocket, in the compartments or with a specific hand-free car kit.

In the ecosystem of artifacts, Satnav systems are preferred to the *Guia*, even by the most experienced drivers who have memorized most of the city knowledge and very rarely make use of the *Guia*. Nowadays, they prefer to interact with their Satnav and open the *Guia* only as fallback (e.g. when the system does not contain a street number or lacks information). Even after 20 years of experience, one informant still perceived retrieving information from the *Guia* as a demanding

task. Compared to it, "hitting the screen of the Tom-Tom is a pure pleasure". As they only rely on the system when driving to unfamiliar destinations, which after 20 years only happens rarely, they keep it the glove compartment, and used it as an occasional "lifesaver".

The following subsections provide more detail on the (evolving) use of the ecosystem of artifacts.

4.2. The ecosystem and the modified strategies of wayfinding

The use of the wayfinding artifacts is different during two main stages. As prior to the appearance of Satnav systems, drivers first take the appropriate overall direction during a "to go" phase while the later "to arrive" phase requires more precise geoinformation to drop off the customer (i.e. the location of a street number, a monument, or an intersection of two streets). When aiming to unknown destinations, drivers access the geoinformation as in a "funnel". First, the goal is to quickly retrieve the area of the destination (usually through the *Guia*, but if it does not provide suitable information such as reference points in the area, the drivers engage with the navigation system); and decide direction based on this broad information. It is only when approaching the destination area, that the exact address in the navigation system is entered – or alternatively, found through a thorough look at the *Guia,* when in slow traffic or stopped by a red light. The more precise route is chosen in this phase. The selection of 3wayfinding artifact depends on the speed to access the information (e.g., a long street name is difficult to be entered in a Satnav) and on the experience of the driver with the geoinformation quality provided (e.g. wrong street numbers in some areas). Informant B explained that he engages with the system only during the second phase to avoid misleading routing information in the first one (Figure 3), as a taxi driver takes alternative routes depending on the time of the day and circumstances (e.g. traffic, weather conditions, passenger preferences). The specific implementation of this "two phase" seemingly general strategy is thus modified by the introduction of the Satnav.

Figure 3. Use of the *Guia* at a stop when approaching destination

A major problem for a taxi driver is to be lost after dropping off a customer in an unfamiliar area.

Therefore, on the way to the destination taxi drivers gather information to get back into known territory and are either very cautious in the path taken to enter the area ("*I am a very good observer*" said informant A) or use their Satnav when going back downtown Barcelona. They observe landmarks (e.g. a tall building), topology (e.g. a mountain/hill); but getting a sense of orientation can easily become problematic (e.g. during nighttime or bad weather conditions when tall buildings and mountains are not clearly visible). Then a Satnav comes in handy. Informant B mentioned that in these situations he entered "Plaza Espana", a large roundabout in the center of Barcelona. Other access their Satnav bookmarks of saved destinations such as "home" or "Barcelona center".

4.3. A modified learning process

These strategies of geoinformation access during navigation modify the learning process of taxi drivers to master the city, knowledge important to their practice. In the past, the driver would open the *Guia* and browse the index of streets and points of interest to access a map of the destination area, which was a way to learn the city by doing. Another important one is from the customers themselves, as they communicate tricks and insights not available through official books and commercial systems. We have discussed that experienced drivers prefer Satnav systems to the *Guia*; for the younger generations, the integration of the Satnav modifies the old learning process with three salient issues: the need to assess the quality of the geoinformation, the ability to temporarily disengage from the environment, and the amputation of some social interactions, which we discuss next.

4.3.1. Learning the quality of geoinformation

The less experienced taxi drivers express mixed feelings about the quality of service of their Satnav: "*It is like my cell phone, sometimes it does not work well*", and the correctness of the information "*it is a potential problem*". The latter reveals that, they did not expect system inaccuracy at acquisition. As the *Gui*a is difficult even for the more experienced drivers, the less experienced ones deeply rely on their Satnav, and they have to learn when not to rely on them, which becomes part of their "Satnav literacy". For instance, informant J could name the places where he found the navigation information to be absolutely irrelevant (e.g., access to major squares). When in doubt on the reliability of his Satnav, he would use the *Guia,* which is "*more accurate and complete*", and remains the better source of information to learn the city particularly as it provides a detailed index of streets, points of interest and city-related information.

