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Public acceptance of semi-automated truck platoon driving. A comparison between Germany and California

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ABSTRACT

Platooning technology aims at achieving fuel savings by reducing the distance between two or more electronically coupled vehicles. This technology has recently been tested on public highways with heavy trucks in Germany and California. The objective of this study is to assess the level of acceptance among other road users as well as influencing factors of acceptance. An online questionnaire was administered in Germany and California with a total of $N = 536$ participants. They received information about truck platoon driving (level-1 and level-2 automation) and answered questions about their attitudes towards the technology as well as their behavioral intention to cooperate with the truck platoons. The overall results showed that 70% of respondents indicated acceptance towards the technology, with acceptance rates being significantly higher in California than in Germany. German respondents were more willing to drive into the gap of platoon vehicles and preferred larger platooning gaps. An adaption of the *Technology Acceptance Model* (TAM) showed that the expected usefulness, and the expected ease of sharing the highway, were the strongest predictors for the behavioral intention to cooperate with platoon vehicles. However, the intention to cut in between platoon vehicles could not be predicted by these variables. Cut-in vehicles are a potential safety risk and decrease the efficiency of platoon driving. Therefore, future research should focus on finding behavioral countermeasures.

1. Introduction

Automation is transforming different areas of the transport sector, namely privately-owned cars, taxi services, and public transport. People are actively confronted with automated transport technology installed in their vehicles, and passively as regular road users when interacting with automated vehicles. Most studies of automated vehicles focus on the attitudes from the users' perspective (Charness, Yoon, Souders, Stothart, & Yehnert, 2018; Howard & Dai, 2014; Kyriakidis, Happee, & De Winter, 2015; Liljamo, Liimatainen, & Pöllänen, 2018; Liu, Zhang, & He, 2019; Madigan et al., 2016; Nordhoff et al., 2018; Xu et al., 2018; Zhang et al., 2019; Zmud & Sener, 2017). However, the interaction of automated vehicles with other road

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users, such as manually driven cars, pedestrians and cyclists, is highly relevant in terms of safety. The fatal crash of an automated *Uber* test vehicle with a pedestrian in 2018 (Griggs & Wakabayashi, 2018) caused concerns about road safety and public acceptance of automated vehicles. In 2019, a study by the *Alabama Transportation Institute* aimed at getting insights on vulnerable road users' perception of automated vehicles in Pittsburg. The city became a proving ground for automated vehicles in 2017. The results showed that most of the 798 respondents of an online survey had rather positive attitudes towards the test of automated vehicles on public roads. 62% believed that automated vehicles could have positive impact on road safety in the future. Furthermore, respondents were more positive regarding safety if they had already experienced a first-hand interaction with an automated vehicle (Penmetsa, Adanu, Wood, Wang, & Jones, 2019).

In the near future, other road users will also encounter (semi-)automated trucks on the highways (Heid, Dago Diedrich, Kässer, Küchler, & Kley, 2018; PwC Strategy&, 2016). One form of automated trucking is called platooning, or Cooperative Adaptive Cruise Control (CACC). It will be easily noticeable for other road users, due to decreased distance between the trucks. It is an automated truck-following system that maintains a constant temporal or spatial gap with Dedicated Short-Range Communication (DSRC) between vehicles. This technology has many advantages over fully autonomous vehicles, which are simply based on sensor data without inter-vehicle communication. The main advantage is the reduced time delay, particularly the cumulative delay from downstream to upstream information of the platoon. This allows the CACC-capable vehicles in the platoon to synchronize the behavior in acceleration and deceleration. In return, vehicles following within the CACC string or platoon can maintain short time gaps. This will reduce the aerodynamic drag and therefore save energy especially in long distance hauls. Currently, it is still a driver assistance system with partial Level 1 (longitudinal, control only) or Level 2 automation (with both longitudinal and lateral control). The driver still needs to be attentive and take over manual control whenever necessary for safety. The technology has been successfully tested on public roads and could be introduced to the market within the next decade (Chottani, Hastings, Murnane, & Neuhaus, 2018; Nowakowski, Shladover, Lu, Thompson, & Kailas, 2015; Yang et al., 2018).

The technological aspects of platoon systems (e.g. fuel efficacy) and the acceptance among truck drivers are well researched. In contrast, the effect of platoon driving on other road users has received far less attention. The limited number of prior studies have shown that driving next to a truck platoon can lead to risky driving behavior and high levels of workload. A driving simulator study showed that short gaps maintained by the platoon vehicles were copied by passenger cars, leading to reduced and potentially unsafe inter-vehicle gaps in the proximity of truck platoons (Gouy, Wiedemann, Stevens, Brunett, & Reed, 2014). Furthermore, first on-road tests showed that passenger cars tend to drive into the gaps between the platoon vehicles (Andersson, Englund, & Voronov, 2017; KONVOI, 2009), although clearly, driving into a 10–15 m gap between two trucks is extremely dangerous and should be avoided. Moreover, each cut-in vehicle reduces the fuel efficacy of the truck platoon, as the platoon has to increase the distance between the trucks to defuse the situation (Bahn, 2019; Shladover et al., 2018). In first test drives on public roads, passenger cars most frequently cut in between platoon vehicles when driving onto or off the highway. These situations also have been rated to be most challenging for passenger car drivers, as reported by a driving simulator study (KONVOI, 2009).

Public acceptance is seen as a key deployment challenge to truck platoon driving and as a "prerequisite for large-scale deployment" (Engström et al., 2019, p.160). Driving with short gaps and undercutting the safety distance is not yet permitted for platoon vehicles on public roads. Therefore, platooning technology will heavily rely on policy makers to adapt legal requirements, and the public opinion could facilitate or impede the deployment of the technology. Platoon driving also relies on the cooperation of other road users. A study by the *U.S. Department of Transportation* put emphasis on the importance of public acceptance of platooning technology. The authors concluded that public acceptance should be taken into account and that merging onto the highway could be a potential problem with multi-vehicle truck platoons (Bevly et al., 2017). The European research project SARTRE concluded that the development of platooning technology will be feasible in the near future, but that public acceptance and the regulatory process would probably take much more time (Ricardo UK Ltd., 2011). In spite of these statements, public acceptance has rarely ever been addressed by research so far. A questionnaire study within the KONVOI project in 2009 was the first to assessed public opinion. The results showed that half of the participants (N = 200) thought platooning would increase traffic safety, but the other half did not. Over 90% assumed that problems with the surrounding traffic would occur (KONVOI, 2009).

