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ORIGINAL RESEARCH

# Drivers' usage of driving automation systems in different contexts: A survey in China, Germany, Spain and USA

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**Abstract**

The purpose of the study was to investigate how drivers use assisted and automated driving systems (DAS), more specifically their usage of SAE Level 1 and Level 2 systems, in different situations. An online survey was distributed to 2500 respondents in China, Germany, Spain, and the USA. The final dataset consisted of 549 respondents, all non-professional drivers, with access to a minimum of a Level 1 system. A subset, 159 in total, had access also to a Level 2 DAS. The survey included questions on the attitude towards, access to, and usage of Level 1 and Level 2 systems in nine different situations respectively. The data was analysed on an individual and a national level. A cluster analysis showed two main groups: frequent and non-frequent users. On an individual level, the reported usage of Level 1 and Level 2 DAS respectively differed depending on traffic situation, weather and daylight conditions and driver state. Reports by respondents with access to both Level 1 and Level 2 systems did not reveal any statistically significant differences in usage between situations. The Spanish sample was the only one that showed a consistently different usage pattern compared to samples from China, Germany, and the USA.

## 1 | INTRODUCTION

The automotive industry is rapidly developing different types of Driving Automation Systems (DAS) with potential to fundamentally change road transportation and traffic safety for all road users. The systems are not only designed to assist the driving task and enhance driver convenience [1], but also the drivers' and other road users' safety, through the detection of hazardous traffic situations, advising, warning and/or actively assisting the driver in avoiding or mitigating accidents [2–4].

According to the SAE [5] standard J3016, DAS can be classified into six levels depending upon the technical system characteristics. The classification ranges from Level 0 'No Driving Automation' to Level 5 'Full Driving Automation', whereby each level describes different function allocations between the driver and DAS and defining who is responsible for which task during the driving activity [5].

DAS have become increasingly standard equipment in vehicles, with Level 1 and Level 2 systems already widespread on the different vehicle markets globally [6]. Level 1 systems are systems that offer driving support through accelerating or decelerating the vehicle to "automatically maintain a driver pre-set speed and driver pre-set gap distance from the vehicle in front" [7]. Level 2 systems in addition maintain the vehicle between lane markings and usually work in combination with Level 1 systems, offering therefore, both longitudinal and lateral support [8].

However, no benefits in terms of increased comfort or traffic safety will be achieved if the systems are not used or are not used as intended. While the projected path of development indicates a relevance to the driving context and the usage of the system, little has been investigated as to when drivers tend to use which DAS, and if there is a difference in usage between driving contexts and the chosen DAS.

### 1.1 | Earlier studies

In earlier studies on DAS, users' attitudes towards different systems and the intention to use for instance Level 1 systems, that

is, Adaptive Cruise Control (ACC), or future fully automated systems have been widely addressed. A common approach in exploring these topics is the use of questionnaires (see, e.g., [9] for an overview), which are distributed to respondents with no prior knowledge of the systems. The intention to use fully automated vehicles, and a priori acceptability have been explored for example by Payre et al. [10], Schoettle and Sivak [11, 12] and Liljamo et al. [13]. Schoettle and Sivak [11, 12] investigated, for example public opinion about self-driving vehicles in China, India, Japan, the USA, the UK, and Australia and concluded that a majority of the respondents had a positive initial opinion of the technology and also high expectations about the benefits. In addition, Payre et al. [10] as well as Liljamo et al. [13] concluded that, although their respondents had not driven a fully automated vehicle, they had positive attitudes towards the concept. Especially men, people with a higher education, those living in more densely populated areas, and households without a car expressed a more positive attitude than others. However, attitude and intention to use appeared to be linked to the driving environment, making contextual acceptability an interesting aspect to investigate further (see Payre et al., [10], Liljamo et al., [13]). Rödel et al., [14] expanded their study to address the effects of different levels of automation on acceptance and user experience. Their results showed that attitude towards the systems and the intention to use an automated system were highest for Level 1 DAS and decreased with an increasing level of autonomy. Furthermore, a correlation between pre-experiences with DAS and attitude towards automated cars was found. These findings are in line with results by Choi et al. [15] as well as by Viktorová and Sucha [16] who found that drivers' awareness and knowledge of DAS played an important role in the acceptance of these kind of systems. The same was shown in the previously mentioned literature review by Becker and Axhausen [9]. However, an overall positive attitude towards, or valuation, of DAS does not necessarily imply usage, as shown by Luarcio et al. (2019). Based on a survey of Spanish drivers he and colleagues found that despite overall positive assessments of systems, certain drivers chose to not use certain systems they had available in their vehicles.

Another stream of research has focused on exposing users without prior knowledge of DAS to the functionalities of the systems, either in driving simulator studies or in field studies (such as Field Operational Tests, FOTs). One example is a driving simulator experiment conducted by Stanton and Young [17] whose aim was to analyse driver behaviour during interaction with ACC functions. They found that the systems fulfilled their respective role as comfort and convenience devices, reducing driver's workload in different situations. Their results indicated however also that these benefits did not support a better understanding of the limitation of systems or an improved situation awareness. These findings are also not consistent with other studies that intended to determine drivers' usage and understanding of ACC systems. For example, Weinberger [18] found in a four week-long FOT that drivers learn how and when to use ACC systems already after two weeks and a survey reported by Larsson [19] indicated that the longer drivers used their systems, the more aware of the limitations they became.

Although several different studies on acceptance and usage of ACC systems have been accomplished, only a few studies have attempted to explore if and how these factors change over a longer period of time, or have investigated users, their experience, and use behaviour in different contexts. An exception is a controlled on-road study that aimed to investigate how drivers use ACC in distinct road environments and if changes in usage occur over time [20]. This study was conducted in Germany over a period of two months and included drives on motorways as well as on urban roads. The results showed that becoming familiar with the functionality of the system was a fairly quick process, but learning about the system's limitations depended on the experiences made as well as on the environment in which the driving (and hence usage of the system) took place. Another long-term FOT with 20 vehicles was conducted over a period of six months in the Netherlands. The study focused on the interaction between driver and ACC systems and the adaption of drivers' driving behaviour as a consequence of ACC use. One of the findings was that the system was not activated in all conditions, for instance in dense traffic conditions [21]. The same conclusion was drawn by Fancher et al., [22] based on a US trial with 100 drivers.

Most earlier studies have had a national focus and only a few have investigated DAS usage across countries. A recent exception is Orlovska et al., [23] who, based on Naturalistic Driving Study (NDS) data from 218 vehicles in China, Sweden, and the USA, found that the use levels of both ACC (Level 1 DAS) and Pilot Assist (Level 2 DAS) differed; they were highest for the US sample and lowest for the Chinese sample. Other studies have implied that drivers' usage of these types of support systems may be explained by differences in perception and culture. For example, Lindgren et al. [24] compared attitudes of Swedish and Chinese drivers and found that although traffic regulations were similar in both countries, drivers' opinions and acceptance were highly mediated by differences in terms of available infrastructure and in driver behaviour. In another study involving focus groups in Sweden and China, Wang et al. [25] identified different information needs based on country specific scenarios that were introduced to the participants. The outcome of the study was that there were differences between Swedish and Chinese drivers' information requirements, especially in complex traffic situations, despite the fact that traffic regulations did not differ for the proposed scenarios. This led the authors to conclude that differences in the traffic environment and safety culture of each country influenced drivers' perception of the driver support systems. Moreover, through focus groups and a survey, Gonçalves and Quaresma [26] tried to identify user needs regarding the design of DAS for the Brazilian market and concluded that factors such as road infrastructure and safety-perceptions affected user experience with more complex DAS.

Thus, the reported studies imply that the characteristics of the technology alone are not the only determining factors in the successful adoption and use of an advanced driver support

function, but that usage of such systems depend also on other, human, factors and on surrounding conditions, such as driving context and traffic environment.

### 1.2 | Rationale

The rationale for the study and, hence, the paper is as follows. Earlier research has focused either on drivers' interactions with DAS by means of simulations or quasi-experimental setups and questionnaires to participants with no prior experience of the systems in question. The present paper focuses on users with use experience.

Secondly, most previous research has described drivers' use of Level 1 DAS, with Adaptive Cruise Control (ACC) as the focus of investigation. To the authors' knowledge, no previous study has considered how the different levels of automation, i.e., how Level 1 compared to Level 2 DAS (as defined by SAE), are used. The present study addresses and compares if and in what situations users use the two levels respectively.