4.3.2. Easier learning and more relaxed engagement with the environment

The Satnav used in the passive mode described earlier is turned sometimes into a learning tool as it tells the street names or the presence of speed radars while driving – which is an easier learning, demanding less attention, than learning from the *Guia*. This mode enables a more relaxed driving: in the past, drivers would count the number of streets to cross (that they knew by heart) before making a turn; when the passive mode is on, the driver can pay less attention to the environment for a while, knowing that a proper position will be provided when needed, even though this functionality was not expected when acquiring the device

4.3.3. Social amputation

A more social learning alternative is to draw on customer's knowledge. The drivers often elicit wayfinding information and learn navigation tricks known to locals by proposing alternatives routes for the customer to choose. This decreases the driver's responsibility to value and assess directions and helps to avoid complaints. However, the Satnav presence might reduce the

opportunities for this learning process to take place: route directions provided by the system give less room to argumentations and discussions between drivers and customers, changing the social configuration. The discussions move to other topics (the state of the traffic, what is being discussed on the radio) or are replaced by silence.

The Satnav presence modifies the social interactions with remote friends and colleagues as well. Informant E was relieved that he did not have to use his radio to ask colleagues about particular location information. And drivers ask less for directions to locals (e.g. in remote villages) or to other knowledgeable people (e.g. to truck drivers at red lights in industrial areas).

4.4. Serenity over efficiency; companionship

Taxi drivers purchased Satnav systems to 'reduce their spatial anxiety'. They might face moments of uncertainty during a ride in a village or an unfamiliar area, such as one of the many suburban business areas rapidly grown in recent years. There is a consensus that a Satnav is currently unbeatable when it comes to reaching (and/or leaving) a specific destination in a village, and this is a strong purchasing reason. But taxi drivers' goal is to feel more confident during their job rather than to be more productive. Informant B describes the Satnav as a tool to be calm rather than to make more money, or to improve efficiency, in his words "*I can go everywhere and relax*", while informant Y said "*the fear of getting lost with a customer I felt in my stomach now disappeared*". Other drivers mention that it calms both them and their customers: "*with it they know I cannot cheat them*", "*it reassures them that I go to the proper destination*". This is an example that efficiency is not always the main goal of the integration of technology at work, as considered usually.

The feeling of relying on a "companion" in critical situations is revealed as well when informants refer to the Satnav as a "he" (and their car as a "she"). This does not prevent that the most experienced keep it in the glove compartment most of the time and retrieve it only when necessary. This "companion" might be a false friend of the less experienced when it provides inaccurate information, as discussed earlier. This could lead them to a vicious circle: to rely on the technology to learn the city and thereby reduce their interactions and social sources of learning, and when they get uncertain on the quality, they are cut from the social sources to solve it. Let us remark that we have shown some taxi drivers escaping this vicious circle by using the *Guia*.

Figure 4 presents the findings within the framework allowing co-evolution observation: from the acquisition reasons through the gaps with respect to expectations to the co-evolution itself. First we focus on placing the satnav in the context of location-aware "systems" that support practice and the overall goals, through the gaps discovered with respect to expectations, to reveal how this context evolves, and how the city knowledge and learning strategies are modified. The specific findings related to the taxi-drivers work practice will surely evolve beyond what we have described, but we believe the framework, the focus on learning, on motivation, on studying the ecosystem of artifacts, on the analysis of the work strategies evolution to be more generally useful for an ethnographical approach to HCI. We discuss this further below.