This paper focuses on acceptance of truck platooning in the general population in Germany and California, U.S. We have chosen these two sites because they share a number of important properties. Traffic density is very high. Environmental standards are comparatively high. And both regions offer technological advances that make platooning probable in the near future. On-the-road tests are being conducted in both places. The current study provides first insights on other road users' opinions regarding the interaction with semi-automated truck platoons, the level of public acceptance, and key influencing factors. We will present overall results on acceptance, as well as country-specific differences between Germany and California. To assess the influencing factors of acceptance, a refined version of the Technology Acceptance Model (TAM; Davis, 1986) will be reviewed.

2. Background and questionnaire design

In Germany, (semi-)automated truck platoon driving was first tested on public highways with commercial truck drivers in 2018 (Castritius et al., 2020). In the U.S., the Institute of Transportation Studies at the University of California developed platoon driving technologies and tested them on public roads in 2017 (Yang et al., 2018). Furthermore, several startup companies in California are currently working on truck automation (*Peloton*: https://peloton-tech.com; *Embark*: https://embark-trucks.com, *Starsky Robotics:* https://www.starsky.io, *TuSimple:* https://www.tusimple.com). Both countries have different infrastructural prerequisites and legal requirements with respect to truck driving on public highways.

In Germany, problems with the surrounding traffic could be most pronounced, because of the large speed difference between trucks and cars. While there is a speed limit of 80 km/h for heavy vehicles, there is no speed limit for passenger cars on 70% of German federal highways (Kollmus, Treichel, & Quast, 2015). Mean speed values of 170 km/h on the left lanes of the highway are not uncommon, whereas trucks and other slow vehicles mostly drive in the righthand lane (Geistefeld, 2007). Trucks that are overtaking each other have a high impact on the surrounding traffic and substantially slow down the passenger cars in the left lane(s). This can lead to negative attitudes towards trucks and their drivers (Ellinghaus & Steinbrecher, 2002), which could also affect the attitude towards automated trucks. In addition, the relative speed differences might cause difficulties for passenger cars when exiting the highway with truck platoons on the right lane. In contrast, in the U.S., speed limits range between 55 and 75 mph, which is equivalent to approx. 90–120 km/h. Furthermore, lower statutory speed limits for trucks are present in few states only (Skszek, 2004). In California, the speed limit for cars on highways is 70 mph (113 km/h) and 55 mph (89 km/h) for trucks, resulting in a lower relative speed difference. Furthermore, U.S. federal law does not restrict the overall length of tractor-trailer combinations (23 CFR § 658.13). In contrast, it is restricted to a maximum of 18.75 m in the European Union (Directive 96/53/EC).

These different prerequisites led to the hypotheses that public acceptance is higher in California than in Germany and that longer platoons with smaller inter-vehicle distances are likely to be supported. In addition to these country-specific differences, we focused on key influencing factors of acceptance, as reflected in a questionnaire based on TAM, which is frequently used to investigate the acceptance of innovative technological systems (Buckley, Kaye, & Pradhan, 2018; Davis, 1986; Fröhlich et al., 2018; Xu et al., 2018). The Unified Theory of Acceptance and Use of Technology (UTAUT) is also frequently solicited in this context (Madigan et al., 2016; Venkatesh, Morris, Davis, & Davis, 2003; Venkatesh, Thong, & Xu, 2016). Both models suggest that behavioral intentions and thus the actual behavior are influenced by the *perceived usefulness* (called performance expectancy in UTAUT), the *perceived ease of use* (effort expectancy in UTAUT) and other factors like social influence, prior experience, and sociodemographic aspects, such as gender and age.

For the assessment of public acceptance of automated truck platoon driving, we refined the TAM. Originally, the TAM investigated influencing factors of the users' *intention to use* a technological system. As surrounding passenger car drivers do not actively use, but passively experience truck platoon driving, we instead conceptualized their behavioral intention as the *intention to cooperate with platooning vehicles*. Likewise, we redefined the original TAM constructs *perceived ease of use* and *perceived usefulness* as *expected ease of sharing the highway with truck platoons* and *expected usefulness* to match the given context. Finally, we included three additional external variables, resulting in the refined TAM for public acceptance of truck platoon driving as shown in Fig. 1.

The results of Xu et al. (2018) suggest that trust towards automated vehicles is an important predictor for the behavioral intention to use them. As the concept of truck platoon driving may be unknown, *trust in driver assistance systems* was included instead. We expected higher trust in driver assistance systems (DAS) to be related to more positive attitudes towards truck platoons. Moreover, the constructs *technology affinity* and *attitudes towards truck drivers* were included exploratively. It was hypothesized that negative attitudes towards regular truck drivers would be related to more positive attitudes towards cooperating with (semi-)automated truck platoons. In a prior study, general technology affinity has been

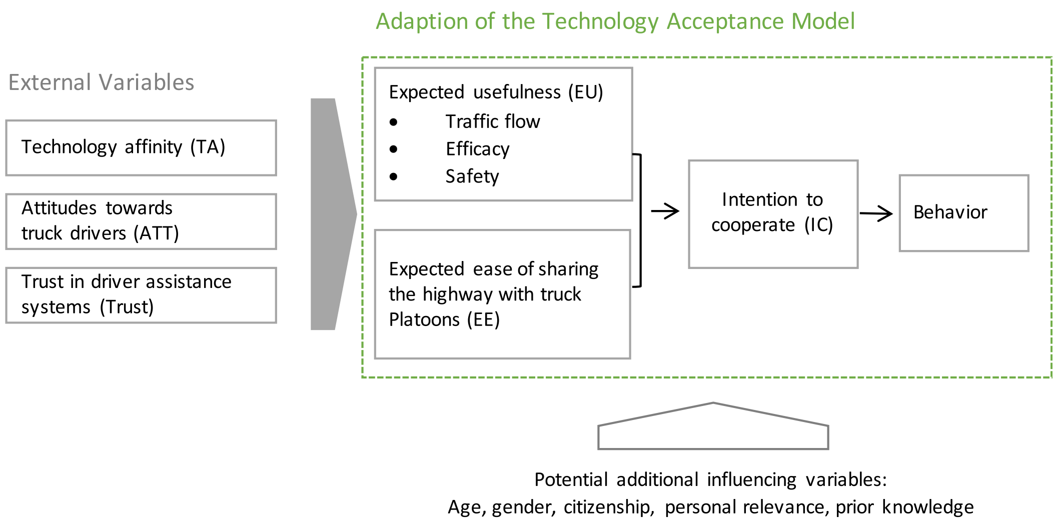

Fig. 1. Refined technology acceptance model for public acceptance of truck platoon driving.

found to be related to the acceptance of truck platooning by professional drivers (Castritius et al., 2020). Therefore, general *technology affinity* was included to explore if it might have a similar impact on public acceptance. Demographics (age, gender, citizenship) and the respondents' prior experience, in this case *prior knowledge,* were identified as possible additional influencing variables as suggested by Venkatesh et al. (2003), Charness et al. (2018), and Nordhoff, Kyriakidis, van Arem, and Happee (2019). Furthermore, the frequency of highway usage was retrieved, as it could determine the *personal relevance* of truck platoon driving for the respondents. The presented refined version of the original TAM forms the basis for this study. The assumptions made by the model are tested in the following.