Thirdly, only a limited number of studies have considered context, that is the traffic environment and different traffic conditions, as an influencing factor for use of DAS despite indications that driving contexts and traffic environments may play a significant role in drivers' usage of automated driving systems. The present study focused specifically on in what traffic situations drivers choose to use or not use the respective systems.

### 1.3 | Research objectives

The aim of the present study was consequently to develop further knowledge on drivers' usage of different types of automated driving support systems. In particular, the following questions were posed:

- To what extent do drivers use DAS Level 1 and Level 2 in different traffic contexts (more specifically types of roads, traffic situation, weather condition) and driver states?
- Does drivers' usage of DAS Level 1 and Level 2 differ between different traffic contexts and driver states?

## 2 | METHOD

### 2.1 | Survey

Data was collected in October 2018 by means of an online questionnaire, set up using the survey tool LamaPoll and distributed via e-mail through a third party with access to different national vehicle markets.

The survey consisted of 36 questions that took the respondents between 10 and 15 min to complete. Definitions of a Level 1 and a Level 2 system were provided, The Level 1 system was defined as "a system which automatically speeds up and slows down the vehicle to keep a set following distance relative to the car ahead, provides some braking." The Level 2 system was defined as a system that "assists the driver with steering support, keeping the vehicle in the centre of the lane, as well as distance and speed control in situations ranging from slow moving traffic jams to free-flowing, long-distance, driving on the highways or other main roads."

As a next step, the participants were asked to indicate if their car (the one they owned, had access to or most often drove) was equipped with a Level 1 and/or a Level 2 system. The respondents were then asked to indicate how often ("never", "sometimes", "most often" or "always") they activated the respective systems considering nine different situations (motorway, city traffic, dense traffic, less dense traffic, snow/heavy rain, slippery road conditions, in the dark, when monotonous driving and driving when tired).

An additional question concerned their general opinion about systems that partially take of the driving task and to indicate their agreement with nine statements regarding in which situations they consider handing over part of the driving control to the car. The scale ranged from "completely disagree" to "completely agree". The statements referred to the same situations that they considered in their reported usage of the DAS.

Additionally, background information was collected on the respondents' age, gender, education level and driving experience (years as well as kilometres per year), if the participants drove for professional or non-professional reasons, as well as their primary driving contexts (urban areas, rural roads, expressways/highways).

The questionnaire was conducted in the official languages of each country and translated by native speakers from a common English version. The data was collected with the informed consent of all respondents and their prior agreement to participate in the study. The retrieval, storage and processing of the collected data was performed strictly according to the European General Data Protection Regulations (GDPR). The data is processed confidentially, and all participant identities are kept strictly anonymous.

### 2.2 | Sample

The sampling strategy required all respondents to be driver's license holders and to be the owners of a car or a user of car sharing services. Further, the strategy aimed to get an equal distribution of gender and different age groups. These criteria were ensured through screening questions at the beginning of the questionnaire.

The questionnaire was distributed to respondents in Germany (DE), Spain (ES), the USA (US) and China (CH). Altogether 2120 complete answers were received (Table 1). However, a substantial number of respondents claimed that their cars were not equipped with any type of ADAS and were therefore excluded from the analysis; only respondents who acknowledged that their cars were equipped with minimum a Level 1 DAS were considered for inclusion. In addition, a

**TABLE 1** Breakdown of responses per country and total.

| | DE n | ES n | US n | CH n | TOTAL |
|---|---|---|---|---|---|
| All respondents | 568 | 532 | 516 | 504 | 2120 |
| Respondents with car not equipped with any type of DAS | 452 | 363 | 282 | 317 | 1414 |
| Professional drivers | 10 | 6 | 45 | 48 | 109 |
| Remaining sample | 73 | 148 | 186 | 142 | 549 |
| Respondents with access to Level 1 system | 73 | 148 | 186 | 142 | 549 |
| Respondents with access to Level 2 system | 18 | 31 | 72 | 38 | 159 |

**TABLE 2** Demographic breakdown for the final 549 respondents.

| | DE (*n* = 73) | | ES (*n* = 148) | | US (*n* = 186) | | CH (*n* = 142) | | TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | % | *n* | % | *n* | % | *n* | % | *n* | % |
| Gender | | | | | | | | | | |
| Women | 33 | 45 | 61 | 41.2 | 86 | 46.2 | 70 | 49.3 | 250 | 45.5 |
| Men | 39 | 53.4 | 87 | 58.8 | 99 | 53.2 | 72 | 50.7 | 297 | 54.1 |
| No statement | 1 | 1.4 | 0 | 0.0 | 1 | 0.5 | 0 | 00 | 2 | 0.4 |
| Age | | | | | | | | | | |
| <20 years | 1 | 1.4 | 2 | 1.4 | 0 | 0.0 | 0 | 0.0 | 3 | 0.5 |
| 21–30 years | 15 | 20.5 | 26 | 17.6 | 39 | 21.0 | 25 | 17.6 | 105 | 19.1 |
| 31–40 years | 18 | 24.7 | 41 | 27.7 | 67 | 36.0 | 68 | 47.9 | 194 | 35.3 |
| 41–50 years | 11 | 15.1 | 35 | 23.6 | 23 | 12.4 | 34 | 23.9 | 103 | 18.8 |
| 51–65 years | 11 | 15.1 | 27 | 18.2 | 35 | 18.8 | 15 | 10.6 | 88 | 16.0 |
| >65 years | 17 | 23.3 | 17 | 11.5 | 22 | 11.8 | 0 | 0.0 | 56 | 10.2 |
| Highest Education Level | | | | | | | | | | |
| Elementary School | 5 | 6,8 | 7 | 4,7 | 1 | 0,5 | 0 | 0,0 | 13 | 2.4 |
| Upper Secondary School | 11 | 15.1 | 48 | 32.4 | 37 | 19.9 | 7 | 4.9 | 103 | 18.8 |
| Apprenticeship or other education after Secondary School | 26 | 20.5 | 3 | 2.0 | 27 | 14.5 | 3 | 2.1 | 59 | 10.7 |
| Higher Education: University College, University, PhD | 31 | 42.5 | 90 | 60.8 | 121 | 65.0 | 132 | 93.0 | 374 | 68.1 |

majority of the respondents were non-professional drivers, although the US and China samples had in comparison a significantly higher share of professional drivers. All professional drivers were removed from the sample, leaving a data set of a total of 549 'respondents.

A majority of the respondents were younger than 40 years old; in the Chinese sample no respondent was older than 65 years and almost no one was younger than 21 years old (Table 2). Overall, the majority had completed upper secondary school or higher education, defined as a minimum of a bachelor or a master's university degree (Table 2).

Almost all respondents owned the car they drove most often, and most respondents drove more than 5,000 km, but less than 30,000 km per year (Table 3). Furthermore, most respondents indicated that their main driving context was 'urban areas' but differences were also noted between samples; for example while a majority (88%) of the Chinese respondents indicated 'urban areas' as their main driving context, whereas 38% of the Spanish sample reported to mainly drive expressways/highways.

## 2.3 | Analysis

After initial screening for invalid responses, 20 questionnaires from Germany, 7 from Spain, 11 from the USA and 8 from China were removed due to suspiciously short overall response time (<300 s.), invalid values for the year of obtaining the driving license, or extreme outliers. Missing values were retained. In total 549 completed questionnaires were analysed using primarily descriptive statistics.

Descriptive statistics were calculated for (i) opinion and (ii) reported usage of Level 1 and Level 2 DAS for each situation, first including all respondents (individual level) and then for the respondents in each respective country (national level).

