Losing a private sphere? A glance on the user perspective on privacy in connected cars

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Abstract

Connectivity is one of the major prerequisites of automated driving. Enabled by numerous connected sensors, new cars offer new functionalities, provide higher security levels and promise to enhance the comfort of travelling. However, by connecting a vehicle with its environment, the car becomes more transparent. The integration of the car into a smart grid seems to conflict with the users' expectation of their car as a private retreat, thus reducing the acceptance and usage adoption of connected cars. This article aims at helping developers and engineers to consider the user's expectations when designing a connected car. Furthermore, this article reviews and compares recent international surveys on user's privacy with our own results on the user's attitude towards connected vehicular services.

1 Introduction

Modern cars offer high levels of safety and comfort. An increasing degree of automation constantly extends the car's ability to anticipate the current traffic situation, thus reducing the workload which is imposed on the driver [1]. For example, advanced driver assistance systems guide the driver's behavior [2] or detect and communicate potential crashes [3] in order to prevent risky manoeuvers. Moreover, future cars are likely to take over all driving tasks as car manufacturers pursue high automation levels [4]. However, high automation levels heavily rely on so-called vehicular ad-hoc networks, which transfer data between multiple entities like cars or infrastructure [5]. Hence, a constantly growing number of sensors observe and communicate the environment as well as the interior including the passengers. While the advent of these means of vehicular ambient intelligence fosters new functionalities, provides higher security levels and promises to enhance the comfort of travelling [6], it might change the perception of our car as private which has been persisting so far.

Private cars are more than a simple means of transport. Car use does not only fulfil pragmatic functions like getting from A to B, but also has affective and symbolic significance [7]. Among others, driving our private car can be associated with pride and enjoyment. People build a relationship towards their vehicles and from an emotional bond to their car [8]. This connection underpins the pursuit of safety, enjoyment and autonomy, but also the desire for a private refuge [9]. When commuting back home, we acknowledge our retreat and enjoy the car as private space. So far, cars have offered this private retreat that protected us from unwanted intrusions. However, with the integration of the car in the smart grid, the image of the car as a private refuge begins to crack. It is not a physical intrusion, which might compromise the driver's private sphere within a car, but a digital one. A multitude of sensors turns the car into a context-aware smart vehicle that relies on ubiquitous computing [10]. Sensors, most of which the driver is not aware of, not only detect the environment [11] [12] or the current state of single components [13], but also sense the driver's health and cognitive state [14] [15]. This poses the question, if the connected car can still be a private place even if it registers and communicates processes that take place in the interior. There is no doubt that connectivity presents new options and enables extended functions, but how do drivers perceive the advent of connectivity within the car? While technological limits of smart cars are currently shifting forward, so far relatively little attention has been payed to the user's acceptance and expectations of connected cars. Therefore, to provide an overview of user acceptance of connected vehicular services, a systematic literature review of user studies on connected cars is conducted. Subsequently, we complement the results of the review with insights from our own user study. Finally, we derive practical implications.

2 Literature review

2.1 Methodology

In order to gain an overview of the consisting literature on privacy-related user studies within the field of the connected vehicle, a systematic literature research was conducted. Using the Web of Knowledge database [16] the existing peer-reviewed literature was scanned using the key words "privacy vehicle", "privacy car", "connected car", "connected privacy" and "connected vehicle". Due to a large amount of hits (> 3000), the last key word was refined using "user", making the final key word combination "connected vehicle user". For each search, a fixed selection process was administered. The first step was to check if each result dealt with a topic directly related to the connected car and if it reported any privacy-related user study. Only papers that reported a user study within the topic of privacy in the connected car were considered. Thus, neither technical papers on connected car technologies, nor user studies on connected devices different from the vehicle were taken into account. Applying this scheme resulted in only five remaining papers. Table 1 reflects the number of hits for each individual search combination and categorizes the final papers. As reflected at the end of Table 1, an additional paper was added to the list of reported papers. [17] was not found using Web of Knowledge. However, it is nonetheless a very valuable contribution to the elucidation of the user acceptance of connected cars and is therefore included here.