To assess country-specific differences, a sample in Germany and California was chosen and specific questions were added to the public acceptance questionnaire. Participants answered questions about the maximum number of trucks in a platoon, and the minimum distance between them that they would support. Furthermore, participants were asked to give an overall direct acceptance rating on the 8-level acceptance-non-acceptance-scale developed by Sauer et al. (2005), reaching from active refusal to active commitment. It is hypothesized that public acceptance is higher in California, U.S., than in Germany and that longer platoons with smaller distance are supported.

3. Methods

3.1. Participants

A total of 536 responses to the online questionnaire were collected. Half of the responses were recruited through an online panel by *QuestionPro* (n = 264), half through e-mail lists and survey flyers (n = 272) in the Rhein-Main Area of Germany and the San Francisco Bay Area of California. The average time to answer the questionnaire was 11.5 min (95%-*CI* = 10.5, 12.5). Participants were excluded if the questionnaire was answered in<4 min or in case of uniform answering behavior. The majority of participants were German or Californian citizens (GER: n = 286, CA: n = 212, Other: n = 38). On average, they were 37 years old (*SD* = 14), drove 1,225 km per month and had a median of 11–20 years of driving experience. 53% of participants were male, 46% were female, 1% was diverse. Samples from Germany and California did not significantly differ in the distribution of age groups ($X^2(12) = 13.563$, $p = .331$), gender ($X^2(2) = 4.538$, $p = .103$), or driving experience ($X^2(8) = 3.964$, $p = .884$). Also, gender did not differ per age group ($X^2(6) = 13.536$, $p = .076$). Table 1 shows demographics of survey participants from Germany and California respectively.

3.2. Procedure and material

After accessing the online questionnaire via desktop computer or mobile device, participants chose a language (German, English) and were forwarded to the respective information page of the online survey. They gave their informed consent to participate. The research complied with the *American Psychological Association Code of Ethics* and was approved by the *Institutional Review Board* at *Johannes Gutenberg-Universität Mainz* (2019-JGU-psychEK-014). The questionnaire included an information page with a short explanation about the basic concept of truck platoon driving with level-1 or level-2 automation (SAE International, 2018). The explanation page included the following wording:

Table 1
Demographics of survey respondents.

		Citizenship			
		California	Germany	Other	Total
	N	212	286	38	536
Gender	female	124	146	16	286
	male	86	137	21	244
	diverse	2	3	1	6
Driving experience [years]	<5	30	47	7	84
	6–10	34	49	8	91
	11–20	66	94	11	171
	20–30	26	35	5	66
	>30	49	60	5	114
Age	16–25	50	52	8	110
	26–35	71	108	14	193
	36–45	40	47	8	95
	46–55	17	45	4	66
	56–65	23	24	1	48
	66–75	8	8	2	18
	76–85	3	2	0	5
	86–95	0	0	1	1
Driving habits [km per month]	Mean (SE)	1,027 (1 8 8)	1,397 (1 3 7)	1,035 (2 4 6)	1,225 (1 0 6)

"With platoon driving technology (also known as Corporate Active Cruise Control CACC), two or more commercial trucks build a convoy. The first truck of the convoy is driven manually, succeeding vehicles are connected electronically and follow semi-automated with reduced distances of up to 15 m (50 ft). The following vehicles are still operated by a commercial driver, who monitors the system and can intervene if necessary, but the platooning system takes over speed control as well as steering. The Platooning system gets information from the first truck and is able to react within milliseconds to a sudden event. If a passenger car cuts in between the platoon trucks, the system registers it and increases the gap between the trucks autonomously to defuse the situation. Expected advantages of the technology are fuel savings through slipstream driving, improved traffic flow as well as enhanced safety and comfort."

Participants were asked to imagine a 3-truck platoon at a speed of 55 mph (80 km/h) and separation gaps of 50 ft (15 m) between the vehicles when answering the questions. A graphic was presented additionally to the text (Fig. 2). A schematic info graphic was chosen instead of a photo or video to prevent the influence of truck type (American/European) and surroundings. Table 2 gives an overview on the used constructs, their sequence and rating scales.

3.3. Data analysis of items and constructs

For an analysis utilizing a structural equations model, the scales used in the questionnaire were examined for normal distribution, internal consistency, reliability, convergent validity, and discriminant validity. 15 multivariate outliers were identified by Mahalanobis distance ($p < .01$) and were excluded, leaving a final sample size of 521. After the exclusion of these outliers, none of the variables exceeded a kurtosis of 1 and a skewness of 0.7 and were therefore not considered as extreme (Curran, West, & Finch, 1996; Kline, 2011). The constructs of the questionnaire were analyzed with confirmatory factor analysis, and items with low factor loadings (<0.65) were excluded. Included items and their specifications are shown in Table 3. After item rejection, all composite reliability (CR) and Cronbach's alpha values were>0.70 confirming internal consistency. Average variance extracted (AVE) values of all constructs, except for ATT, exceeded the criterion of being at least 0.50 (Fornell & Larcker, 1981), establishing convergent validity. The construct ATT shows an AVE value of 0.49, which we still considered acceptable.

The square root of each AVE was greater than the associated inter-construct correlations, confirming discriminate validity as shown in Table 4 (The square root of AVE is shown in the diagonal and inter-construct correlation off-diagonal). The variance inflation factor (VIF) of the constructs was max. 1.4, indicating an absence of multivariate collinearity issues (Hair, Ringle, & Sarstedt, 2011). Thus, the validity and reliability of the used constructs are adequate. Note that the scale *intention to cooperate with platooning vehicles* did not meet the above criteria and was split into two single-item constructs – the *intention to share the highway* (IC1), and *the intention to cut in* (IC2).

4. Results

First, descriptive results of the questionnaires and constructs are presented and compared between the main countries of interest: Germany and California. Then, the results of a structural equations model (SEM), as an improvement of prior technology acceptance models (TAM, UTAUT), is introduced. Moreover, a separate logistic regression is calculated to get a deeper understanding of additional influencing factors, such as age and prior knowledge.