**TABLE 3** The respondents' car ownership and car usage patterns.

| | DE ($n = 73$) | | ES ($n = 142$) | | US ($n = 186$) | | CH ($n = 142$) | | TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Country** | ***n*** | **%** | ***n*** | **%** | ***n*** | **%** | ***n*** | **%** | ***n*** | **%** |
| Car ownership | | | | | | | | | | |
| Own car | 72 | 98.6 | 148 | 100 | 184 | 98.9 | 142 | 100 | 546 | 99.5 |
| Use car sharing services | 1 | 1.4 | 0 | 0.0 | 2 | 1.1 | 0 | 0,0 | 3 | 0.5 |
| Annual mileage (km) | | | | | | | | | | |
| Less than 5,000 | 3 | 4.1 | 19 | 12.8 | 40 | 21.5 | 11 | 7.7 | 73 | 13.3 |
| 5,001–10,000 | 17 | 23.3 | 45 | 30.4 | 39 | 21.0 | 48 | 33.8 | 149 | 27.1 |
| 10,001–20,000 | 34 | 46.6 | 56 | 37.8 | 58 | 31.2 | 49 | 34.5 | 173 | 35.9 |
| 20,001–30,000 | 14 | 19.2 | 21 | 14.2 | 31 | 16.7 | 27 | 19.0 | 93 | 16.9 |
| More than 30,000 | 5 | 6.8 | 7 | 4.7 | 18 | 9.7 | 7 | 4.9 | 37 | 6.7 |
| Main driving context | | | | | | | | | | |
| Urban areas | 33 | 45.2 | 73 | 49.3 | 118 | 63.4 | 125 | 88.0 | 349 | 63.7 |
| Rural roads | 23 | 31.5 | 19 | 12.8 | 28 | 15.1 | 9 | 6.3 | 79 | 14.4 |
| Expressways/highways | 17 | 23.3 | 56 | 37.8 | 39 | 21.0 | 8 | 5.6 | 120 | 21.9 |

At the individual level, non-parametric tests were used to determine differences between attitude on the one hand and gender and country on the other, similarly between gender and reported DAS use in different situations. Furthermore, Spearman correlation coefficients were calculated to determine associations between age, education level and annual mileage, on the one hand, and reported DAS use in different situations on the other.

A further analysis was made to find out if the respondents reported similar usage levels across situations. In this case, cross-tabulations were first produced and analysed before possible associations were calculated using Spearman's rho. In addition, Friedman's test was run to determine differences in reported usage of the Level 1 system, usage of the Level 2 system, and if the respondents with access to both a Level 1 and a Level 2 system reported similar usage levels for the respective systems across the nine situations. In cases where such a difference was identified, post-hoc analyses with Wilcoxon signed-rank tests were performed.

Furthermore, a two-step cluster analysis was conducted to determine sub-groups within the dataset (cf. [27, 28]). The goal of the cluster analysis was to identify groups of frequent and infrequent usage of the investigated systems throughout the different situations. In the case of users of Level 1 systems, the subset of $n = 549$ was analysed and in the case of Level 2 systems, the subset of $n = 159$ was analysed.

Finally, responses from the respective country samples were grouped and for each situation a Kruskal–Wallis H-test was run to determine if there were any statistically significant differences between the groups. In cases where such a difference was identified, a post-hoc, pairwise comparison was made to identify which groups differed from each other. This was done for data on the Level 1 system and the Level 2 system usage respectively.

The statistical analyses were conducted with IBM SPSS statistics software, version 25. Statistical significance was accepted at the $p < 0.05$ level.

## 3 | RESULTS

### 3.1 | Opinion of DAS

Attitudes have been claimed to impact people's usage of any technology why the respondents were asked to indicate their opinion about systems that partially take of the driving task. In general, the respondents reported a positive opinion of such systems (Figure 1). No difference was found between men and women ($p = 0.115$) or between national samples ($p = 0.18$) and only a weak correlation was found between age and opinion ($rs = -0.221$, $p = 0.01$). However, it is important to note that due to a technical error, no data was available from the Chinese respondents.

The respondents' agreement with the nine statements regarding in which situations they consider handing over part of the driving control to the car varied (Figure 2).

### 3.2 | Reported usage of Level 1 DAS

DAS are not designed to handle all traffic, weather, or road conditions. For example, limitations associated with ACC include an inability to control headway in reference to slow vehicles or vehicles that do not move and to adjust to the topography of curved roads (e.g. Dickie and Boyle, 2009). In addition, it is recommended that the system should not be used when heavy rain, snow or on icy or slippery roads. Respondents were therefore

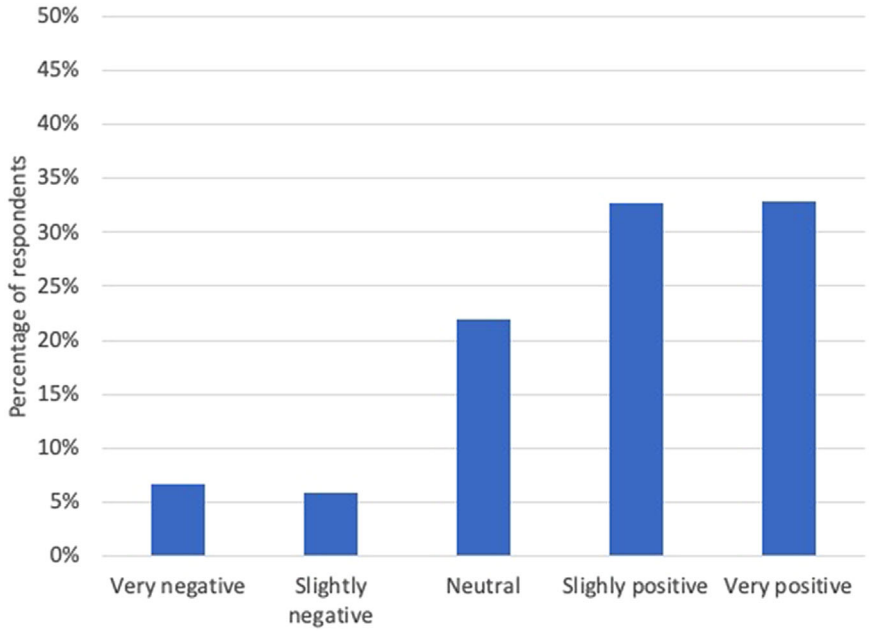


**FIGURE 1** Respondents' responses to the question "What is your general opinion of technical systems that could partially take over driving?" The responses were given on scale from very negative to very positive. ($n = 407$, as Chinese respondents not included).

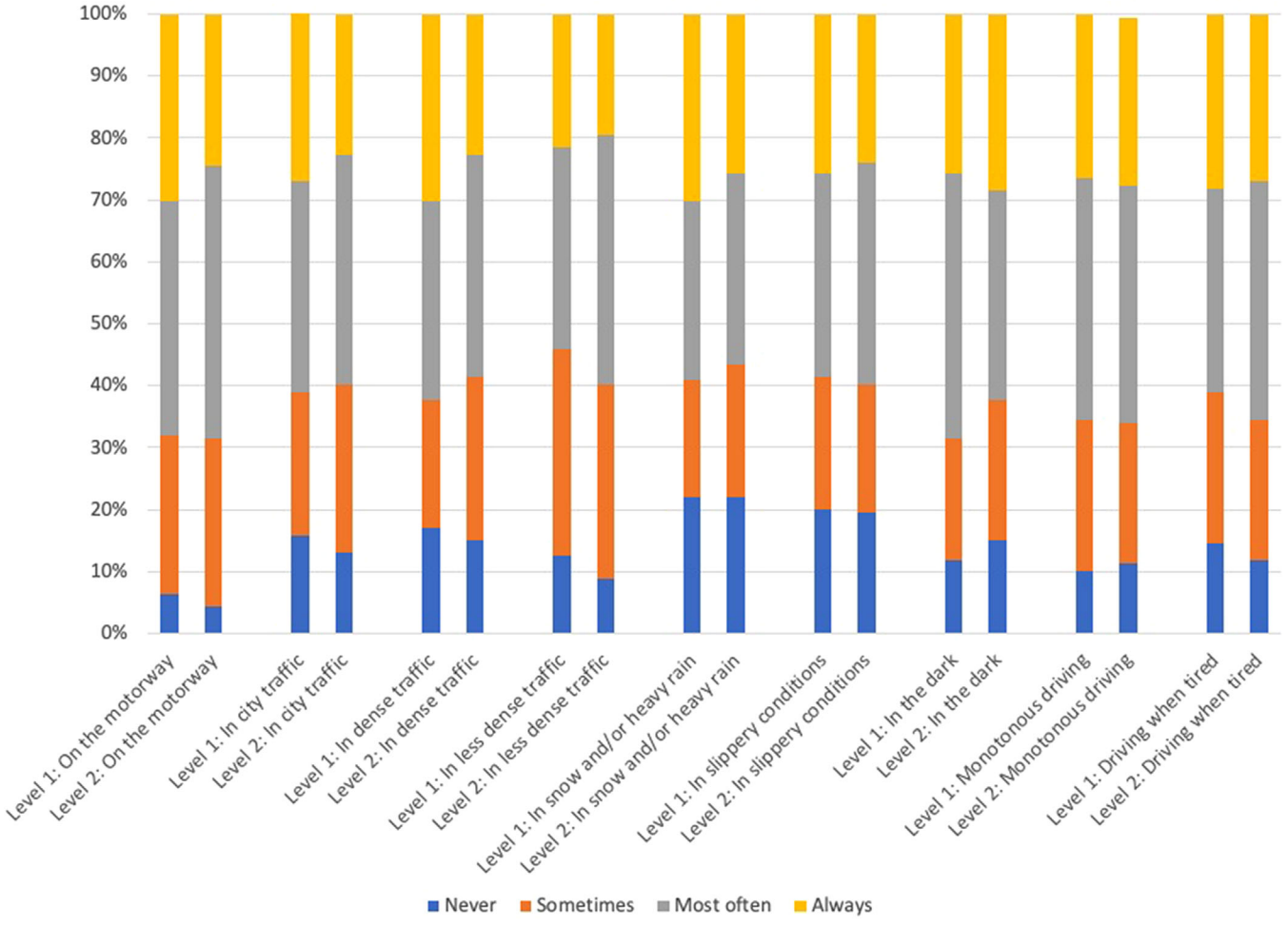


**FIGURE 2** Participants' agreement with statements on which situations they would consider handing over part of the driving control to the car ($n = 407$, as Chinese respondents not included).

asked to consider their usage of Level 1 systems in different situations.