Table 1. Search scheme and result categorization for literature review.

Key word combination	Hits (unselected)	Identified paper
"privacy vehicle"	500	[18] [19]
"privacy car"	89	[20] [21]
"connected car"	54	-
"connected privacy"	526	-
"connected vehicle user"	157	-
Additionally added (found at IEEE Xplore)	-	[17]

Thus, this article reviews five papers (published between 2012 and 2016). To categorize these papers with respect to their focus, several content focus are identified. Firstly, [17] provide a good overview within a comprehensive survey on conducted cars. These findings are smoothly complemented by [20] with an overview of privacy setting acceptance in connected cars. Secondly, [18] & [19] put their focus on the acceptance of event data recorders and related technologies. Finally, [21] sheds a light on the relevance of single attributes of connected services for users.

2.2 Relevant privacy factors for the adoption of connected services

Connected vehicular services are trending, but are still uncommon. Users therefore have none or only little practical experience with these services. Do users even know about their existence? Under which circumstances would users use these services? To tackle these questions, [17] conducted an international online survey with 1596 respondents from the United States, the United Kingdom and Australia on connected cars in 2014. Most participants were unaware of connected cars. However, the authors reported a generally positive impression of connected cars. Accordingly, the participants expected multiple benefits of connected cars.

They expected the number and severity of crashes to decline the strongest, while effects on traffic conditions and driver distraction were rated as least expected. On the other side, there were also manifold concerns, though the participants' concerns were less pronounced than the expected benefits. Exaggerated trust in the system, system failure and legal liability issues were the strongest concerns, but participants also mentioned data privacy concerns. 69.3 % of participants were concerned about data privacy in cars. Moreover, among connected car features, safety was the most important, followed by mobility and environment. Internet connectivity and the possibility to integrate one's smartphone in the car was moderately important. Finally, participants were moderately interested in connected vehicular technologies and were willing to pay on average 44 $ extra for those technologies.

As for most technology adoptions, the acceptance of connected vehicular services is at least partly based on the weighing of expected benefits against anticipated costs [22]. Anticipating this process, [20] further elucidated relevant factors for the user acceptance of connected cars by conducting a qualitative interview study in Japan. To identify privacy concerns and factors engaging data disclosure, the authors presented 20 participants with 14 use cases of data utilization in connected vehicles. For each use case, the authors varied the number of involved parties in data processing. Together, the use cases covered safety and security functions as well as entertainment services. [20] reported that participants rated services offering safety and security benefits more positively than infotainment-related services. Moreover, participants who drove alone were more accepting to some infotainment-related services like navigation assists, than those who had a co-driver. Critically, the range of data sharing as well as the nature of acquired data influenced the initial acceptance of a service. The more sensitive the data and the higher the number of data receiving parties, the lower the acceptance of a service was. Subsequent in-depth interviews further highlighted the relevance of data parsimony. Participants felt uncomfortable in cases of intensive data consumption, but were quite easily encouraged to disclose data by transparent usage communication.

As most personal decisions, privacy-relevant decisions also have a social aspect [18]. To study the influence of the social context, [18] studied the acceptability of event data recorder (EDR) by conducting focus groups in two French civil services which agreed to the adoption of EDRs in their vehicles (n = 28). The authors found that social context is an important predictor of acceptability of EDR systems. While most respondents accepted an implementation of EDR in their professional vehicles, most refused to equip their private car as they perceived this to be an invasion of privacy. Moreover, the respondent's decision on EDR acceptance and thus data disclosure depended greatly on data access, data usage and data identity. Next to the drivers, the authors identified manufactures as authorized parties to access the EDR data for the sake of vehicle safety. However, the systems released only car-related and driving behavior-related data, while retaining personal data allowing a direct identification (like video sequences). In contrast, management or insurance companies were completely excluded from data access.