4.1. Descriptive results and country-specific comparison

4.1.1. TAM constructs

As 6-point rating scales were used to assess the TAM constructs, mean values of 3.5 imply neutral responses. The mean *technology affinity* rating was 4.3 and the mean *trust* rating was 4.8, implying high levels of trust in driver assistance systems and technology affinity among respondents. The comparison between German and Californian citizens revealed significantly

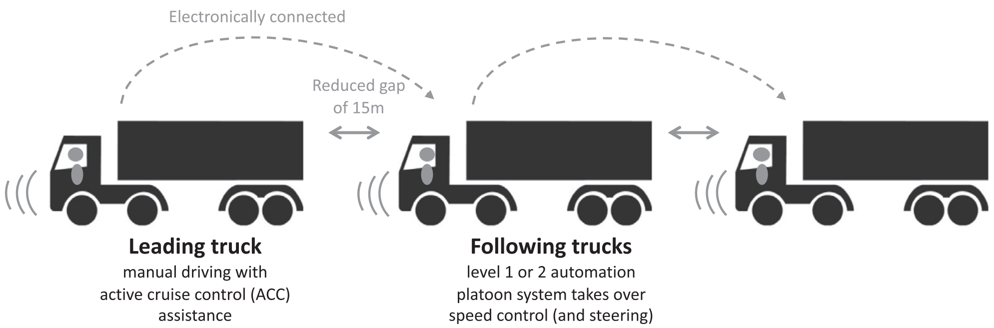

Fig. 2. Information graphic on truck platoon driving.

Table 2
Public acceptance of platoon driving questionnaire.

Constructs	ID	Item	Scale
Demographics		Citizenship Age Gender How many years of driving experience do you have? How many miles do you drive per month?	Ger, Cal, Other 16–90 M, F, D 5-point scale Amount
Highway usage	HU	How frequently do you drive on the highway?	5-point scale (never ¬ very often)
Technology affinity[a]	TA 1–9	Affinity of Technology Interaction questionnaire ATI (Franke, Attig, & Wessel, 2019)	6-point scale (completely disagree ¬ completely agree)
Attitudes towards truck drivers[a]	ATT1 ATT2 ATT3 ATT4 ATT5 ATT6	I am annoyed by heavy trucks on the highway (–) I feel threatened when heavy trucks get too close to me (–) Sometimes I feel stressed driving onto the highway because trucks block the right lane (–) If a truck driver tries to change lanes, I let him go ahead I am considerate towards commercial truck drivers If I need to exit the highway, I don't mind cutting in between two trucks if necessary (–)	6-point scale (completely disagree ¬ completely agree)
Trust in driver assist. systems	Trust 1–7	Adapted trust in automated systems questionnaire (Jian, Bisantz, & Drury, 2000)	7-point scale (not at all ¬ extremely),
— Information on truck platoon driving —			
Prior knowledge	PK	Have you heard about of Platoon driving or Corporate Active Cruise Control driving before participating in this study?	Yes, No
Expected usefulness of platoon driving[a]	EU1 EU2 EU3 EU4 EU5 EU6 EU7 EU8 EU9	I think new technologies like platoon driving are necessary because the streets are getting more and more crowded I think the technology could lead to less traffic jams on the highways in the future I think this technology can achieve fuel savings I think platoon driving is environmentally friendly I think platoon driving is safer than manual driving on the highway Platoon driving will help to avoid accidents I rather support other transport solutions like the railway (–) I fear that such a system could be hacked (–) I think the technology is not mature (–)	6-point scale (completely disagree ¬ completely agree)
Expected ease of sharing the highway with platoons[a]	EE1 EE2 EE3 EE4	The short distance of 15 m between the platoon trucks scares me (–) I am concerned about taking an exit when sharing the highway with truck platoons (–) I am concerned about driving onto the highway when sharing the highway with truck platoons (–) I would feel uncomfortable in the vicinity of a truck platoon (–)	6-point scale (completely disagree ¬ completely agree)
Intention to cooperate	IC1 IC2	I would not mind sharing the highway with truck platoons I would cut in between two platoon vehicles if it is necessary (–)	" – "
Acceptance-non-acceptance[b]	ACC	Which of the following definitions best describes your attitude towards truck platoon driving?	8-point scale (refusal–commitment
Platoon specifications	PS1 PS2 PS3	What is the minimal distance between the truck platoon vehicles you would support? What is the maximal number of trucks you would support? What are your biggest concerns about truck platoon driving?	9-point scale (5–50 m) 10-point scale (1–>10) Item rank 1–6

(–) Items have been reversed for analysis.
[a] Custom construct.
[b] Acceptance-non-acceptance-scale developed bySauer et al. (2005).

higher *technology affinity* ratings in Germany than in California (Ger: M = 4.40, Cal: M = 4.08, t(444.06) = −3.270, p = .001, Hedges' g = 0.298). For *trust in driver assistance systems* no significant difference was found (t(445.98) = 1.214, p = .226). The *attitude towards truck drivers* was slightly negative in both countries without a significant difference (t(436.48) = 1.260, p = .208). *Expected usefulness* ratings were slightly higher in Germany (Ger: M = 4.18, Cal: M = 3.95, t(424.80) = −2.401, p = .017, Hedges' g = 0.222) and *ease of sharing* ratings did not differ between countries (t(476.10) = −1.926, p = .055). The majority of respondents expected platoon driving to be rather useful—70% of *expected usefulness* ratings were higher than 3.5. In contrast, 63% of ratings on the *expected ease of sharing* were lower than 3.5, indicating that problems when driving on or off the highway were expected, as well as a feeling of discomfort. Concerning the *intention to cooperate* with platooning vehicles, 68% of respondents would not mind sharing the road. There was no significant difference

Table 3
Reliability and validity of the constructs used.