Statistically significant differences were found for reported usage of Level 1 DAS across the nine situations ($\chi^2 = 324.436$ (8), $p < 0.001$). Furthermore, the two-step cluster analysis ran 11 inputs and revealed two clusters, where Group 1 included 57.2% ($n = 314$) respondents identified as infrequent users (i.e. rated usage as "never" or "sometimes"), and Group 2 included 42.8% ($n = 235$) of the respondents identified frequent users ("most often" or "always").

### 3.2.1 | Usage considering context

In response to the question "In which of the following situation do you activate …?" the respondents reported usage varied depending upon situation. Regarding difference between men's and women's reported usage of using Level 1 DAS, differences were found for stated usage on the motorway ($p = 0.010$), when driving in less dense traffic ($p = 0.045$) and when driving in the dark ($p = 0.024$). No difference in usage was found when considering types of roads driven ($p = 0.949$) and participants' age, education level or annual mileage showed only weak correlations with reported usage of the system in any of the nine situations ($r_s < 0.3$, $p < 0.001$ in all situations).

#### *3.2.1.1 Traffic situations*

At the individual level, a majority, or 59% of the total number of respondents with access to Level 1 DAS, reported to be frequent users of the systems when driving on the motorway whereas the share of respondents who "never" used the system was less than 10% (Figure 3). The reported usage was in general lower when driving in city traffic; 37% reported to use the system "most often" or "always" but almost as many (42%) stated to "never" user the system in this situation. Usage in dense traffic showed a similar pattern as city traffic usage; more than 40% of the total number of respondents reported to "never" use the system and an additional 20% indicated "sometimes" (Figure 3). In less dense traffic, the share of non-users was smaller (approx. 30%) but so was the share of "always" users. Considering traffic situations, statistically significant differences were found for reported usage on the motorway and all other situations ($p < 0.0001$), between usage in city traffic and less dense traffic ($Z = -3.676$, $p < 0.001$), and between dense traffic and less dense traffic ($Z = -2.925$, $p = 0.003$).

At the national level, the highest share of respondents reporting to "always" use the system in city traffic was found in the US sample (19%) and the smallest share was found in the Spanish one (8%). Similarly, the largest share of non-user (57%) was found in the same sample. No correlation could be found between usage of Level 1 DAS on the motorway ($r_s = 0.11$, $p < 0.0001$) or city ($r_s = 0.17$, $p < 0.0001$) and country sample. A statistically significant difference was found for reported usage when driving in city traffic ($\chi^2 = 21.272$ (3), $p < 0.001$) between the Spanish sample and other samples ($p < 0.05$) but not for usage on the motorway ($\chi^2 = 4.870$ (3), $p = 0.182$).

In less dense traffic, 6% of the Chinese sample (smallest share) reported to "always" use Level 1 DAS compared to, for example, 16% of the US sample (largest share). The largest share of non-users was found in the Spanish sample (38%) and the smallest in the Chinese sample (20%). In dense traffic, the share on non-users was 55% in the Spanish sample compared to 34% of the German sample. The share of respondents reporting to "always" use Level 1 in this situation varied between 9% (Spanish sample) and 21% (the US sample). A statistically significant difference in reported usage was found for dense traffic ($\chi^2 = 18.994$ (3), $p < 0.001$) between the Spanish and Chinese samples ($p = 0.017$), as well as for less dense traffic ($\chi^2 = 18.994$ (3), $p < 0.001$) and then between the Spanish and the other samples ($p < 0.05$).

#### *3.2.1.2 Weather and daylight conditions*

At the individual level, approximately 45% reported "never" to use the system in poor weather conditions, exemplified by snow/heavy rain or slippery conditions (Figure 4); when driving in the dark the proportions were differed slightly in that the share of more frequent users were higher and less (35%) respondents stated to "never" use the system when driving in this situation.

When considering reported usage in different weather and daylight conditions, no statistical differences were found for snow/heavy rain compared to slippery conditions ($Z = -0.59$, $p = 0.953$) but between driving in the dark, on the one hand, and driving when snow/rain ($Z = -3.674$, $p < 0.001$) and when slippery conditions ($Z = -3.755$, $p < 0.001$) on the other.

At the national level, respondents from the Chinese, German as well as the US samples reported to use the systems more often when driving in poor weather conditions compared to the Spanish sample. For example, between 15% and 20% of the respondents from the former samples reported to use the system "always" in snow/heavy rain whereas 9% of the Spanish respondents did so. At the same time, a substantial share (between 30% and 44%) of all national samples reported "never" to use the systems in these conditions. A statistically significant difference was found between the Spanish sample and all other samples ($p < 0.05$) regarding usage in snow/heavy rain ($\chi^2 = 15.914$ (3), $p = 0.001$) and in slippery conditions ($\chi^2 = 15.005$ (3), $p = 0.002$).

When driving when dark, 70% of the Spanish sample reported "never" or "seldom" usage but also substantial shares of the Chinese, German and US samples did so (between 55% and 57%). The largest share of "always" users (20%) was found the US sample A statistically significant difference was found ($\chi^2 = 10.446$ (3), $p = 0.015$) but only between the Spanish and the US samples ($p = 0.028$).

A statistically significant difference was found between the Spanish sample and all other samples ($p = 0.05$) regarding usage in snow/heavy rain ($\chi^2 = 15.914$ (3), $p = 0.001$) and in slippery conditions ($\chi^2 = 15.005$ (3), $p = 0.002$). For driving in the dark a significant difference was found ($\chi 2 = 10.446$ (3), $p = 0.015$) between the Spanish and the US sample ($p = 0.028$).

