
Proceedings Paper:
Kolarova, V, Ertl, D, Aittoniemi, E et al. (4 more authors) (2020) Assessing user expectations, requirements, and concerns toward automated driving progressed by internet of things – a user-centric development approach. In: Lusikka, T, (ed.) Proceedings of TRA2020, the 8th Transport Research Arena. Transport Research Arena, 27-30 Apr 2020, Helsinki, Finland. Finnish Transport and Communications Agency Traficom , p. 119. ISBN 978-952-311-484-5

Rethinking transport
27–30 April 2020

TRA 2020 HELSINKI

Proceedings of 8th Transport Research Arena TRA 2020, April 27-30, 2020, Helsinki, Finland

Assessing user expectations, requirements, and concerns toward automated driving progressed by internet of things – a user-centric development approach

Viktoriya Kolarova[1*], David Ertl[2], Elina Aittoniemi[3], Gillian Harrison[4], Katerina Touliou[5] , Yvonne Barnard[4], Lara Naendrup-Poell[1]

[1]*German Aerospace Center, Institute of Transport Research, Rudower Chaussee 7, 12489 Berlin, Germany*
[2]*FIA, Rue de la Science 41, 5TH Floor 1040 Brussels, Belgium*
[3]*VTT Technical Research Centre of Finland Ltd, P.O.Box 1000, FI-02144 VTT, Finland*
[4]*Institue for Transport Studies, University of Leeds, Leeds, LS2 9JT, UK*
[5]*CERTH, 6th km Charilaou-Thermis, 57001 Thermi Thessaloniki, Greece*

Abstract

Road vehicles are becoming increasingly automated and connected due to rapid technological progress and digitalization trends. Vehicle connectivity might improve automated driving (AD) in various ways. The EU project "AUTOPILOT" develops, tests and evaluates different services and use cases of automated driving focusing on the potential of Internet of Things (IoT) to progress AD. In order to provide early insights on expectations, requirements and concerns of potential users, an online survey was conducted following a user-centric development approach. Three different scenarios of AD progressed by IoT as well as desirable functions of the services were evaluated from user perspective. The analyses look into how IoT enhances, enables and accelerates AD. The results suggest the following benefits of IoT for AD when considering user acceptance: first, IoT can enable using the services with AD through easier trip planning by providing real-time traffic system information. Second, IoT can accelerate the market deployment of AD services as trust in the system is increased by providing information about the vehicle operation – one aspect which is crucial for user acceptance of AD. Third, IoT can contribute enhancing the user experience by providing real-time information about POIs and enabling customization options. This contribution summarizes the main results and discusses their implication for the development of the technology.

Keywords: automated driving, internet of things, connected driving, user acceptance

* Corresponding author. Tel.: +49 30 67055-500;
E-mail address: viktoriya.kolarova@dlr.de

1. Introduction

Rapid technological development and digitalization in almost all areas of daily life leads to ever increasing automation in transportation, including vehicle automation. The vehicle automation can be defined in five levels - from no automation (level 0), through low or partly automation (level 1 and 2), conditional automation (level 3) and high (level 4) to full (level 5) automation (SAE, 2018). While highly and fully automated driving can be achieved only relying on vehicle sensors, additional connectivity of the vehicle with its environment, i.e. converging sensor-based technologies and connected-vehicle communications, can progress the vehicle automation in various ways (e.g., KPMG, 2012). The main potential benefits of connectivity include accelerating and enhancing the technology of automated driving and its acceptance, and/or in some cases also enabling automated driving. Whilst there is already a body of literature about the user acceptance of autonomous driving and its drivers and barriers (see e.g. Fraedrich et al., 2016, Frison et al., 2018, Helgath et al., 2018, Payreet et al., 2014, Rödel et al., 2014), there is only little to no literature focusing on the impact of the Internet of Things (IoT) in automated cars on user acceptance (see e.g. Dominic et al., 2016 for a qualitative approach to understand the expectancies towards smart vehicles in an IoT context). Therefore, the focus of this research is on the added value of IoT in automated driving scenarios.

The research project "AUTOPILOT" (https://autopilot-project.eu/), funded by EU H2020 Research and Innovation programme, addresses the potential benefits of using Internet of Things (IoT) for automated driving (AD) by bringing together experts from the automotive as well as the information and communication technologies (ICT) world. Different use cases of AD progressed by IoT were developed by the project partners and tested at five pilot sites in Europe. The proposed use cases were evaluated from technology, business, user, society and legal perspectives. Understanding the user acceptance of the tested services is one important part of the evaluation and plays a crucial role for the future market penetration of the technology. Thus, analysing requirements, expectations and concerns of potential users is needed in order to evaluate the potential of the services and help us understand the users' mental models. Moreover, focussing on user expectations, requirements and concerns allows for user-centric development of the services and features ensuring that the technology serves the needs of the users.