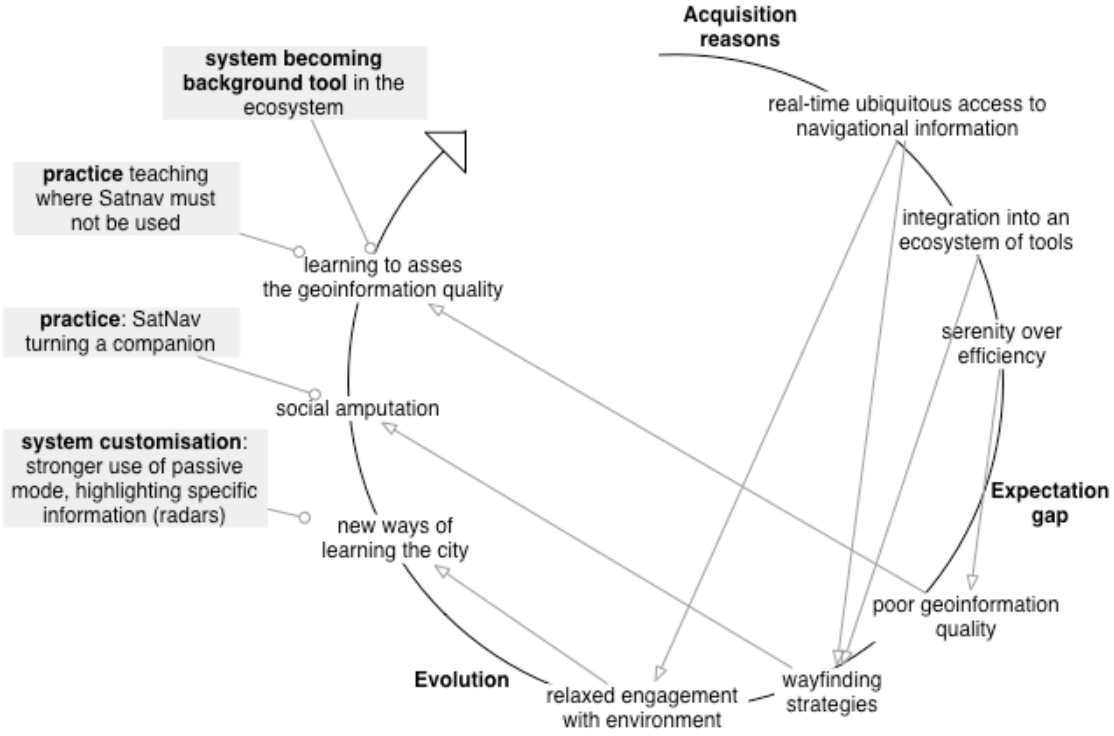

Figure 4. The findings within the observation framework of co-evolution aspects from acquisition, through expectation gap, into the evolving appropriation

5. Discussion

Some researchers have looked at the integration of new mobile technologies into the mobile workers's practices, aiming at understanding the role of technology and artifacts at this work and identifying opportunities to develop appropriate solutions to support workers [25] and understand the socio-technical aspects of their work [26, 27].

5.1. Beyond usability

In-vehicle navigation system usage and driving behavior patterns studies [4] show that systems are frequently set in active mode when users travel in unfamiliar environments, but use them less in familiar ones, when they can benefit from local knowledge, as in our findings. Their focus is usability issues; our additional consideration of experience and context of use, allows us to relate this usage with wayfinding and learning strategies. We go beyond focusing on the device, and we share [28] interest in the contextual practice with mobile and location-aware devices, in the losses and opportunities, taking a full-circle perspective [22].