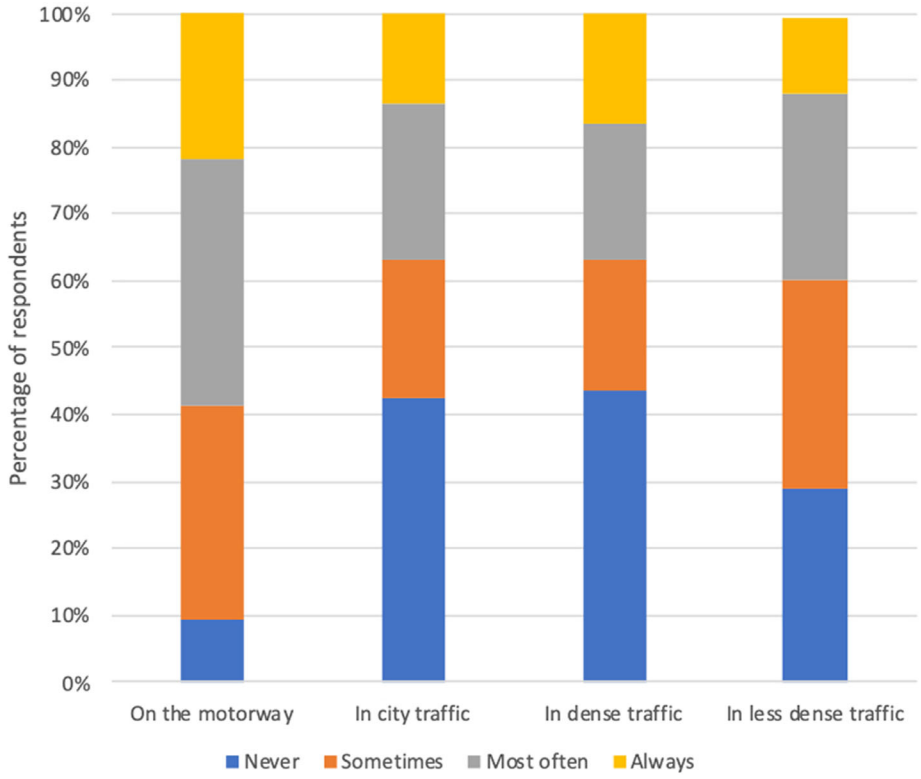


**FIGURE 3** Respondents' self-reported usage of Level 1 system in different traffic contexts ($n = 549$).

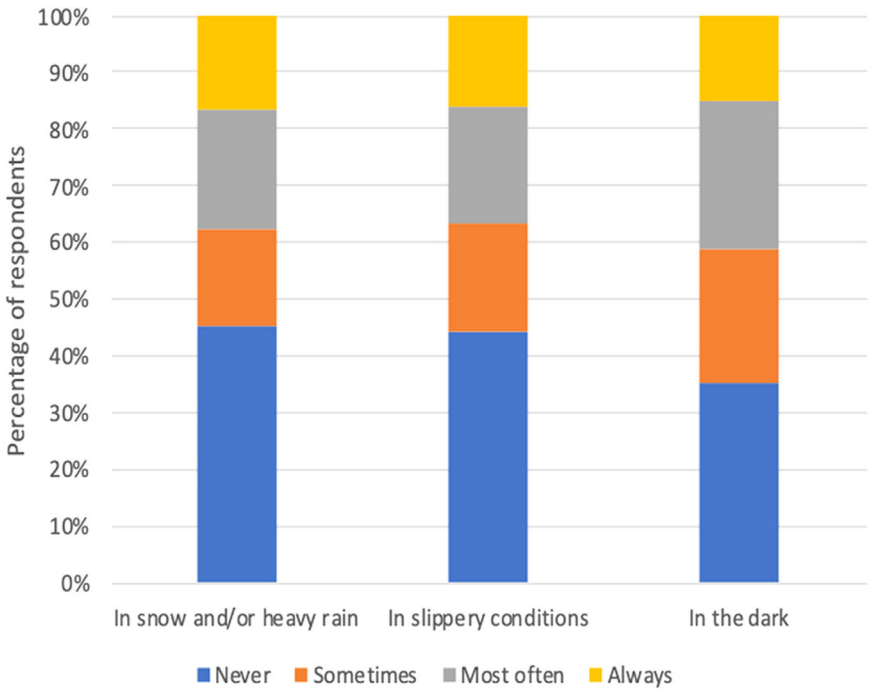


**FIGURE 4** Respondents' self-reported usage of Level 1 systems in different weather and daylight conditions ($n = 549$).

*3.2.1.3 Driver states*

Finally, the respondents were asked to consider usage of Level 1 DAS in situations where the driving was experienced as monotonous and/or when they felt tired.

At the individual level, reported usage differed slightly between monotonous driving and driving when tired ($Z = -2.875$, $p = 0.004$) but overall, the respondents could be divided into almost to equally large groups (Figure 5); those

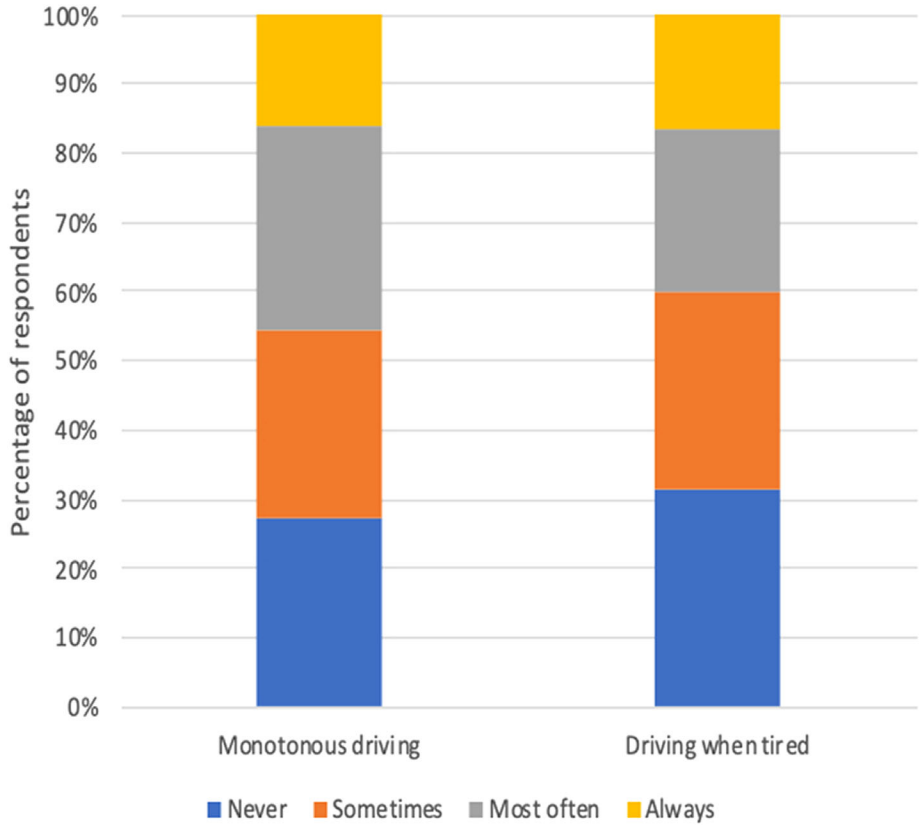


**FIGURE 5** Respondents' self-reported usage of Level 1 DAS in different driver states ($n = 549$).

who use the system "most often" or "always" and those who use it "sometimes" or "never", that is, comparable with the clusters. Approximately 15% were "always" users and 30% were reported non-users in these situations.

At the national level, during monotonous driving, the US sample reported the lowest usage of Level 1 DAS whereas the most frequent users were found in the German sample. The reported usage pattern for driving when tired was similar. Statistical differences were found for monotonous driving ($\chi^2 = 11.432$ (3), $p = 0.010$) and driving when tired ($\chi^2 = 12.777$ (3), $p = 0.005$), in the former case between the Spanish and Chinese samples ($p = 0.002$) and in the latter between the Spanish and the German samples ($p = 0.026$) as well as between the German and the US samples ($p = 0.020$).

### 3.2.2 | Correlations between usage of Level 1 DAS and contexts

The study was also concerned with whether respondents used the systems to the same extent across situations. At the individual level, correlation values varied between weak ($r_s < 0.5$), to moderate ($0.7 \geq r_s \geq 0.5$) to high ($r_s > 0.7$); for Level 1 DAS the latter were found for reported usage in city traffic, dense traffic, poor weather conditions, and when driving in the dark (Table 4).

At the national level, correlation values for the German sample indicated some relation between usage levels when driving in the city and dense traffic, and between driving in snow/rain, slippery conditions and when tired. A similar pattern was found for the US respondents' usage. The responses from the Chinese and the Spanish samples differed, in that calculated relationships between usage and situations existed, but was less consistent, and correlations were overall moderate to weak ($r_s \leq 0.7$)

## 3.3 | Usage of Level 2 DAS

Approximately 30% (or $n = 159$) of all respondents with stated access to a Level 1 DAS also reported to have access to a Level 2 DAS.

Statistically significant differences were found ($\chi^2 = 21.512$ (8), $p = 0.006$). In this case, the subset of 159 respondents was analysed and revealed two clusters, whereas Group 1 included 56.5% ($n = 90$) infrequent users and 43.4% ($n = 69$) frequent users of the system.

### 3.3.1 | Usage considering context

As was the case for use of the Level 1 DAS, the Level 2 DAS was reported to be used to different degrees depending on the situation. No differences could be found between men and women ($p > 0.3$ in all situations) or main driving context ($p > 0.2$ in all

**TABLE 4** Spearman correlation matrix at the individual level ($n = 579$; correlations were multiplied by 100).

| | On the motorway | In city traffic | In dense traffic | In less dense traffic | In snow and/or heavy rain | In slippery conditions | In the dark | Monotonous driving | When tired |
|---|---|---|---|---|---|---|---|---|---|
| On the motorway | | 37** | 49** | 35** | 36** | 34** | 41** | 50** | 43** |
| In city traffic | | | 79** | 60** | 77** | 76** | 71** | 60** | 68** |
| In dense traffic | | | | 58** | 81** | 82** | 77** | 59** | 68** |
| In less dense traffic | | | | | 50** | 52** | 58** | 56** | 53** |
| Driving in snow and/or heavy rain | | | | | | 88** | 75** | 60** | 72** |
| In slippery conditions | | | | | | | 76** | 62** | 73** |
| In the dark | | | | | | | | 61** | 67** |
| Monotonous driving | | | | | | | | | 73** |
| When tired | | | | | | | | | |

*Note.* **) Correlation is significant at the .01 level The colour gradient runs from light blue (weak) to light green (moderate) to darker blue (strong).