Construct	Item	M	SD	Skew	Kurtosis	FL	α	CR	AVE
Technology affinity (TA)	TA1	4.46	1.23	−0.74	0.29	0.79	0.906	0.91	0.67
	TA2	4.45	1.26	−0.65	−0.01	0.86			
	TA4	4.34	1.11	−0.60	0.19	0.82			
	TA5	4.25	1.21	−0.56	0.01	0.86			
	TA7	3.98	1.38	−0.47	−0.49	0.74			
Trust in DAS (Trust)	Trust1r	4.81	1.53	−0.44	−0.30	0.80	0.876	0.88	0.64
	Trust2r	5.09	1.58	−0.52	−0.51	0.83			
	Trust3r	4.85	1.71	−0.38	−0.85	0.86			
	Trust4r	4.30	1.59	−0.13	−0.70	0.72			
Attitudes towards truck drivers (ATT)	ATT1	4.03	1.34	−0.30	0.68	0.68	0.737	0.74	0.49
	ATT2	4.38	1.36	−0.60	0.68	0.70			
	ATT5	3.70	1.50	−0.14	0.71	0.72			
Expected usefulness (EU)	EU1	4.33	1.26	−0.63	0.71	0.72	0.867	0.87	0.63
	EU3	4.16	1.23	−0.48	0.75	0.76			
	EU5	3.98	1.25	−0.43	0.84	0.85			
	EU6	3.96	1.13	−0.39	0.83	0.83			
Expected ease of sharing the highway (EE)	EE2r	3.03	1.30	0.28	0.91	0.91	0.851	0.86	0.68
	EE3r	3.06	1.31	0.23	0.87	0.88			
	EE4r	3.27	1.39	0.14	0.65	0.67			
Intention to share	IC1	4.02	1.31	−0.36	−0.35				
Intention to cut in	IC2r	3.57	1.54	−0.13	−0.13				

Note. Mean (M), standard deviation (SD), skew, kurtosis and factor loadings (FL) of the selected items per construct. Composite reliability (CR), average variance extracted (AVE) and Cronbach's alpha (α) for each construct. $N = 15$ multivariate outliers have been excluded.

in the intention to share the road between countries ($t(460.10) = -0.499$, $p = .618$). However, higher mean values in Germany than in California indicated that Germans were more willing to cut in between platoon vehicles (Ger: $M = 3.79$, Cal: $M = 3.36$, $t(444.95) = -3.021$, $p = .003$, Hedges' g = 0.276). Overall, 53% of respondents indicated that they would consider cutting in between platoon vehicles. Mean values of the TAM constructs are shown in Fig. 3.

4.1.2. Main concerns

The direct comparison between respondents from California and Germany revealed that the main concerns were similar. For 69.3% of Californians and 69.1% of Germans, one of the following three concerns was ranked as the most important: reliability issues of the technology (Cal: 30.1%, Ger: 25.0%), problems when entering/exiting the highway (Cal: 23.9%, Ger 25.4%), and issues with cut-in vehicles (Cal: 15.3%, Ger: 18.7%). Other predefined problems – the risk of hacker attacks, driver job loss, and legal liability issues – were seen as less important. The ranks for each topic (rank 1 to rank 6) were compared between countries using a *Man-Whitney-U* test. The result revealed significant differences in rankings of the concern *issues with cut-in vehicles* in California ($n = 209$, $Mdn = 3$) and Germany (Ger: $n = 284$, $Mdn = 3$, $U = 25776.5$, $p = .011$). Higher ranks were attached to this topic in Germany than in California. All other comparisons were not significant ($p > .077$).

4.1.3. Acceptance-non-acceptance scale

The distribution of answers on the acceptance-non-acceptance scale is shown in Fig. 4. A Chi-square test revealed significant differences between Germany and California ($X^2(7) = 21.899$, $p = .003$). 30.2% of Californian citizens indicated that "conditional acceptance" best described their attitude towards truck platoon driving. In contrast, 28.7% of German respondents indicated that the definition "partial rejection" best described their attitudes.

According to Sauer (2005), the ratings "active refusal", "rejection" and "partial rejection" can be combined to describe non-acceptance. When summarizing the ratings in these categories, the difference becomes apparent: 37.0% German respondents and 24.5% of Californians were not accepting the technology.

4.1.4. Platoon specification

Ratings on the supported number of trucks and the minimal distance between them are shown in Fig. 5. The median number of supported trucks was 3 in California ($n = 212$) and 4 in Germany ($n = 286$). This difference was not significant ($U = 29310.5$, $p = .517$). The ratings of minimal supported distance differed significantly between countries ($U = 26382.5$, $p = .011$). The median rating was a distance of 15 m in California and 20 m in Germany.

4.2. Results of the structural equations model

To get a deeper understanding of the influencing factors of the intention to share the road or cut in between platoon vehicles by other road users, a structural equations model was applied using maximum likelihood with IBM AMOS (version 23). A

Table 4
Mean (standard deviation) and correlations between constructs.

	M (SD)	TA	Trust	ATT	EU	EE	IC1	IC2
TA	4.30 (1.06)	(.82)						
Trust	4.76 (1.37)	-.06	(.80)					
ATT	3.00 (1.14)	-.08	.02	(.70)				
EU	4.11 (1.03)	.29	.01	-.01	(.79)			
EE	3.12 (1.17)	.15	.13	-.37	.39	(.83)		
IC1	4.02 (1.31)	.20	.06	.20	.57	.49		
IC2	3.57 (1.54)	.08	-.05	.13	.17	.20	.31	

Numbers in parentheses on the diagonal are square roots of AVEs. Significant correlation at $p < .05$ are colored in grey. IC2 was included with its original coding (without inversion) for better interpretation. $N = 15$ multivariate outliers have been excluded.

Numbers in parentheses on the diagonal are square roots of AVEs. Significant correlation at $p < .05$ are colored in grey. IC2 was included with its original coding (without inversion) for better interpretation. $N = 15$ multivariate outliers have been excluded.

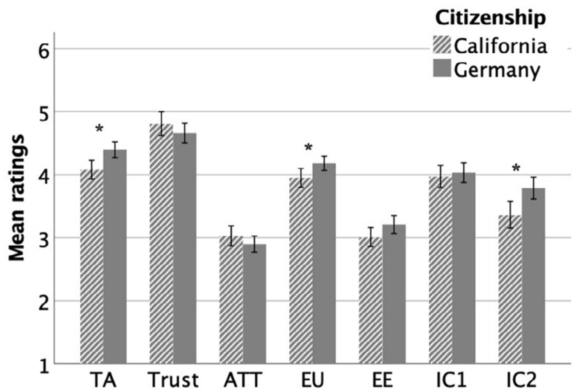

Fig. 3. Ratings of refined TAM constructs in Germany and California. The ratings were given on a 6-point scale (completely disagree–completely agree) by $n = 386$ German and $n = 212$ Californian citizens. Error bars show 95% confidence intervals. Significant differences $p < .05$ are marked with an asterisk. Technology affinity (TA); Trust in driver assistance systems (Trust); Attitudes towards truck drivers (ATT), Expected usefulness (EU); Expected ease of sharing the highway (EE); Intention to share the road (IC1); Intention to cut in (IC2).