Elaluf-Calderwood & Sørensen [29] conducted a longitudinal ethnographic study of London driver behavior with empirical data provided by qualitative interviews to discover relationships between the drivers' practices and the supporting mobile technology. Corroborating our findings, they point out that the most interesting technological opportunities may be thwarted by practical

barriers such as problems of supporting individual taxi work with Satnav devices. The devices designers seem to assume the driver gives control entirely away and simply follows directions - when these are far from perfect. This creates problems in job allocation, billing and payments when systems lack positioning accuracy in dense urban areas or do not take into account physical obstacles to compute a distance. While their study focused on dispatching taxi drivers and looking for customers, we did it on wayfinding practices that include social interactions, which allows us to deal with the evolution of city learning strategies

Leshed et al. [30] focused on people's everyday practices, interpretations of and experiences with their Satnav, analyzed the complexity of changes created by the technology introduction with an understanding of losses and opportunities, specifically discussing the implications of the drivers' relationship with their systems on their engagement with the environment. As we do, they argue that the full understanding of issues of the (dis)engagement with the environment needs perspectives that go beyond usability issues. Their results on observations of 10 North-American drivers are echoed in our findings, despite the different cultures, for instance, that the active presence of a navigation system alters the social interaction. We have seen the Satnav relevance related to the car as a social place for learning; they more generally suggest the car as a place of conversations. Both works support the need to reveal the geoinformation ambiguity as a design feature. As we observed the job as based on the environment knowledge, we improved the understanding via an "ecosystem of artifacts model", supporting (the evolution of) the geoinformation access. It allowed us to identify better users' strategies to appropriate the technologies and the context of use, leading us to reveal a modification of the learning process and the importance of the geoinformation granularity during (the different phases of) a ride.

5.2. Deskilling?

Field studies on navigation systems have shown evidences that their introduction had de-skilling effects on orientation and navigation [31] and spatial knowledge [32], the latter stating that "*The more the driver relies on the system to locate jobs, the less he or she relies on their in-depth knowledge of where they need to position themselves to maximise income*". Leshed et al. [30] show a few instances of social de-skilling. We have shown social amputation signs in experienced taxi drivers, but location de-skilling deserves further discussion. While informant F, an experienced driver, thought that "*the newcomers who use a navigation system do not gain knowledge of the city, because they follow the recommendations and stop thinking*", our analysis of the less experienced does not reveal negative affects on their acquisition of geo-knowledge skills: they are eager to learn the city and master the imperfections of their Satnav systems to perform better their job. Drivers learned using traditional sources such as the *Guia* and the newspapers. Now they also use the Satnav in passive mode to learn in familiar areas (e.g., keeping track of the street names and their sequence) as well as to detach themselves from the orientation process. Less experienced drivers must access multiple sources of information from an ecosystem of artifacts, slightly breaking the myth that Satnav system change a "skilled" job unto an unskilled one, whereby anyone with a GPS could do the taxi driver job. Our observations suggest that the Satnav loses over time its usefulness to support navigation to the point of finishing in the glove compartment most of the time.

Our study reveals the appearance of new skills such as assess the geoinformation quality with respect to navigation and orientation. Indeed a Satnav provides only a reduced, disembodied understanding of the environment [33], and the fluctuating quality of the geoinformation is a source of uncertainty [34], as in many other location-aware systems. We observed the reliance on

an ecosystem of artifacts to patch complementary limited information. Our informants learned not to rely completely on their Satnav when they could not assess the information quality. Besides learning to interpret the system and its inaccuracies, they open their *Guia*. Informant G claimed that when a conflict emerged between his Satnav and his intuition he started to "improvise" and he would either switch it off or ignore it for a while. The location and opportunity determined the action, as theorized by Suchman in her situated action theory [35]: "*Idiosyncrasy, improvisation and knowledge are all useful tools when choices between planned and situation acts are complex*". In our case, the understanding of the limitations and imperfections of the technology is part of the knowledge.

However, the presence of the technology altered the social practices that were at the source of learning the "unofficial" city from the knowledgeable customers. This may trigger new social sources and practices to capture this kind of information. At this stage we have no evidences of this, but it is clear that the Satnav does not provide it.

5.3. Design implications

Our ethnographical based findings can contribute to the design of navigation systems. But instead of formulating a requirements list, our aim is to open the design space rather than limiting it [18]. We aim at informing design at a high-level through considerations of human perception and socio-cultural issues, rather than following the classical engineering design, focused on competitors benchmarking and system integration, on providing usability guidelines and feature-centered recommendations; which has been adopted by the GPS technology development so far (Svahn [19]).