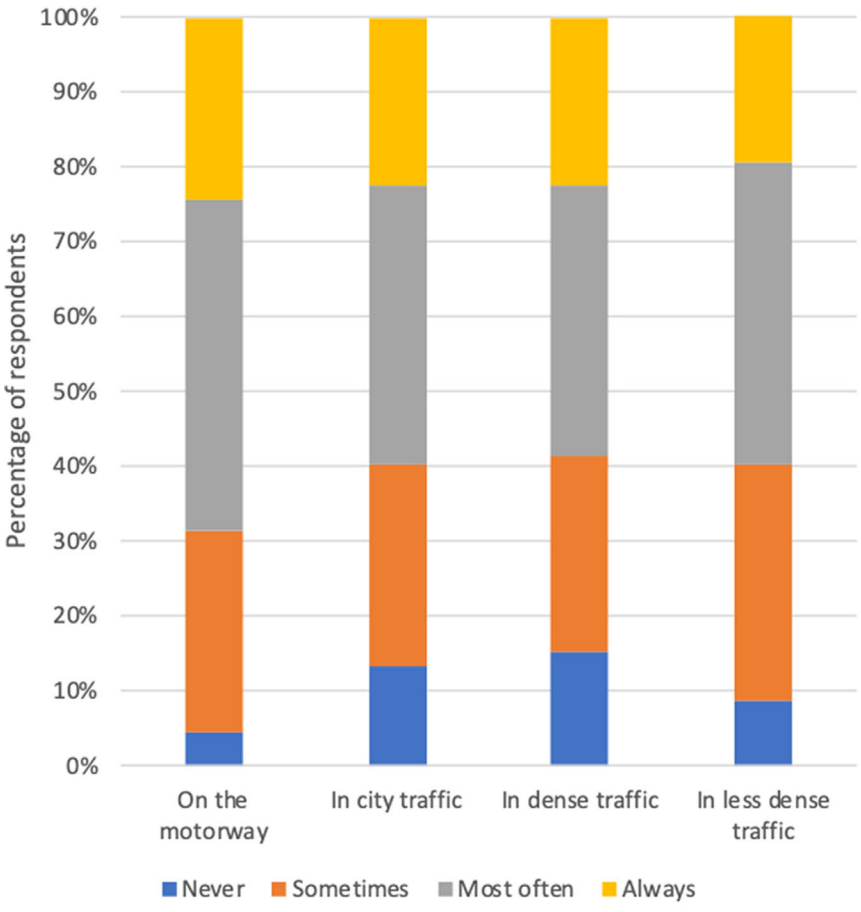


**FIGURE 6** Respondents' self-reported usage of Level 2 DAS in different traffic contexts ($n = 159$).

cases); neither did age ($r_s < 0.2$ in all situations) or mileage driven per year ($r_s < 0.1$ in all situations) show any strong correlation with usage of Level 2 DAS.

*3.3.1.1 Traffic situations*

At the individual level, a majority, or 69% of the total number of respondents with access to a Level 2 DAS, was frequent users of the systems when driving on the motorway (Figure 6). The reported usage was lower when driving in city traffic but nevertheless almost 60% of respondents reported using it "most often" or "always".

In dense traffic, slightly more than half of all respondents used the systems "most often" or "always". In comparison, in less dense traffic, the share of "always" users was slightly higher and the share of non-users lower (8% of the total number of respondents).

Considering reported usage in different traffic situations there were statistically significant differences between usage on the motorway and in dense ($Z = -2.891$, $p = 0.004$) as well as in less dense traffic ($Z = -2.720$, $p = 0.007$) but not between dense and less dense traffic ($Z = -639$, $p = 0.523$).

At the national level, the largest share of non-users was found in the Spanish sample; 1/4 reported "never" to use the system in city traffic. None in the German and Chinese samples claimed to be non-users of the system in this context whereas 6% of Spanish and 7% of the US samples did. Significant differences in reported usage between countries were not found for use on the motorway, but for usage when driving ($\chi^2 = 10.236$ (3), $p = 0.017$) and then between the Spanish and the US samples ($p = 0.010$).

In less dense traffic, the non-users and the "always" users across all national samples formed smaller shares; the share of non-users varied between 5% (Chinese sample) and 11% (US sample) and the share of "always" users varied between 10% (Spanish sample) and 28% (US sample). In dense traffic, the highest share of non-users was found in the Spanish sample (29%) while the largest share was found in the US sample (31%). No significant difference between samples was found for usage in less dense traffic ($\chi^2 = 5.251$ (3), $p = 0.154$) but for usage in dense traffic ($\chi^2 = 12.551$ (3), $p = 0.006$) and then between the Spanish and the US samples ($p = 0.04$).

#### *3.3.1.2 Weather and daylight conditions*

At the individual level, the participants' reported usage of the system in weather situations which involved snow/heavy rain or slippery roads or when driving in the dark showed similar patterns although the share of "always" users was slightly higher and the share of "never" users slightly smaller (Figure 7). Statistically significant differences were not found, neither between driving in the dark and in snow/heavy rain ($Z = -2.214$, $p = 0.27$), between driving in the dark and slippery conditions ($Z = -1.820$, $p = 0.069$), or between driving in snow/heavy rain and slippery conditions ($Z = -785$, $p = 0.433$).

At the national level, the Chinese, German as well as the US samples reported a more frequent usage of Level 2 systems also in poor weather conditions than did the Spanish sample. A statistically significant difference was found for usage when driving in snow/heavy rain ($\chi^2 = 14.898$ (3), $p = 0.002$) and when slippery conditions ($\chi^2 = 11.577$ (3), $p = 0.009$) but only between the Spanish and the US samples ($p = 0.002$ and $p = 0.006$ respectively)

The Spanish sample reported the lowest level of usage when driving in the dark, 55% reported "never" or "sometimes". On the other hand, no respondent in the German sample reported to not use the available Level 2 system when driving in this condition; 67% used it "most often" or "always". A statistically significant difference was here found ($\chi^2 = 10.571$ (3), $p = 0.054$) between Spanish and the US samples ($p = 0.012$).

#### *3.3.1.3 Driver states*

Overall, more than 60% of the total number of respondents claimed to use their Level 2 system "most often" or "always" in situations where the driving was experienced as monotonous and when they felt tired. (Figure 8) A similar pattern was found for reported regarding usage when tired. No statistically significant differences were found ($Z = -0.602$, $p = 0.496$).

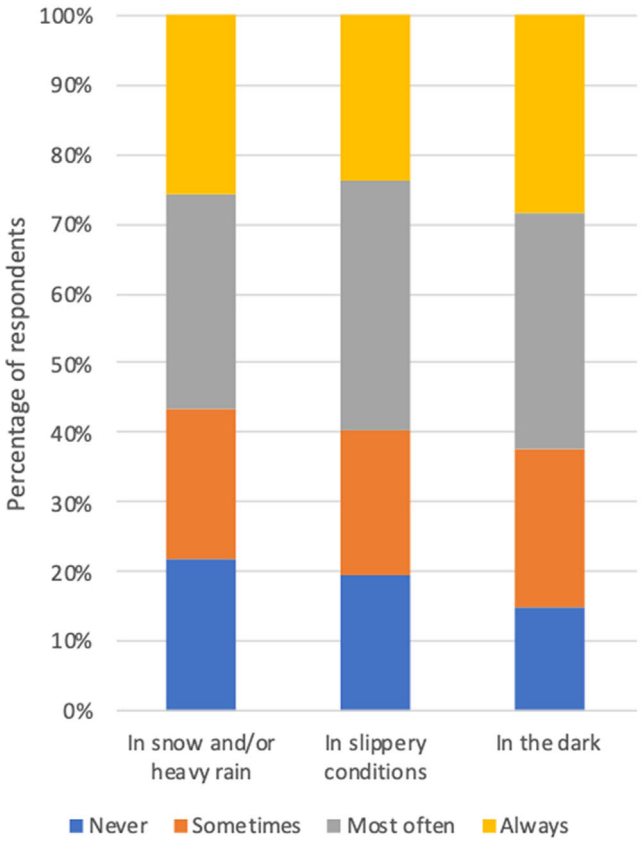


**FIGURE 7** Respondents' self-reported usage of Level 2 DAS in different weather and daylight conditions ($n = 159$).

At the national level, differences between samples were statistically significant both for driving when tired ($\chi^2 = 9.807$ (3), $p = 0.020$) and usage when monotonous driving ($\chi^2 = 11.085$ (3), $p = 0.011$) but also in these cases the differences were found only between the Spanish and the US samples ($p = 0.004$).