The aim of the work presented in this paper is to assess the user acceptance of selected use cases of automated driving progressed by the use of IoT technologies by the general public. Since the services and functionalities tested in the project are in an early development phase, this study focuses on the preferences of potential users related to different anticipated features of the final products that make it useful and easy to use (two crucial determinants of user acceptance of technologies). Also, as the project focuses on the benefits of IoT for automated driving, the analyses look into how IoT enhance, enable and/ or accelerate AD.

2. Methodology

2.1. Overview of the empirical approach

As the services and features considered in the project were in an early development phase, the evaluation of the user acceptance in terms of willingness to use the technology followed a user-centric approach. Participation of users in the design process can take place at different levels including conducting surveys with potential users about their wishes and needs and letting users testing prototypes and giving feedback to the researchers (Friedhof, 2016). The approach of this project integrates those two main parts for the evaluation of the developed services – the first one is assessing user preferences of the general public in an online user survey and the second one is using the results as recommendations for developers and as input for pilot testing of the developed services with potential users within the "AUTOPILOT" projects. This paper focusses on the first phase – assessing user preferences from surveying the general public.

Many studies on user acceptance in the context of automated and connected driving are based on theoretical approaches on acceptance of new technologies, such as the Technology Acceptance Model (TAM) developed by Davis (1985) and the Unified Theory of Acceptance and Use of Technology (UTAUT; Venkatesh et al., 2003).This survey is not directly based on this approach. However, it is in line with its main concepts, which suggest that user acceptance (in terms of willingness to use a service or function) is determined by evaluation of the usefulness and the ease of use of the technology. Following this approach, in the survey we identify functions

or features of services that use IoT which are desirable for the users and which are the main concerns or acceptance barriers related to them. Thus, the assessment focusses on how services can be developed in a way to be perceived as useful and ease to use from a user perspective. In this sense, we have added an explorative pre-phase assessment of user acceptance determinants by addressing the expectations and requirements of potential users in the development stage of new services. Since the focus of the study is on the IoT part of services and IoT primary enables exchange of information and data, we explore deeper the requirements of the users on required information (e.g., real-time traffic or vehicle operation information) as well as concerns related to data exchange (e.g., data privacy or cyber security). Finally, we derived conclusions from the analyses about how will IoT enhance, enable or accelerate AD when considering user acceptance and user expectations, requirements, and concerns.

2.2. Considered use cases/ scenarios

Three scenarios were considered in the online survey for the general public. The selected use cases represent use cases of automated driving progressed by IoT that are developed and tested in the framework of the project "AUTOPILOT" and all rely on the user accessing the services through a mobile phone app. All use cases were presented to the respondents in short stories with pictures and short text description. The participants were led through the use case by describing briefly different phases of the usage of the service including booking of the service, using the service or during operation and finishing the use of the service. In this sense, we covered the full user experience addressing requirements and concerns on each stage of the user´ "journey" with additional overall evaluation of the service. Respondents were asked to report their requirements, concerns and evaluation of the service in each phase of the story by asking them to imagine being in the place of the main character of the story.

Scenario A "Carsharing as a touristic experience" considers a use case where tourists can use a new service in Versailles – they can rent a small vehicle using a smartphone application and use it in the city following a pre-defined route. In the Gardens of Versailles, tourists have the option to ride in the vehicle in automated mode and receive information about sights on the route. This scenario represents a use case where IoT functions enhance the user experience during automated driving by providing touristic information to the users. Additionally, IoT enables booking a vehicle, planning the route and reserving a parking spot at a return station.

Scenario B "Platooning" addresses a use case where users can drive together in a so-called "platoon" on a highway. A "platoon" is a formation of cars that drive as a group in close proximity to each other, with one manually driven car leading the group and the other cars following the leading car in self-driving mode. In addition to booking the service and matching the routes of the users, the IoT serves to connect the cars with each other as well as with the smart infrastructure, thus ensuring smooth communication between the leading car and the following cars. Platoon users can drive on a priority lane and reach their destination quicker and at lower cost and emissions than if they travel independently.