Let us note that our design suggestions are inspired by observations within a specific community – more and different opportunities might emerge in different cultural contexts and work settings.

5.3.1. Designing for trust and dependability

The current central goal of Satnav is to support driving safety and travel efficiency, for example by identifying best routes. Efficiency - the main goal of the integration of technology at work – is sometimes translated into poor design through strong and silent automation [36]. Promoting the driver's peace of mind is not seen a design goal. Our field study shows that the comfort of trusting a "lifesaver" is a prime motivation for purchase; fitting with trust being an important factor of new technology adoption as key component of human-automation interaction [37]. As they do not know whether their navigation system is always reliable, some taxi drivers might riskily transfer their trust to artifacts of their in-car ecosystem. Trust poses even more issues in terms of design for dependability with the future integration of real-time information from navigation systems that act as sensors[4] or cellular probes [38] and of map corrections with the participation of volunteers[5] and customers[6]. Instead of offering the most efficient indications based on hidden algorithms and real-time information, we suggest that the system should provide reasons to trust the information (e.g. others have navigated successfully in this neighborhood, the presence of this radar has been validated today), and that it even surrenders to other resources when some real-time information cannot be trusted, unlike the current approach to normalize fuzzy, incomplete GIS data and present navigation assistance as trustworthy information [39].

[4] Dash: http://www.dash.net/
[5] Open-Street Maps: http://www.openstreetmap.org/
[6] TomTom Map Share: http://www.tomtom.com/page/mapshare

5.3.2. Highlighting the quality of geoinfomation

Elaluf-Calderwood and Sorensen [29] point out "*even the most interesting technological opportunity may be thwarted by minor practical barriers. Include discussion of problems with support of individual taxi work (not coordination) through GPS systems when these assume the driver relinquish control entirely and simply follow directions when these are far from perfect*". In their study, this uncertainty was the main reason taxi drivers felt discouraged to try new location-aware technology. Positioning data are fairly accurate, but they could be embedded in poor information due to erroneous or outdated GIS data, and, as we mentioned, a lot of drivers think they received inaccurate device instructions [4]. Our study shows that poor geoinformation quality, its lack of timeliness and completeness or inaccuracies challenge drivers' decision-making, who experience frustrations but develop new strategies to manage these situations. A design approach supporting this development is the seamful provision of enough knowledge to support drivers' assessment of geoinformation quality [40]. Rukzio *et al*. [41] have shown that the display of uncertainty by navigation devices improves solutions in spite of unreliable and incomplete data. The system could reveal some information quality (has it generated problems before?) and timeliness (when was the map last updated?). Additionally it could take into consideration that different levels of granularity are needed in different navigation phases to display the uncertainty only when the appropriate granularity is not available.

5.3.3. Supporting social interaction and learning

We have shown instances of social de-skilling, not necessarily, rather than navigational or orientational. Since Satnav systems are designed to interact with the driver, they decrease the opportunities for customers to engage socially with drivers, needed in the city learning process. One could think of systems pretending to acknowledge the presence of passengers and taking advantage of ambiguity or the detection of new elements in the environment to elicit interactions. For instance, the system could reveal the geoinformation uncertainty as a ground for interpretation and argumentation [42]. Reveal rather than hide error-prone or outdated information could reduce the driver's over-reliance on the system, but also raise the passenger's participation in the navigation in "normal" circumstances (of course, not in "lifesaving" situations!).

Svahn [19] points out that navigation services primarily address traveling in unfamiliar driving environments, while most driving takes place in familiar areas, concluding that a wider range of navigation services tailored for different contexts is needed. We did find evidence of different use in those different areas, and the learning process of unfamiliar areas could be improved with the disclosure of difficult aspects by highlighting the names of narrow streets.