### 3.3.2 | Correlations between contexts

At the individual level, correlations varied between weak ($r_s < 0.5$), to moderate ($0.7 \geq r_s \geq 0.5$) to high ($r_s > 0.7$). High correlations (Table 5) were found for driving in dense traffic and driving in the dark ($r_s = 0.71$, $p < 0.001$), and when driving in poor weather conditions ($r_s = 0.81$, $p < 0.001$).

Also, the national level, correlations varied. The reported usage by the German, Spanish, and Chinese samples showed strong correlations (i.e. $r_s > 0.7$) between level of usage on motorway and in city traffic or between in city traffic and driving in poor weather conditions. For other situations the correlations were weaker, for example, level of usage on the motorway and in poor weather conditions or when driving in less dense traffic and driving when tired. In case of the German and Spanish samples many correlation values were not statistically

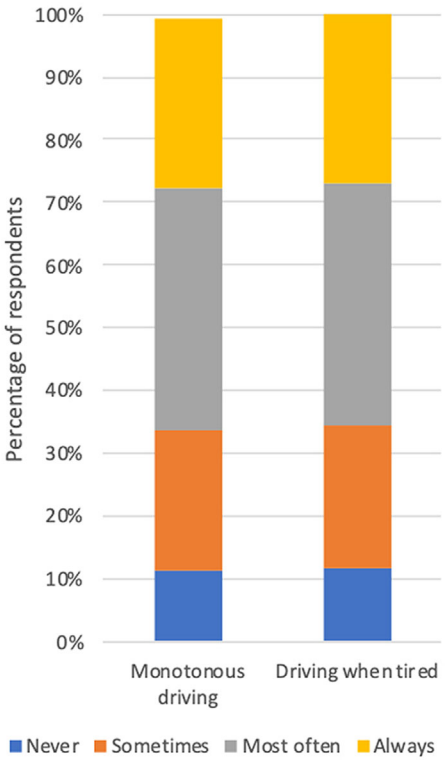


**FIGURE 8** Respondents' self-reported usage of Level 2 DAS in different driver states ($n = 159$).

significant. The responses from the US sample showed consistent but lower correlations across all situations.

### 3.3.3 | Comparison between usage of Level 1 and Level 2 DAS

As described earlier, the number of respondents with access to both Level 1 and Level 2 DAS was a subset (or $n = 159$) of the total number of respondents. When comparing the reported usage of Level 1 and Level 2 (Figure 9) statistically significant differences were not found for any of the nine situations ($p > 0.3$ in all cases).

## 4 | DISCUSSION AND CONCLUSIONS

The aim of the survey was to gain further insights regarding drivers' usage of different types of driving automation systems in different contexts. In particular, the purpose was to find out to what extent drivers use the DAS that they have available in their cars, and to what extent driving contexts influence the usage of the Level 1 and Level 2 DAS respectively. Driving context was addressed in two ways: (i) By asking respondents to indicate their usage of the respective systems in different traffic situations, weather conditions, and driver states, and (ii) by comparing the answers from respondents in four countries: China, Germany, Spain, and the USA.

An important limitation with implications for the findings is that the respondents per country with reported access to DAS (in particular access to a Level 2 system) was considerably fewer than initially anticipated (and hoped for); if the survey had been distributed today a larger share of respondents would probably have had access to a DAS, in particular a Level 2 DAS, which would have provided a more solid basis for any comparison. As one of the purposes with the paper was to investigate differences between countries (as an example of contexts), a related limitation is the uncertainty as to on how representative the samples are, overall but more importantly of drivers with access to Level 1 and Level 2 systems. Although more respondents would not have assured better representativeness it would have increased the probability. Furthermore, in the study reported here, the connection between frequency of use and context was key and would have been very difficult, if not impossible, without the choice of self-reports. However, there is always a risk that response anchors are understood differently by respondents, that the respondents engage in straight-line responding, and/or that they underestimate or exaggerate their usage of DAS which must be taken into consideration when interpreting the results. In addition, the original survey was designed in English and then translated into Chinese, German, and

**TABLE 5** Spearman correlation matrix at the individual level ($n = 159$; correlations were multiplied by 100).

| | On the motor-way | In city traffic | In dense traffic | In less dense traffic | In snow and/or heavy rain | In slippery conditions | In the dark | Mono-tonous driving | When tired |
|---|---|---|---|---|---|---|---|---|---|
| On the motorway | | 46** | 39** | 47** | 42** | 46** | 41** | 49** | 39** |
| In city traffic | | | 60** | 55** | 67** | 62** | 66** | 51** | 55** |
| In dense traffic | | | | 47** | 59** | 67** | 71** | 51** | 54** |
| In less dense traffic | | | | | 51** | 50** | 59** | 51** | 51** |
| Driving in snow and/or heavy rain | | | | | | 81** | 69** | 60** | 67** |
| In slippery conditions | | | | | | | 70** | 61** | 64** |
| In the dark | | | | | | | | 53** | 56** |
| Monotonous driving | | | | | | | | | 61** |
| When tired | | | | | | | | | |

*Note*. **) Correlation is significant at the 0.01 level The colour gradient runs from light blue (weak) to light green (moderate) to darker blue (strong).