[19] also picked up EDR technology, but compared it to further traffic safety measures with potential impact on privacy. In a large questionnaire study in Norway, Sweden and Denmark, the authors compared section control, informative intelligent speed adaption (ISA) and EDR (n = 1319). While the function of all techniques is related to crash prevention or crash investigation, the amount and frequency of data recording as well as transparency varies. While EDR is least transparent and might record the largest amount of data, section control is a modern technique for civil speed control that collects fewer data, as it is a stationary setup at certain roadsides. ISA, a driver assistant system dedicated to the support of speed control, is likely to collect more data than section control units but bears a higher transparency due to its immediate user feedback. [19] found that acceptability of the traffic safety measures varied with perceived privacy threat. Respondents perceived privacy infringement to be the highest in EDR, which thus had the lowest acceptability. Highest acceptability was indicated for section control. Moreover, the more transparent the measures were the higher acceptability was, as ISA was preferred over EDR.

The above reported studies elucidated general acceptance of connected vehicular technologies. They demonstrated that privacy plays an important role when it comes to acceptability of new technologies. However, while the studies research the adoption of new technologies, they did not simulate real choice behavior. In contrast, [21] mimicked real choice behavior by choice-based conjoint analysis on mobile insurances. 60 participants indicated their preferences for various insurances that varied in the amount of data collection and consumer saving. Insurances were able to collect location and/or road behavior data. The insurances either kept this data, exploited it for additional offerings or forwarded it to third parties for advertisement purposes. The authors found that monetary savings could compensate privacy concerns. Specifically, privacy of behavior was more important to respondents than privacy of location. In contrast, participants declined data sharing with third parties. Hence, even if choice behavior is experimentally mimicked, data type, data receiver and the perceived strength of the benefit are important factors for privacy relevant product decisions.

Taken together, our review yielded a limited number of studies that provided first insights on the impact of privacy characteristics on the acceptance of connected vehicular services. Though quite unknown to users so far, connected vehicular services are perceived as somewhat promising upcoming techniques, which are associated with distinct privacy concerns. All the studies identified the data type, the identity of the data receiver and the expected benefit as decisive privacy-relevant factors. Social context was found to be influential for adoption decisions as certain privacy-invasive services are accepted in professional, but not in private contexts. However, the studies show that transparency in data consumption and data procession as well as monetary incentives can compensate privacy concerns. Hence, these results provide us with a broad overview over relevant settings. However, to derive distinct practical implications, these insights are too shallow. For example, if the type of collected data is relevant for the adoption for a service, which data types do users perceive as sensitive? Furthermore, if users differentiate among data receivers, who do they trust? To gain more detailed insights in the user's opinion on connected vehicular services, we conducted an online-survey study that tackled the following research questions (for more results see [23]:

- How relevant is privacy in comparison to safety, security or entertainment benefits?
- Which data in connected cars is sensitive to users?
- To whom would users release their data?
- Under which circumstances are users prepared to disclose their data?

3 User study

101 participants (33 women) participated in an online-survey on connected vehicular services. The mean age was 36.74 years (*sd* = 14,17). 87 participants (86,1 %) possessed their own car. The majority of participants drove between 5000 and 15000 km per year (54,5 %). All reported results stem from either tests for binomial distribution or one-sample student *t*-tests with $\alpha = ,05$. If not reported differently, one-sample *t*-tests were tested against deviation from the center of the scale.

3.1 Results

First, we wanted to know if users perceived privacy to be more critical in cars than in other connected devices like smartphones. Participants did not report any differences (binary response options; 61.4 % do not see any differences, test for binomial distribution: $p \leq .05$). Second, we attempted to locate the relevance of privacy in comparison with different types of benefits. For this purpose, we asked how much users would agree to release personal data in exchange for mobility, safety or comfort benefits. Participants indicated their agreement on a five-point Likert scale from "agree" (1) to "do not agree" (5). Users were ready to disclose personal data like their location for advanced traffic information in real-time ($M = 1.74$, $sd = 1.13$, $t(100) = -11.20$, $p \leq .001$) as well as for an automatic emergency call system (eCall; $M = 1.56$, $sd = 0.98$, $t(100) = -14.73$, $p \leq .001$). In contrast, users were undecided whether they should release their data for automatic hotel reservations at their travel destination ($M = 3.24$, $sd = 1.42$, $t(100) = -1.68$, $p = .24$).