6. Conclusions and future work

We explored aspects related to the evolution of the practice of driving and navigating and how drivers feel, learn the physical environment (the city) and engage socially within a change of technology, and we report evidences of co-evolution, i.e., drivers adapt practices to their new systems and adapt their use to their needs. To be able to do this, we needed a perspective broader than previous Satnav studies typically focused in usability issues based on experimental approaches inside labs; and moved beyond the concept of technology as an autonomous, external force imposing societal change. We are interested in people's everyday practices, experiences, and interpretations with their Satnav, and we developed an ethnographically informed study, through observations and interviews of taxi drivers. We have extended the ethnographical

technique "artifacts model" to an "artifacts ecosystem model" analyzed through a grid that allows to identify better users' strategies. Our framework to analyze real use co-evolution might be used in other contexts, and through it we identified new strategies addressing significant issues in the mobile work environment, such as promoting the driver's peace of mind as a design goal, or new ways to manage and communicate the geoinformation quality by satnav systems. We identified areas where social interaction is relevant and connected them with city and surroundings learning, and uncertainties sharing; and suggested losses and opportunities that might arise.

At a higher level, we showed that the integration of location-aware technologies has not created a different sphere of practice despite the access to a digital representation of a physical space (as argued by Dourish [43]), but that the knowledge acquisition evolves by people using systems in ways unanticipated by the designers, and by adapting resources to their needs in new ways, e.g. creating handwritten notes to complete the limitation of official information provided by a navigation system and a street directory; or keeping the navigation system in passive mode to learn the urban environment. Thus, system designers should assume that people will try to tailor their use [44] by placing them within a modified ecosystem of tools and their interrelated use, in which part of the knowledge might not be digitally represented.

Our study emerged from 12 taxi drivers using Satnav in Spain, and further work could overcome their related limitations, extending findings and exploring other questions, for instance by comparing the practice of those who remain without Satnav with those who have adopted them, or focusing on the practice when drivers are on their own, without customer, or developing a larger more longitudinal study. Cameras and post-hoc discussions could be additional observation strategies, possibly augmented by an underlying logging of activities to fuel post-hoc discussion.

Questions on the integration and appropriation of next generation navigation systems integrating real-time mobility information similar to those of this paper should be posed again [45], for instance, whether in practice this leads to taxi driving becoming an unskilled job as indicated by Elaluf-Calderwood and Sorensen [29], or the appropriation of real-time urban data is a deskilling or stress reducing factor or whether their lack of geographical relevance [46] keeps triggering the co-evolution of process of taxi-drivers and their navigation systems. Or posed with respect to the integration of mobile phone-based navigation services that incorporate various modes of transportation [47]. A rather unexplored research question is how new technologies can improve the services provided by taxi drivers to passengers.

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References

[1] S. Azuma, K. Nishida, and S. Hori, "The future of in-vehicle navigation systems," in Vehicle Navigation and Information Systems Conference, pp. 537–542, 1994.

[2] R. Heft, "The navigation market for road vehicles," in IEEE Position Location and Navigation Symposium, pp. 109–114, 1998.

[3] Harris Interactive, National Study Shows GPS Adoption Rates Relatively Low, but Offers Recommendations to Accelerate Market Penetration.

http://www.harrisinteractive.com/NEWS/allnewsbydate.asp?NewsID=1241, 2007.

[4] N. Forbes, "Online survey of in-vehicle navigation system users." http://www.mrl.nott.ac.uk/ nlf/, 2006.

[5] S. Benford, "Future location-based experiences," tech. rep., JISC Technology and Standards Watch, 2005.

[6] G. Look, B. Kottahachchi, R. Laddaga, and H. Shrobe, "A location representation for generating descriptive walking directions," in IUI '05: Proceedings of the 10th international conference on Intelligent user interfaces, (New York, NY, USA), pp. 122–129, ACM Press, 2005.

[7] R. Suomela and J. Lehikoinen, "Taxonomy for visualizing location-based information.," Virtual Reality, vol. 8, no. 2, pp. 71–82, 2004.