The use case presented in Scenario C "Automated Valet Parking" describes a new parking service where users can drive their car to a drop-off station, allowing their car to park autonomously in a free parking space. The IoT connects the parking management system with an app to provide the user with information on the availability and location of free parking spots. In addition, the IoT ensures that the self-driving car moves safely to the selected parking space and to the pick-up point when the user wants to retrieve it again via the app.

2.3. Study set up and sample

In order to assess requirements, expectations and concerns of different potential users, the online survey was conducted in eight countries: UK, Germany, France, Italy, Spain, Netherlands, Greece, and Finland. The countries were selected to represent different European countries as well as to cover the countries where the "AUTOPILOT" services are piloted. For the online implementation of the survey as well as for the recruiting of the study samples a professional service provider was used. The samples were selected to be representative for the population demographic in the selected countries by age and gender for the population between 18 and 69 years old. The sample size was n=200 persons per country for the first two scenarios (total n=1600 each) and n=100 for the third scenario (automated valet parking, total n=800).

The online questionnaire included detailed descriptions of the selected scenario and closed questions focussing

on evaluation of single stages of the scenario. The scenario was presented in a storyboard format, using pictures and short text describing each scenario phase. In the scenarios, the story included three scenario parts – i) booking a vehicle/ service, ii) using the service (i.e., using the vehicle on a trip including an automated driving part), and iii) returning the booked vehicle or finishing the use of the service.

2.4. Instruments and data analyses

The questions used in the questionnaire were mostly closed questions where respondents were asked to evaluate different aspects on a seven-point Likert scale ranging from "very relevant" to "not relevant at all" for requirements regarding information provided by the service and "very concerned" to "not concerned at all" for concerns related to the booking or use of the service. The relevance of different types of information was considered as information which can be from the user perspective important, necessary, and interesting (or desirable) or a combination of these types of information. Additionally, questions related to the overall evaluation of the scenario as well as socio-economic factors were assessed. Descriptive analyses of the data were performed using the statistic software IBM SPSS (IBM Corp., 2011) and Excel. Selected results from these analyses regarding requirements, concerns and overall evaluation of the service from the user perspective are presented in the section that follows. The relationships between the assessed variables can provide additional insights into the data and will be considered in future work as this contribution focuses on descriptive statistics.

3. Results

The presented results are based on the analysis of data from the full sample and only in some part of the text selected results that indicate country specific differences are briefly mentioned. The questionnaire was developed in order to explore which features make the use case useful and easy to use. Identification of anomalous aspects would be an interesting finding.

3.1. Scenario A: Carsharing as a touristic experience

3.1.1. Requirements on information provided before and during the using the service

In the survey, the respondents were asked about the relevance of different types of information provided by the service in different phases of the use of service – before using the service (i.e., when booking the service) and during the usage (i.e., during operation). The results suggest that overall most of the respondents consider the presented information as relevant. There is some variation between the information types. Information most rated as "very relevant" includes the availability of a vehicle (53%), followed by instructions on how to use the service (49%). Less relevant than the mentioned aspects were estimated waiting time in case that no car is currently available, the route of the tour, availability of a free parking space when returning the vehicle, and contact information for a customer service. Information about restaurants, hotels and cafés was rated as least relevant from user point of view. When considering the information required during operation, i.e., using the vehicle in the Gardens, one finds that most of the potential users (66%) evaluate real-time tourist information as (very) relevant. This is not surprising considering the main purpose of the introduced service and indicates a positive assessment of this function. The other types of information that can be provided by the service during the usage phase are considered equally relevant.

The country specific analysis revealed rather small differences in the relevance of the provided information. Respondents from the UK, Greece, Finland and Italy seem to rate the information more relevant whereas respondents from the Netherlands tend to rate them slightly less relevant than the other countries.

Together, the results show that potential users attach high relevance to various kinds of information that supports them by planning their tour, improving the booking option, and making it easier to use the service. Moreover, one of the core features of the service - real-time touristic information - is evaluated as the most relevant information (of those questioned) from the user perspective, with nearly 70% of respondents rating it in the top two levels of relevance.