Next, we identified the data types that the users perceived as personal. For this, participants rated their agreement to the sensitivity of a list of data on the Likert scale mentioned above. Table 2 lists the results for the rating. Most data belonging to the category of user preferences (like seat adjustment settings) were perceived as being personal as well as physiological, driving behavior related (like distance to the vehicle in front) and location data (all $p \leq .001$). An exception was air conditioning usage which was not found to be sensitive (M = 2.71, sd = 1.26, $t(100) = -2.25$, p = .027). Users only rated environmental data (like temperature) or operational characteristics (like engine temperature) as not being sensitive. In contrast, users rated data related to car usage differentially. While mileage was found to be sensitive (M = 2.33, sd = 1.19, $t(100) = -5.60$, $p \leq .001$), participants did not agree on the sensitivity of fuel consumption (M = 2.69, sd = 1.40, $t(100) = -2.25$, p = .029).

Table 2. Sensitivity of various data types (Likert scale from 1: *agree* to 5: *do not agree*)

Data type	***M***	***sd***	***t***	***p***
Contacts	1.65	1.00	-16.11	≤ .001
Music favorites	1.65	1.05	-12.88	≤ .001
Heart rate	1.70	1.11	-11.67	≤ .001
Location	1.97	1.14	-9.02	≤ .001
Seat adjustment	2.11	1.28	-6.93	≤ .001
Mean velocity	2.15	1.27	-6.67	≤ .001
Distance to lead vehicle	2.33	1.33	-4.98	≤ .001
Mileage	2.33	1.19	-5.60	≤ .001
Service interval	2.37	1.26	-5.00	≤ .001
Fuel consumption	2.69	1.40	-2.22	n.s.; .029
Air conditioning	2.71	1.26	-2.25	n.s.; .027
Engine temperature	3.65	1.36	4.70	n.s.; $t > 0$
Tire pressure	3.67	1.43	4.65	n.s.; $t > 0$
Environmental temperature	3.96	1.43	7.41	n.s.; $t > 0$

Note: N = 101; one-sided t-test for $X < 3$ ($\alpha = .025$). Sorted by perceived sensibility (*M)*.

Aside from the data type, users see the identity of the data receiver as an important privacy factor. To elucidate whom users trust, we let our participants indicate their agreement on the trustworthiness of various parties on the same Likert scale as mentioned before. The parties the participants had to evaluate ranged from close relatives to providers of connected services. Participants had a strong trust in ambulance (M = 1.85, sd = 0.95, $t(100) = -12.04$, $p \leq .001$) and police (M = 2.16, sd = 1.24, $t(100) = -6.71$, $p \leq .001$), which was even stronger than for their own family (*M* = 2.40, *sd* = 1.31, *t*(100) = -4.52, $p \leq .001$). On the contrary, insurances (*M* = 3.79, *sd* = 1.30, *t*(100) = 6.05, $p \leq .001$) and app providers (*M* = 4.63, *sd* = 0.71, *t*(100) = 22.84, $p \leq .001$) were the least trusted parties. Table 3 displays the complete ratings for (dis-)trusted parties.

Table 3. Trust in data-receiving parties (Likert scale from 1: *agree* to 5: *do not agree*)

Data-receiving party	*M*	*sd*	*t*	*p*
Ambulance	1.85	0.95	-12.04	≤ .001
Police	2.16	1.24	-6.71	≤ .001
Family	2.40	1.30	-4.52	≤ .001
Traffic control center	3.00	1.36	0.00	> .5
Breakdown service	3.28	1.27	2.15	≤ .05
Garage	3.49	1.29	3.82	≤ .001
Car manufacturer	3.59	1.29	4.53	≤ .001
Insurance	3.79	1.30	6.05	≤ .001
App provider	4.63	0.71	22.84	≤ .001

Note: N = 101; Sorted by mean trust (*M*).