[8] M. Rohs and G. Essl, "Which one is better? : information navigation techniques for spatially aware handheld displays," in ICMI (F. K. H. Quek, J. Yang, D. W. Massaro, A. A. Alwan, and T. J. Hazen, eds.), pp. 100–107, ACM, 2006.

[9] M. S. Ackerman, "The intellectual challenge of CSCW: The gap between social requirements and technical feasibility," Human-Computer Interaction, vol. 15, pp. 181–203, September 2000.

[10] S. Benford, H. Schnädelbach, B. Koleva, R. Anastasi, C. Greenhalgh, T. Rodden, J. Green, A. Ghali, T. P. Pridmore, B. Gaver, A. Boucher, B. Walker, S. Pennington, A. Schmidt, H. Gellersen, and A. Steed, "Expected, sensed, and desired: A framework for designing sensing-based interaction.," ACM Trans. Comput.-Hum. Interact., vol. 12, no. 1, pp. 3–30, 2005.

[11] M. Dodge, R. Kitchin, and M. Zook. How does software make space? Exploring some geographical dimensions of pervasive computing and software studies. Environment and Planning A, June 2009

[12] J. Raper, "The mistakes that satnavs make (and what they don't know)," in Situating Satnav 2, paper session at the Association of American Geographers meeting, 2008.

[13] W. J. Orlikowski, "The duality of technology: Rethinking the concept of technology in organizations," Organization Science, vol. 3, no. 3, pp. 398–427, 1992.

[14] V. L. O'Day, D. G. Bobrow, and M. Shirley, "The social-technical design circle," in CSCW '96: Proceedings of the 1996 ACM conference on Computer supported cooperative work, (New York, NY, USA), pp. 160–169, ACM, 1996.

[15] E. Hutchins, Cognition in the Wild. MIT Press, 2005.

[16] W. Skok, "Knowledge management: London taxi cabs case study," in SIGCPR '99: Proceedings of the 1999 ACM SIGCPR conference on Computer personnel research, (New York, NY, USA), pp. 94–101, ACM, 1999.

[17] A. Crabtree, S. Benford, C. Greenhalgh, P. Tennent, M. Chalmers, and B. Brown, "Supporting ethnographic studies of ubiquitous computing in the wild," in DIS '06: Proceedings of the 6th ACM conference on Designing Interactive systems, (New York, NY, USA), pp. 60–69, ACM Press, 2006.

[18] P. Dourish, "Responsibilities and implications: further thoughts on ethnography and design," in DUX '07: Proceedings of the 2007 conference on Designing for User eXperiences, (New York, NY, USA), pp. 2–16, ACM, 2007.

[19] F. Svahn, "In-car navigation usage: An end-user survey on existing systems," in IRIS27,

Falkenberg, Sweden, 2004.

[20] L. Liu and Z. yu Duan, "Activity-based mobility intelligence," IEEE Pervasive Computing, vol. 7, no. 2, pp. 58–59, 2008.

[21] G. E. Burnett and K. Lee, "The effect of vehicle navigation systems on the formation of cognitive maps," in Traffic and Transport Psychology: Theory and Application (G. Underwood, ed.), 2005.

[22] N. Chrisman, "Full circle: more than just social implications of GIS," Cartographica, vol. 40, no. 4, 2005.

[23] P. Atkinson, A. Coffey, S. Delamon, and J. Lofland, eds., Handbook of Ethnography. Sage, 2001.

[24] H. Beyer and K. Holtzblatt. Contextual Design. Defining Customer-Centered Systems. Morgan Kaufmann, San Francisco, 2007.

[25] M. Perry, K. O'Hara, A. Sellen, B. Brown, and R. Harper, "Dealing with mobility: understanding access anytime, anywhere," ACM Trans. Comput.-Hum. Interact., vol. 8, no. 4, pp. 323–347, 2001.

[26] J. E. Orr, Talking About Machines: An Ethnography of a Modern Job. Cornell University Press, 1996.

[27] S. Kristoffersen and F. Ljungberg, Mobility: from stationary to mobile work, pp. 41–64. Planet Internet, 2000.