3.1.2. Concerns

Besides the relevance of different types of information, respondents were asked to what extent they would be concerned or not concerned about different aspects related to the booking and usage the service. The given options for potential concerns in the booking phase were all rated in a similar way, as expected. The option on which the most respondents chose "very concerned" was regarding the payment process for using the service. For all mentioned aspects (including cyber security, payment process, data privacy), less than 10% of the respondents reported that they were not at all concerned. A similar question regarding potential concerns of users was asked also for the phase during the operation of the vehicle, i.e., when using the service. This question was more limited than the first question, focussing on concerns related to safety aspects in the automated driving mode and impact on other road users. There is also very little difference in responses between the three aspects – probability of vehicle malfunction, making vulnerable users feel uncomfortable, and malfunction or loss of data affecting information - , suggesting relatively equal levels of concerns. Trends between countries showed that participants from the UK, Finland and Spain seemed to be most concerned, both before the operation and during the operation, whereas respondents from Italy and Greece appeared least concerned. In summary, more potential users expressed security concerns related to the payment for the service than any other aspects.

3.1.3. Overall assessment of the presented scenario from the user perspective

The overall assessment of the presented scenario was positive - the vast majority (>80%) of the respondents evaluated the service described in the survey as a positive experience (i.e., scoring it between 1 and 3 on a seven point scale ranging from a positive experience to negative experience), which was perceived by over 75% (scores 1-3 on a seven point scale ranging from very exciting to very boring) of respondents as exciting, useful and easy to use. These aspects were all rated relatively equally, suggesting consistency of respondent answers. Although a lower number of respondents (66%) felt the service was safe (scoring 1-3), this was still over half of respondents. However, this finding suggested that challenging perceptions of safety may be a main barrier to user acceptance.

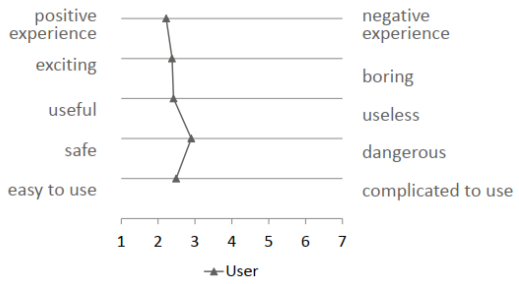

Fig. 1 Semantic differential of the overall assessment of Scenario A

3.2. Scenario B: Platooning

3.2.1 Requirements on information provided before and during the using the service

In the survey, the participants were again asked about the relevance of different types of information supplied by the service at different stages of its use. The information prior to the use of the service that was judged to be (very) relevant by the majority of participants is information about the current traffic situation on the highway (60%) and the estimated travel time (59%) while information about emission savings when platooning (38%) and other options for reaching the destination were rated (very) relevant by fewer respondents. Overall, most of the presented information during operation seems to be more relevant to the respondents than those before using the service.

The questions were asked from the perspective of both – platoon leader and user sitting in the following car. For the platoon leader especially real-time information about accidents and congestions are considered (very) relevant (75% and 73%) as well as information about road works (69%) and suggestions for alternative routes (65%). In comparison to the above aspects, information about concerns or other communications from other users in the platoon and real-time information about the weather are rated (very) relevant by fewer participants,

although it is still relevant for almost half of them. As one of the following cars in self-driving mode the information rated (very) relevant by the most participants are, generally speaking, information about the driving behavior of the leading car, thus why the leading car is doing something (66%) and what the leading car is doing or about to do (e.g. reduction) (65%). Information about what the self-driving car is doing or about to do and the estimated time left in self-driving mode are rated equally relevant.

The country specific analysis showed again that respondents from the Netherlands have a tendency to rate the required information less relevant than most of the other countries, while Greece and Germany tend to evaluate the presented information more relevant. It is noteworthy that especially the rating of "very relevant" is chosen less frequently by participants from the Netherlands.

In total, the results show that information during platooning have a high relevance to potential users. In particular information on the driving behavior of the leading vehicle and the following cars in self-driving mode as well as events that might influence this behavior are highly relevant to the respondents. Information when considering the service is overall rated relevant by fewer people, but here as well information concerning the trip itself is the most relevant.

3.2.2. Concerns

The presented concerns relate to the use of the service and take into account the perspective of the platoon leader and the cars in self-driving mode. General concerns during operation refer to cyber security (44% (very) concerned) and data privacy (40% (very) concerned) as well as the unknown platoon leader. 44% of the respondents are (very) concerned, that the leader might not be a safe driver and 40% are (very) concerned, that the leader might not be the person they say they are. The least concerns relate to the effect of the platooning app on the smartphone battery (25% (very) concerned). In the platoon leaders perspective the responsibility for the safety of the following car(s) is most concerning (41% (very) concerned) followed by cyber security (40% (very) concerned) and technical failure of a following car (36% (very) concerned). From the perspective of a potential user in a self-driving car that follows the platoon leader 46% of the respondents claim to be (very) concerned about the safety of the self-driving mode, which is not necessarily an aspect that can only be attributed to the platooning use case, but probably refers to autonomous driving as such. Regarding the platooning service, participants are (very) concerned that the driver in the leading vehicle might have a bad driving style (44%). Cyber Security is for 41% of the respondents also a concerning aspect again.