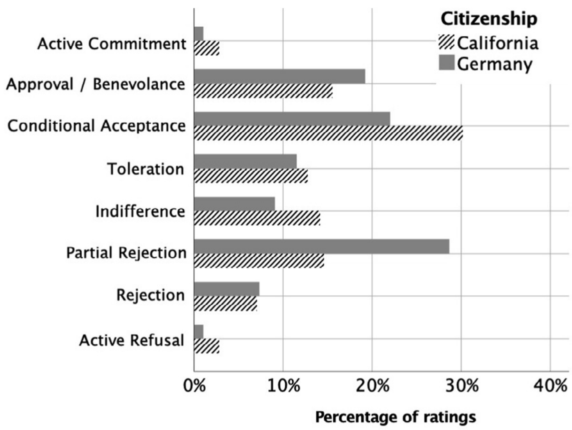

Fig. 4. Acceptance ratings in California and Germany. The ratings were given on the 8-point acceptance-non-acceptance scale (Sauer, Luz, Suda, & Weiland, 2005), by $n = 286$ German and $n = 212$ Californian citizens.

first model included the main TAM constructs *expected usefulness* (EU) *and expected ease of sharing* (EE) as well as the *intention to share* the highway (IC1) and the *intention to cut in* (IC2) as dependent variables. It achieved acceptable model fit (NFI = 0.950, CFI = 0.960, RMSEA = 0.085) but was further improved by including the additional constructs *technology affinity* (TA), *trust in driver assistance systems* (Trust), and *attitudes towards truck drivers* (ATT) as external variables. As dependent variables, the *intention to cut in* as well as the *intention to share* the highway were included separately. The comparative

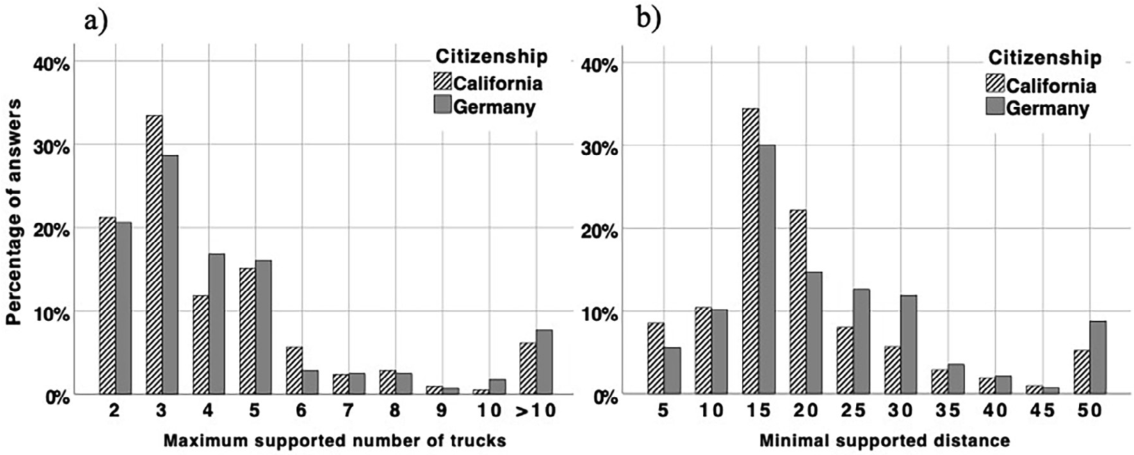

Fig. 5. Ratings on supported platoon specifications. The percentage distribution of ratings by German (n = 286) and Californian respondents (n = 212). a) Ratings on the maximum supported number of trucks in a platoon. b) Ratings on the minimal supported distance between platoon trucks.

fit index (CF) = 0.96, the Tucker-Lewis fit index (TLI) = 0.95, and the RMSEA = 0.05 indicated a good fit between the model and the observed data. The structural equations model including the standardized regression weights and the squared multiple correlations is shown in Fig. 6. Unstandardized and standardized regression weights for each effect are shown in Table 5. It was also tested if model fit could be improved by including all predictors on the same level or including demographic variables as moderating effects, as suggested by the UTAUT model (Venkatesh et al., 2016). However, model fit could not be further improved.

The results of the suggested model show that both EE and EU significantly affect the behavioral intention (*intention to share*, the *intention to cut in*). EE also significantly influenced EU, as suggested by the original TAM (Davis, Bagozzi, & Warshaw, 1989). The external variables in turn had a significant effect on either EE, EU, or both. *Technology affinity* had a significant effect on both EU and EE (EU: β = 0.252, p < .001, EE: β = 0.155, p < .001). In other words, high ratings of general *technology affinity* were related to higher *usefulness* and *ease of sharing* ratings. *Attitudes towards truck drivers* had a significant effect on the *ease of sharing* (β = −0.422, p < .001). More negative attitudes towards truck drivers were associated with higher ratings of the ease of sharing. In contrast, trust towards driver assistance systems did not show significant effects on EU and small effects on EE. All in all, the *intention to cut in* between platoon vehicles accounted for R^2 = 0.06 of variance, whereas the *intention to share* the highway explained R^2 = 0.44 of variance. While the prediction of the *intention to cut in* between two platoon vehicles was rather poor, the more general *intention to share* the highway with truck platoons was predicted quite well by the model. It is perceivable that there must be more predictor variables for the intention to cut in, which were not included in the model. To discover additional predictor variables, the correlations between the *intention to cut in* (IC2) and additional predictor variables such as demographic data, highway usage (HU) and prior knowledge (PK) of platooning technology were considered. As shown in Table 6, the highest correlation (*eta* = 0.22) occurred with the variable gender.

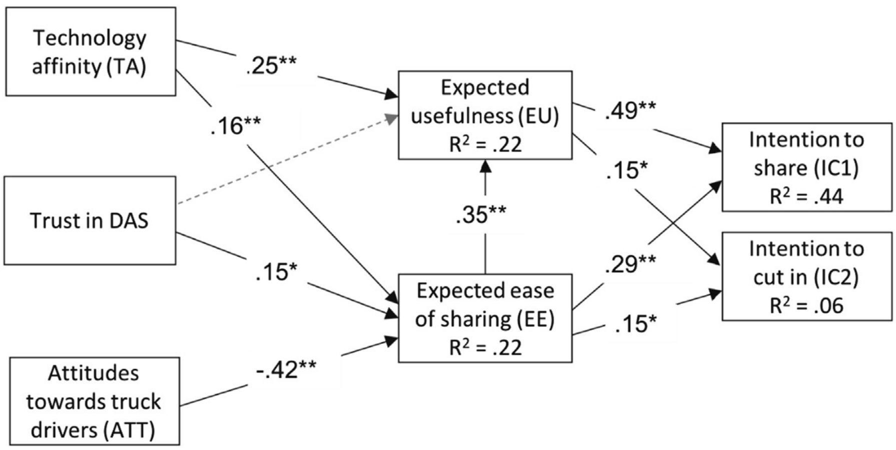

Fig. 6. Structural equations model of the public acceptance questionnaire.