[28] S. Tamminen, A. Oulasvirta, K. Toiskallio, and A. Kankainen, "Understanding mobile contexts," Personal Ubiquitous Comput., vol. 8, no. 2, pp. 135–143, 2004.

[29] S. Elaluf-Calderwood and C. Sørensen, Organizational Agility with Mobile ICT? The Case of London Black Cab Work. Butterworth-Heinemann, 2006.

[30] G. Leshed, T. Velden, O. Rieger, B. Kot, and P. Sengers, "In-car GPS navigation: engagement with and disengagement from the environment," in CHI '08: Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems, (New York, NY, USA), pp. 1675–1684, ACM, 2008.

[31] C. Aporta and E. Higgs, "Satellite culture: Global positioning systems, inuit wayfinding, and the need for a new account of technology," Current Anthropology, vol. 46, no. 5, pp. 729–753, 2005.

[32] S. Elaluf-Calderwood and C. Sørensen, 420 Years of Mobility: ICT Enabled Mobile Interdependencies in London Hackney Cab Work. Mobile Work/Technology. 2008.

[33] H. Lorimer and K. Lund, "Performing facts: finding a way over Scotland's mountains," The Soc. Review, vol. 51, no. s2, 2003.

[34] S. Benford, R. Anastasi, M. Flintham, A. Drozd, A. Crabtree, C. Greenhalgh, N. Tandavanitj, M. Adams, and J. Row-Farr, "Coping with uncertainty in a location-based game." IEEE Pervasive Computing, vol. 2, pp. 34–41, July-Sept. 2003.

[35] L. Suchman, Plans and Situated Actions. The Problem of Human-Machine Communication. Cambridge Univ. Press, Cambridge, 1987.

[36] D. D. Woods, Human-centered software agents: Lessons from clumsy automation, pp. 288–293. Washington, DC: National Science Foundation, 1997.

[37] J. Lee and K. See, "Trust in automation: Designing for appropriate reliance," Human Factors, vol. 46, no. 1, pp. 50–80, 2004.

[38] Y. Yim, "The state of cellular probes," tech. rep., California Partners for Advanced Transit and Highways (PATH), 2003.

[39] A. K. Lobben, "Tasks, strategies, and cognitive processes associated with navigational map reading: A review perspective," The Professional Geographer, vol. 56, pp. 270–281, May 2004.

[40] M. Chalmers and A. Galani, "Seamful interweaving: heterogeneity in the theory and design of interactive systems," in DIS '04: Proceedings of the 2004 conference on Designing interactive systems, (New York, NY, USA), pp. 243–252, ACM Press, 2004.

[41] E. Rukzio, J. Hamard, C. Noda, and A. D. Luca, "Visualization of uncertainty in context aware mobile applications.," in Mobile HCI, (New York, NY), pp. 247–250, ACM, 2006.

[42] W. W. Gaver, J. Beaver, and S. Benford, "Ambiguity as a resource for design.," in CHI (G. Cockton and P. Korhonen, eds.), pp. 233–240, ACM, 2003.

[43] P. Dourish, "Re-space-ing place: "place" and "space" ten years on.," in CSCW, pp. 299–308, 2006.

[44] G. D. Abowd and E. D. Mynatt, "Charting past, present, and future research in ubiquitous computing.," ACM Trans. Comput.-Hum. Interact., vol. 7, no. 1, pp. 29–58, 2000..

[45] M. Bierlaire, M. Thémans, and K. A. 2, "Analysis of driver's response to real-time information in Switzerland," European Transport, vol. 34, pp. 21–41, 2006.

[46] J. Raper, "Geographic relevance," Journal of Documentation, vol. 63, no. 6, pp. 836–852, 2007.

[47] M. Arikawa, S. Konomi, and K. Ohnishi, "Navitime: Supporting pedestrian navigation in the real world," IEEE Pervasive Computing, vol. 6, no. 3, pp. 21–29, 2007.