Country differences regarding the concerns are rather small and most participants seem to have the same level of concerns, but participants from Italy seem to be less concerned than other countries. For example, for cyber security just a quarter of the Italian respondents, but almost half of the British respondents claim to be (very) concerned.

All together the main concerns are related to both the reliability of the system, including cyber security and the self-driving mode, as well as the driving behavior and identity of the platoon leader. In general, at least a quarter of the participants evaluate any aspect as alarming, showing that there are a lot of concerns that need to be addressed in the future.

3.2.3 Overall assessment of the presented scenario from the user perspective

The overall assessment of the platooning scenario was evaluated separately for the perspectives of the platoon leader and follower. The majority of the participants rated the scenario as a positive experience (77% from the follower's perspective scoring between 1 and 3 on a seven point scale ranging from a positive experience to negative experience and 78% from the platoon leader's perspective), whereas it was perceived as exciting, useful and easy to use for more than two thirds of the respondents. The biggest difference, though still rather small, between the two perspectives refers to the safety. 64% rated the scenario from the platoon leader's perspective as a safe experience in contrast to 60% from the follower's position. In general, the results indicate that the scenario is assessed slightly more positively from the perspective of the platoon leader. Even though most of the differences between both perspectives are statistically significant (e.g. for exciting vs. boring the score was lower, i.e. shifting more towards exciting, from the leader perspective (M = 2,63, SD = 1,42) than the follower perspective (M = 2,69, SD = 1,31), with t = -2.25, p = .025), the Cohens d effect sizes reveal only very small, negligible effects (e.g. exciting vs. boring, d = .055) with the biggest effect size for safe vs. dangerous (d = .16),

which still has to be judged as small according to Cohen's conventions (Cohen, 1988). The small effect size can result, however, from a high variation within the full sample. Thus, in the next step, clustering the sample around smaller groups (e.g. extremes coupled together) might provide additional insights on potential differences. Once again, the results suggest that the perception of safety might be a potential barrier to user acceptance of autonomous driving.

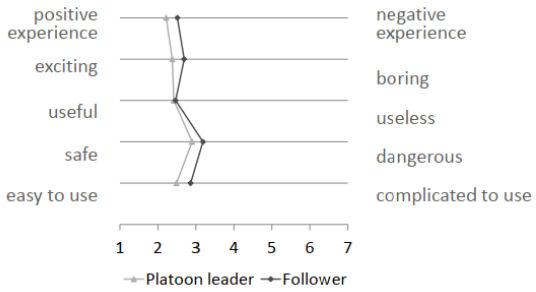

Fig. 2 Semantic differential of the overall assessment of Scenario B from the perspective of a platoon leader and a follower

3.2. Scenario C: Automated Valet Parking

3.3.1 Requirements on information provided before and during the using the service

In Scenario C, the relevance of the required information for the situations during operation and when picking up the parked vehicle was assessed. The information rated (very) relevant during operation by most participants was the availability of a free parking spot (70%) followed by the location where the service is available on a city map (61%) as well as the (real-time) location of the car while it is parking and the free parking spot (58%). Least relevant, though still relevant for more than half of the respondents, is the parking status of the car (e.g. it is parked now). When picking up the parked vehicle the various presented information is judged as slightly less relevant than during operation. Most important is the information on real-time location of the car which is judged (very) relevant by 61% of the participants. Contact information for customer service is (very) relevant for half of the respondents while Information about what the car is doing or about to do (e.g. turning, braking) and what the car "sees" (e.g. detected pedestrians) is perceived as (very) relevant by less than half of the participants (42% and 44%).

With regard to the country-specific analysis, the picture is the same as before in the other scenarios; participants from the Netherlands seem to rate the information as somewhat less relevant than respondents from the other countries.

In summary, potential users demand information that enables the use of the service, such as the availability of the service and the availability of free parking spots as well as monitoring options during operation.