Table 5
Results of the structural equations model.

Direct effects			Regression Weights	Standardized Regression Weights	S.E.	C.R.	P
EU	←	Trust	−0.008	−0.010	0.034	−0.229	0.819
EU	←	TA	0.234	0.252	0.044	5.351	<0.001
EU	←	EE	0.274	0.254	0.038	7.203	<0.001
EE	←	Trust	0.141	0.147	0.044	3.232	0.001
EE	←	ATT	−0.539	−422	0.071	−7.584	<0.001
EE	←	TA	0.187	0.155	0.054	3.462	<0.001
IC1	←	EU	0.711	0.492	0.066	10.828	<0.001
IC1	←	EE	0.323	0.290	0.045	7.172	<0.001
IC2	←	EU	0.247	0.146	0.086	2.880	0.004
IC2	←	EE	0.191	0.146	0.065	2.922	0.003

Comparative fit index (CFI) = 0.96, the Tucker-Lewis fit index (TLI) = 0.95, and RMSEA = 0.05.

Table 6
Correlations between behavioral intentions and additional predictor variables.

	IC2	Age	HU	Citizen-ship	Gender	PK
IC2						
Age	.02[a]					
HU	.15[a]	.07[a]				
Citizenship	.14[b]	.03[b]	.18[b]			
Gender	.22[b]	.07[b]	.08[b]	.11[c]		
PK	.12[b]	.05[b]	.04[b]	.16[c]	.18[c]	

Note. Dependent on the measurement scale, Pearson[a], Eta[b], or Phi[c] correlation coefficients were calculated. IC2 was included with its original coding (without inversion) for better interpretation.

4.3. Results of explorative logistic regression

As only 6% variance of the *intention to cut in* between platoon vehicles was accounted for in the above model, it is hardly possible to predict this specific behavioral intention with the TAM. However, for the application of platoon driving in real traffic, this prediction is most interesting. The question at hand is what type of driver is prone to cut into the gaps between platoon trucks. To answer this question a separate logistic regression model was fitted. This model was chosen as it constituted less requirements on data distribution and scale of measures. For this purpose, the dependent variable *intention to cut in* was transformed into a binary variable combining the following rating categories: 0 = completely disagree, largely disagree, slightly disagree; and 1 = slightly agree, largely agree, completely agree. This procedure resulted in 243 responses coded as 0: no intention to cut in and 278 responses coded as 1: intention to cut in. As predictor variables, demographic data (age, gender, citizenship) and additional explanatory variables (prior knowledge, highway usage) that were expected to influence the intention to cut in were analyzed. Correlations between the predictor variables were rather low ($r < 0.20$), indicating the absence of multicollinearity. Highway usage and age entered the analysis as metric predictor variables. Prior knowledge was entered as a binary nominal predictor variable (0 = no prior knowledge, 1 = prior knowledge). Gender (f, m, d) and citizenship (Cal, Ger, Other) were dummy-coded and entered as binary nominal predictor variables.

The result of the logistic regression analysis showed that gender, citizenship, and highway usage were significantly related to IC2, whereas age and prior knowledge were not. The odds of German citizens to drive into the gap were 1.82 times

Table 7
Results of the multiple logistic regression.

Predictor variables	B	S.E.	Wald	df	Sig.	Exp(B)
Age	−0.003	0.006	0.289	1	0.591	0.997
Gender			21.384	2	0.000	
m vs. f	0.864	0.189	20.895	1	0.000	2.373
d vs. f	−0.238	0.950	0.063	1	0.802	0.788
Citizenship			11.893	2	0.003	
Ger vs. Cal	0.596	0.199	9.013	1	0.003	1.815
Other vs. Cal	−0.283	0.384	0.540	1	0.462	0.754
PK	−0.293	0.204	2.055	1	0.152	0.746
Highway usage	0.230	0.084	7.552	1	0.006	1.258
Constant	−0.760	0.545	1.947	1	0.163	0.468

Note. Cox and Snell R = 0.085, Nagelkerke R = 0.113, c-statistic = 63.1%.

higher than the odds for Californian citizens (p = .003). Also, driving more frequently on the highway was positively related to the intention to drive into the gap (Odds ratio = 1.26, p = .006). Furthermore, men were more likely than women to do so. That is, the odds were 2.37 times higher for male than for female respondents (p < .001). The Hosmer-Lemeshow (H-L) goodness-of-fit showed that the model adequately fit the data ($X^2(8) = 7.835$, p = .450). The results of the logistic regression are shown in Table 7.

5. Discussion

An online questionnaire with N = 526 respondents was designed in order to assess the public acceptance of truck platoon driving, potential differences between Germany and California, and the main influencing factors of acceptance. Regarding the positive effects on safety and traffic flow, platoon driving was seen as rather useful by the respondents. 70% of ratings were higher than medium. Likewise, the majority of respondents (70%) indicated that one of the following statements best described their attitude towards truck platoon driving: Active approval, benevolence/commitment, conditional acceptance, toleration, indifference. According to Sauer et al. (2005), these categories can be summarized as technology acceptance. These results are somehow similar to a population-representative survey in Finland, reporting that 64% of respondents had positive attitudes towards automated vehicles in general (Liljamo et al., 2018). However, our results showed that about 60% of respondents expect certain efforts when sharing the road with platoon vehicles. In a prior study on the public acceptance of truck platoon driving within the KONVOI project in Germany, 50% of respondents rated the system as useful with regard to traffic safety, and 90% expected problems with the surrounding traffic. An additional driving simulator study had shown that participants' subjective workload was higher while driving onto the highway or exiting it when platoon vehicles were in the vicinity (KONVOI, 2009). In contrast, the results presented in the current study, conducted about ten years later, show a higher level of expected usefulness and a decreased level of expected effort. It can be summarized that the overall opinion of truck platoon driving was rather positive in this sample. However, sharing the road with platoon vehicles is not expected to be effortless. The highest concerns with the technology that we found were the reliability of the technology, problems when entering/exiting the highway and issues with cut-in vehicles. In contrast, the risk of hacker attacks, driver job loss, and legal liability issues were seen as less important.