Finally, we wanted to identify a compensation threshold for data disclosure. As reported above, we found that perceived benefits in mobility and safety are strong motivators to disclose one's data. To highlight further incentives for disclosure, we confronted participants with certain circumstances and asked if they would agree to release their data. On the before mentioned Likert scale, participants indicated that they were not ready to release neither their car's operational characteristics (*M* = 3.43, *sd* = 1.53, *t*(100) = 2.78, $p \leq .01$) nor their driving profile (*M* = 3.40, *sd* = 1.49, *t*(100) = 2.66, $p \leq .01$) for monetary incentives.

3.2 Discussion

Our study contributed more detailed insights into the user's preference for privacy relevant factors. While previous studies highlighted the relevance of data type and identity of the data receiving party, we went a step further and elucidated which data are personal to users and who they trust. According to our results, users seem to be critical towards those parties that act on the private market. This even holds true for garages and breakdown providers. Moreover, our participants rated a broad range of data to be sensitive, while seemingly uncritical data like tire pressure has been shown to bear the potential to reveal delicate information about the passengers [24]. Surprisingly, we could not find a positive effect of monetary incentives on data disclosure. Hence, our results are in contrasts to those of [21]. However, as [21] assessed the effect of monetary incentives in a more concrete manner, methodical differences might have caused our diverging results.

4 Conclusion and practical implications

The advent of connected cars offers plenty of new technological options, most importantly automated driving [4]. However, connecting the car with its environment means transferring a lot of data which might include data directly related to the passengers. Hence, connected cars are relevant to the passenger's privacy. Therefore, this paper raised the question if the loss of a private zone is associated with the connectivity of the car.

As our literature review demonstrated, the connected car has so far been mainly researched from a technical perspective. We could identify only a few articles dedicated to privacy impacts from a user's point of view. Nonetheless, together with our own results, the literature review sketched users out to be ambivalent towards connected vehicular services. While viewing the integration of the car into the smart grid as a promising opportunity for enhanced functions, users had severe privacy concerns. As [18] reported, users do not want their private car to be equipped with smart sensors. During the course of this paper, we identified important factors that influence these concerns and thus the acceptance of connected vehicular services. Next to data type, the reviewed studies reported the purpose of data collection and the identity of the data receiving party to be influential. Our own results allowed a closer look on some of these factors and detailed the acceptance of single data types as well as the trust in different data receiving parties. However, we identified possibilities for manufactures and service providers on how to foster the adoption of connected vehicular services. Besides a perceived benefit from the usage of the service and monetary incentives, transparency in data collection and data processing motivates users to disclose their data.

User acceptance is indispensable for the successful introduction of new technologies [25]. This especially applies for connected vehicular services that introduce pervasive computing into the private car [26] and thus might turn a so-far private refuge transparent. Developers need to be particularly cautious when designing these systems or services. Highlighting important privacy-relevant aspects that should be taken into account, this paper provides first suggestions on how to configure those connected vehicular services in order to comply with user expectations.

First, collect your data parsimoniously. Though data have become a new source of high economical value [27], developers should not only be parsimonious from a legal point of view. User view a broad range of data that are available within the vehicle as being sensitive. Collecting this data is likely to lower the acceptance of a new service.

Second, if this data is collected, share it with as few as possible. Our review showed that if more parties are granted access to the collected data, the lower user acceptance becomes.

Third, differentiate between private applications of the connected vehicular service in private versus professional contexts. Users tend to be more reluctant towards connected vehicular services in their private car than in professionally used cars. Therefore, privacy-relevant factors become even more relevant when designing a connected system or service for private cars.

Finally, communicate the extent and purpose of data collection transparently. User expect an honest and transparent communication of intention and purpose of data collection. As studies have identified transparency as an important success factor of information systems [28], it should be a core interest of manufactures and service providers to design transparent connected vehicular services. Here, one might characterize transparency by the honest communication of privacy-relevant factors that have been found to be important for user acceptance: data type, identity of data receiver(s) & purpose of data. Moreover, during the course of this paper, we identified transparency as a strong incentive for users to disclose their data. Transparency builds trust between consumers and firms [29] and thus is a powerful tool to gain consumers.

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6 Keywords

Connected car, privacy, user, acceptance.