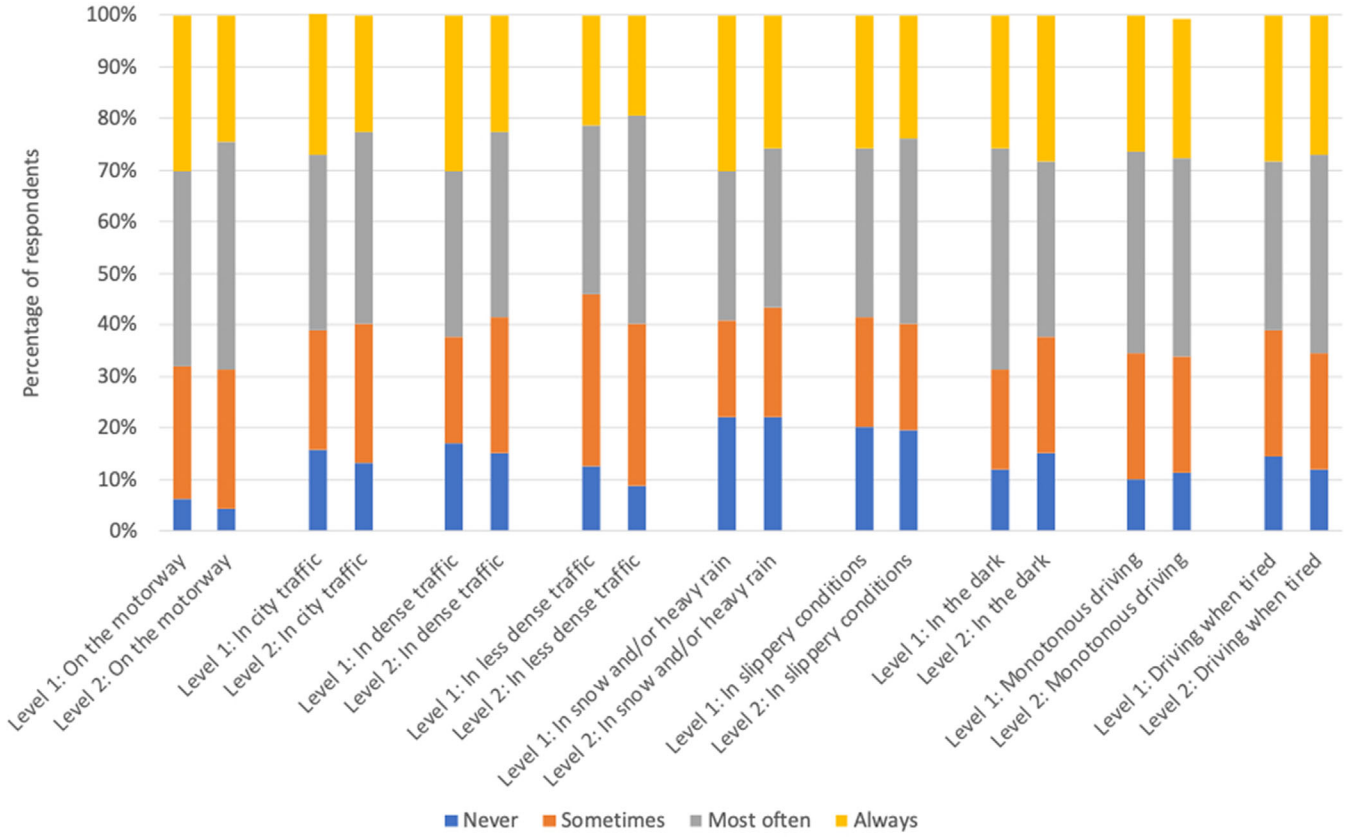


**FIGURE 9** Respondents' self-reported usage of Level 1 and Level 2 DAS in different situations ($n = 159$).

Spanish. Even though considerable efforts were made to maintain intended meanings, it is possible that intended meanings were lost in translation. Also, this aspect must be considered.

Considering the available data, drivers' reported usage differed in different situations. The same pattern was found for both the Level 1 and the Level 2 systems. Furthermore, the cluster analysis resulted in two main groups: those who "never" or "seldom" used the systems and those who "most often" or "always" did so. The findings correspond with the findings from earlier studies, for example the study by Orlovska et al., [29] in which sensor data from a Naturalistic Driving (ND) study was collected and analysed.

User attitude is often used to explain differences in usage of technological solutions, but the analysis of the survey data does not provide support for this as the respondents overall had a positive attitude towards DAS. However, it must be acknowledged that due to technical issues, the Chinese responses to the questions on their opinion about systems that partially take of the driving task and their willingness to hand over in different situations are missing. The observed attitude—behaviour gap finds support in other studies, for example by Lijarcio et al. [30] where the respondents were positive to advanced driver support features but did not necessarily use the available systems. Explanations must therefore be sought elsewhere. Novakazi et al. [31] proposed for example that drivers differ in perceptions of and/or trust in the respective systems in different contexts and that these factors can explain in part the differences in usage. Several other studies have shown the importance of trust, including a recent study by Stiegemeier et al. [32]. However, the same study concluded that the most common reason for non-use was that the drivers did not feel that they needed the system or needed it seldom in relation to the character of their daily drives, that is, on which type of roads or for how long. Other studies have shown individual differences in users' perception of system usefulness. For example, Novakazi et al. [31] discovered via in-depth interviews that drivers' views on the usefulness of the systems differed; whereas some found benefits in using the systems primarily during long drives, others perceived additional safety when using the systems also in stop-and-go situations or in heavy traffic. Lijarcio et al. [30] concluded based on their study that low perceived value but also lack of confidence and potential distractibility constituted constraints to use assisting technologies while driving.

Overall Level 1 and Level 2 DAS were reported to be used more frequently when driving on the motorway, for example, compared to in dense traffic and, in addition, that dense traffic and poor weather (snow, rain, and/or slippery roads) appeared to form a constellation of situations where usage was less frequent, at least for a large part of the drivers. The differences in usage of Level 1 DAS but so also Level 2 DAS are in line with previous reports, for example by Fancher et al., [22] as well as by Viti et al., [21]. Also, Reagan et al., [33] found that

usage differed depending on the situation; in their study drivers were more comfortable using ACC and lane keeping systems on free-flowing highways and were least comfortable using ACC in stop-and-go traffic and lane keeping on winding roads. A survey of 1200 American car owners [34] revealed that approximately 80% of the respondents agreed to that ACC was useful for highway driving compared to 47% who agreed to the same for in-town driving. Orlovska et al., [29] found differences in drivers' usage of DAS depending on the length of the trip; the longer the trip the more the systems were used, where longer trips could infer usage when driving on motorways and highways, that is, type of road.

The survey results add to the list of contextual factors in that driver state also appears to influence drivers' usage of DAS. According to the responses, DAS is used by a group of drivers as support when driving long monotonous roads and/or driving when tired. The reported use of DAS in these situations could be a strategy to compensate for drivers' experiencing a decline in alertness etc., which in turn indicates an overreliance and/or over-trust in the systems. However, as inattention and drowsiness have been reported as unintended consequences associated with intermediate levels of automation (e.g. [35]), the reported usage could also mean that already drowsy drivers use a function that potentially could lead to further decline, with consequently negative effects on traffic safety, that is, the opposite to the purpose of the systems.

Driver-reported usage level of DAS differed considerably less between national samples than anticipated from earlier reported impacts of differences in road infrastructure, for example, or driving culture between countries (e.g. [24]). However, as mentioned in the introduction, studies addressing usage of DAS in different countries are rare. One exception is the previously mentioned study by Orlovska et al., [23] who found differences between Chinese, Swedish and American Volvo drivers regarding their usage of ACC (i.e. a Level 1 system) as well as Pilot Assist (i.e. a Level 2 system). However, in the survey presented here, it was the responses from Spanish users (in terms of a lower level of reported usage) that showed consistent dissimilarities with responses from the other three countries, for the Level 1 system in particular.

Part of the explanation for the reported lower usage could evidently be that Spanish drivers are not exposed to the same conditions as drivers from other countries, for example not as frequently to snow or slippery road conditions. However, this explanation does not cover all situations where differences were noted. Another explanation could be that the respondents in the Spanish sample drove shorter distances or drove on other types of roads, but this does not appear to be the case; a higher share of the Spanish respondents reported driving primarily on highways/motorways for which DAS are considered to offer particular benefits. In comparison, Chinese respondents, who reported driving primarily in urban areas, were among those who reported the most frequent use of the systems. Nevertheless, even though differences in infrastructure or, for example, driving culture (cf. [24–26]) cannot be confirmed as explanations for differences in the national sample's reported DAS usage, the importance of differences in driving culture and associated attitudes towards traffic safety, risk perception, and traffic safety measures (cf. [36]) cannot be disregarded. The results imply instead that further studies are needed to investigate the impact of for example driving culture on drivers' use and non-use of DAS.

The reported usage of DAS complies in part with the recommendations from DAS manufacturers (e.g. limited usage in poor weather conditions). At the same time there were those drivers who reported to not use the system in situations for which they are recommended and yet again others who reported usage where DAS is not recommended. It can be argued that if a large group of drivers with access to DAS do not use the systems, the potential benefits in terms of increased traffic safety and driving comfort etc., will be considerably less than anticipated. On the other hand, if the systems are used in situations outside situations for which they are designed, they may malfunction which in turn may result in negative attitudes, mistrust, or even accidents. The study shows that further knowledge is needed to understand in more depth drivers' usage and non-usage of DAS, not only to what degree different DAS are used (which was the focus on the present study), or general reasons for use or non-use, but also the underlying reasons for drivers' use and non-use in different contexts. It is, for example, important to find out which contexts are perceived by drivers as suitable for DAS, and whether the contexts are encountered often enough for drivers to experience the systems as useful (cf. [32]). Based on the present study these contexts include different traffic situations, weather conditions, as well as differences in driver state. This argumentation finds further support in the results of a field trial by Johansson and Novakazi [37] where participants found value in having advanced support functions during different traffic conditions (e.g. road type or specific traffic situations), and external or internal conditions (e.g. time of day or mood of user). Such further knowledge is important to be able to support drivers in learning to use DAS, or not, as they are usually designed with specific operative domains in mind. However, the solution is most probably not a further focus on user manuals (cf. Oviedo-Trespalacios et al., 2021). Available manuals are in most cases not used and are, in addition, difficult to understand for a large group of drivers (ibid.). More importantly though, more in-depth knowledge on drivers' perception and use of DAS is vital as a basis for the development of advanced driver support systems that are assessed as useful and an enhanced support for drivers in different contexts.

## AUTHOR CONTRIBUTIONS

MariAnne Karlsson: Conceptualization; Formal analysis; Methodology; Supervision; Writing—original draft; Writing—review and editing. Fjollë Novakazi: Conceptualization; Formal analysis; Investigation; Methodology; Writing—original draft; Writing—review and editing.

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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

## DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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