The results on platoon specifications presented in this study suggest that a distance of 15–20 m between the platoon vehicles, and a maximum number of up to 5 vehicles is supported by most respondents. The intra-platoon distance is in line with prior findings of Larburu et al. (2010). Participants of a driving simulator study stated to feel uncomfortable, as soon as the distance between the platoon vehicles fell below 17 m. However, the same authors suggested a maximum acceptable number of up to 15 platoon vehicles. Note that this conclusion had been derived from a simulator study in which participants passed platoons of different length and therefore gained first-hand experience. Without such first-hand experience, however, our results indicate that a maximum number of 5 vehicles is accepted by respondents.

The direct comparison of ratings by Californian and German citizens revealed country-specific differences. Ratings on *technology affinity* and *expected usefulness* of truck platoon driving were higher in Germany than in California. However, there was no difference in the ratings on the *intention to share* the road with platoon trucks between countries. Respondents of both countries rather agreed to be willing to share the road with platoon vehicles. At the same time, Germans were more prone to drive into the gap between platoon vehicles than were Californians. Furthermore, the minimal accepted distance differed between countries. Whereas Californians mostly accepted a distance of 15 m, the median accepted distance for German citizens was 20 m. This trend was further confirmed by the country-specific results of the acceptance-non-acceptance scale. >75% of Californian respondents indicated to accept the technology, in contrast to 63% in Germany. Among German respondents, 29.0% stated to partially reject the technology. This rather negative attitude could be explained by the different infrastructural prerequisites, such as higher relative speed differences in Germany and California and resulting difficulties when entering and exiting the highway with truck platoons on the main lane. Note that in Germany, trucks are the slowest vehicles on the Autobahn. They are not allowed to go faster than 80 km/h. According to these results, the hypothesis of higher acceptance in California than in Germany can be confirmed. Although not representative for the general population of the countries, the samples did not differ in the main demographic aspects (age, gender, driving experience) and are therefore assumed to be comparable. A very extensive survey on the public acceptance of automated vehicles with 23,000 respondents showed a similar trend of country-specific differences. A higher percentage of U.S. than German respondents were in favor of full automation (U.S.: 36%, Ger: 29%; Brown et al., 2014). However, a recent review concluded that the behavioral intention towards automated driving differs considerably among studies (Becker & Axhausen, 2017).

With regard to the predictor variables for the behavioral *intention to share* the road with truck platoons, *expected usefulness* and *expected ease of sharing* were found to be of the highest influence. Together with *attitudes towards truck drivers*, *trust* in driver assistance systems and *technology affinity*, they accounted for 44% of the variance. Structural equation models following the TAM also found *perceived use* and *perceived ease of use* to be important influencing variables of the intention to use in similar contexts. The models were found to account for 40–60% of variance and included different external variables such as trust, perceived safety, social influence, and perceived risk (Buckley et al., 2018; Xu et al., 2018). In this study, *trust* was a less important predictor than previous studies had suggested. However, it was defined as the trust in driver assistance systems in general, not towards the automated vehicles. Interestingly, the *attitudes towards truck drivers* had a negative effect on the *perceived ease of sharing* in the study presented here. That is, negative attitudes towards regular trucks and their drivers were related to a more positive expectation of the interaction with

(semi-)automated truck platoons. In other words, the more threatened/annoyed/stressed the respondents felt by regular trucks on the highway, the more positive they felt about interacting with (semi-)automated ones. *Technology affinity* was found to be positively related to the *expected usefulness*, as well as the *expected ease of sharing*. In sum, the suggested variables predict the *intention to share* the highway to an adequate extent, but fail to predict the *intention to cut in* the gaps between platoon trucks. Cut-in behavior seems to be rather independent of the intention to cooperate and the acceptance of the technology. We found that the additional variables such as gender, citizenship and highway usage are related to higher probability of intending to drive into the gap. However, it is conceivable that situation-specific variables like the traffic volume and the road geometry of the merging area or other characteristics like driving style have an influence on cut-in behavior. To prevent frequent cut-ins, external signaling on the platoon trucks could be a possible solution (Andersson et al., 2017).

5.1. Limitations

The respondents of the online questionnaire are not representative of the German or Californian population. It might be positively biased as subjects had volunteered to participate in the questionnaire study. However, the subsamples from both countries do not differ significantly in age distribution, gender, and driving experience. Therefore, the comparison is justified and meaningful. Another potential problem that should be mentioned is the lack of first-hand experience when answering the questionnaire. The participants rated their comfort with platoon vehicles by relying on their expectation and imagination of platooning vehicles from prior knowledge and/or written information and an infographic. The specifications that were presented in the questionnaire might have influenced the survey results. However, it also brings along the advantage that the ratings were based on a common understanding and specific concept. Although ratings could differ substantially when people gain first-hand experience and are confronted with platoon vehicles on the road, public acceptance often develops without actual experience, and attitudes as well as behavioral intentions are often built on beliefs based on secondary information only. The a-priori assessment without actual experience is important to anticipate the public opinion on the technology. It should also be mentioned that the question format PS2 *"What is the maximal number of trucks you would support?*" was restricted to an answer between 2 and >10. Therefore, we cannot say anything about how far beyond 10 trucks some people may have been willing to go. Another limitation that should be mentioned is that the construct *intention to cooperate with platoon vehicles* was split into two single-item scales due to lack of consistency. In retrospect, it could have been beneficial to use more items to detect this behavioral intention.

6. Conclusion

The results show that the majority of respondents were convinced of the usefulness of truck platoon driving, but were concerned about driving on the highway with truck platoons at the same time. In fact, safety issues and problems with the surrounding traffic were seen as the most serious concerns. The risk of hacker attacks, job loss, and legal liability issues were seen as less important. When informing the public about truck platoon technology, these major concerns of traffic safety should be addressed first. Furthermore, truck platoons with 15–20m gaps and up to 5 vehicles were rated as acceptable in this sample. The results also show that the intention to share the highway was well predicted by the expected usefulness, expected ease of sharing the highway, and additional external variables. However, the prediction was less strong for cut-in behavior. As frequent cut-ins can substantially decrease the efficiency of truck platooning, further research should focus on the main influencing variables that predict cut-in behavior and on finding adequate countermeasures or communication strategies to further investigate and address the intention to cut in between platoon vehicles.

CRediT authorship contribution statement

Sarah-Maria Castritius: Conceptualization, Methodology, Writing - original draft, Investigation. **Xiao-Yun Lu:** Funding acquisition, Resources, Writing - review & editing. **Christoph Bernhard:** Writing - review & editing. **Magnus Liebherr:** Writing - review & editing. **Patric Schubert:** Formal analysis. **Heiko Hecht:** Supervision, Writing - review & editing.

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