3.3.2. Concerns

General concerns during operation refer to the reliability of the system, 43% are (very) concerned that the automated system of the car might not work reliably, and relate to cyber security, 39% of the respondents claim to be (very) concerned, e.g. about vulnerability to hacking. Data privacy is a concern for a quarter (26%) of respondents. While waiting for the car to drive to the pick-up station the concerns are rather similar and include the reliability of the automated system (44% (very) concerned), cyber security (37% (very) concerned) as well as incorrect information due to malfunction or data loss (39% (very) concerned) and data privacy (26% (very) concerned). Thus, the main concerns regardless of the situation are related to both the reliability of the vehicle technology and cyber security. Cyber security is for respondents from Italy and Greece less concerning than for the other respondents, but the reliability of the system concerns all respondents equally.

3.3.3. Overall assessment of the presented scenario from the user perspective

The overall assessment of the automated valet parking scenario is positive. Over 70% evaluate the scenario as a positive experience (71% scoring between 1 and 3 on a seven point scale ranging from a positive experience to

negative experience), as exciting (75% scoring between 1 and 3 on the scale ranging from exciting to boring) and useful (76% scoring between 1 and 3 on the scale ranging from a useful to useless). Furthermore, 63% of the respondents perceived the scenario as easy to use. It is noteworthy that the safety aspect again receives the lowest approval, with only 44% of the participants rating this scenario as safe (scoring between 1 and 3 on the scale ranging from safe to dangerous).

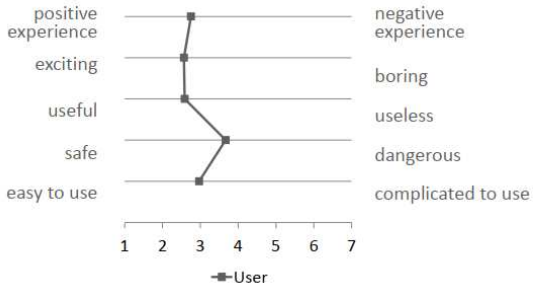

Fig. 3 Semantic differential of the overall assessment of Scenario C

4. Discussion and conclusions

The survey presented in this paper aimed to assess potential user acceptance, in terms of usefulness and ease of use, of features and services based on automated and connected driving. For this purpose a an online survey was conducted where a concrete scenario is presented to potential users asking them about expectations, requirements and concerns regarding the service in different phases of the use (when booking the service, during operation and after usage). The main advantage to the proposed approach is that the results of the survey can be used in a user-centred development of functions and services, which potentially contribute to the user acceptance after introducing the final product to the market. In this paper, first results from the survey on one of overall three evaluated scenarios were presented. The analyses were focused around the question how IoT enhances, enables and accelerates AD.

Based on the results for the first scenario, some general recommendations for developing the services were derived. The results suggest that making the service easy to use and customizable plays an important role in ensuring user acceptance (i.e. willingness to use the service). In particular, coping with concerns related to the safety during the execution of the self-driving functions by providing sufficient information about what the vehicle is doing or about to do for instance, would be crucial. In all these aspects, the IoT will play a crucial role in enabling the provision of more detailed information in real time. Concerns related to payment security and malfunctions are important for both developers and service providers and users, as they can potentially affect users' trust in IoT systems' use during automated driving. Therefore, we concluded the following benefits of IoT for AD when considering user acceptance: first, IoT can enable using the services with AD through easier trip planning by providing real-time traffic system information. This aspect is related to the performance of the system. Second, IoT can accelerate the market deployment of AD services as trust in the system is increased by providing information about the vehicle operation – one aspect which is crucial for user acceptance of AD. This point can be considered as a base IoT-function for AD mainly because it increases the sense of control when driving automatically. Third, IoT can contribute enhancing the user experience by providing real-time information about POIs and enabling customization options. This aspect is rather an excitement than a performance factor which can be also crucial when considering using an AD-based service. All in one, all aspects – making the service useful from user perspective, its performance understandable and reliable as well as enhancing the experience - have to be considered when developing new services. The weight, i.e., the importance, of the different factors on the decision for using the service, can be further explored in future research. Moreover, user tests allowing potential users to experience the service, as planned within the "AUTOPILOT" project, can additionally provide important insights on developing key features of the service and suitable human-machine-interaction.

Acknowledgments
The project "AUTOPILOT – Automated driving progressed by Internet of Things" is funded by the European Union´s Horizon 2020 Research and Innovation programme under Grant Agreement No 731993. Detailed

description and analyses of the survey data are presented in deliverable "D4.7 User Requirements Analysis", available under http://autopilot-project.eu/deliverables/. The authors want to thank all project partners who contributed to the development of the concept for the survey and the data analyses especially other D4.7 authors.

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