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Mirror or camera? Acceptance and valuation of camera-monitor systems

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ABSTRACT

Manufacturers are increasingly considering the replacement of side-mounted rear-view mirrors with camera-monitor systems (CMS). These systems offer advantages that can improve rearward vision and safety, such as image enhancement. However, these systems must also be accepted and valuated by users. We examined acceptance of CMS, the willingness to change from rear-view mirrors to CMS, and the willingness to pay for this replacement, using an online questionnaire. We also explored the relationship between these variables using an adaption of the technology acceptance model. In total, 364 subjects completed the questionnaire. Items were aggregated using confirmatory factor analysis and factors were analyzed using (non-) parametric tests as well as path model analysis. Despite a positive attitude and high intention to use standard CMS, a combination of mirror and blind spot detection system was preferred. Subjects were willing to pay around 300 € for standard CMS, which is comparable to the preferred price of driver assistance systems. Perceived usefulness, perceived ease-of-use, and satisfaction were strong predictors of intention-to-use, but only satisfaction had a direct effect on willingness-to-change, and none of these variables predicted willingness-to-pay. Finally, customization was identified as a promising way to increase acceptance of and preference for CMS.

1. Introduction

During the last years, a new paradigm shift in rearward vision has begun: the substitution of side-mounted rear-view mirrors with camera-monitor systems (CMS). In these systems, a camera is placed at the side of the vehicle and transmits its image to a monitor placed in the cockpit. For more details on this technology, please refer to Terzis (2016). CMS change the rearward viewing conditions of drivers fundamentally, since they decouple the camera from the driver's viewing axis (Terzis, 2016). This presents new advantages, but also challenges. Cameras improve the aerodynamics and fuel efficiency of vehicles, they provide a larger field of view, and their image can be enhanced (Indinger and Devesa, 2012; Terzis, 2016). However, drivers cannot yet adapt their field of view flexibly. Moreover, high-resolution cameras and monitors are required, which are more expensive than mirrors and require additional space in the cockpit (Schmidt et al., 2016; Terzis, 2016). Consequently, it is important to examine how potential users will evaluate and adopt CMS. However, CMS research so far has mostly focused on perception, driving behavior, or preferences for different monitor and camera positions (Beck et al., 2017; Bernhard et al., 2021; Bernhard and Hecht, 2020; Flannagan et al., 2002; Flannagan and Mefford, 2005; Flannagan and Sivak, 2003; Large et al., 2016; Murata et al., 2018; Murata and Kohno, 2018; Schmidt et al., 2016). The general acceptance and valuation of CMS have not been examined. The present research represents a first approach to model and investigate these factors.

1.1. Measuring acceptance and valuation of in-vehicle systems

Whereas user acceptance of CMS has not been examined in detail, it has been studied with respect to many advanced driver assistance systems (ADAS; e.g. Beggiato and Krems, 2013; Biassoni et al., 2016; Huth and Gelau, 2013; Isa et al., 2015; Owens et al., 2015; Rahman et al., 2017; Rahman et al., 2020; Roberts et al., 2012). In these studies, acceptance was usually defined as the intention to use a new system

Abbreviations: CMS, Camera-monitor system; PU, Perceived usability; PEOU, Perceived ease-of-use; BI, Behavioral intention; TAM, Technology acceptance model; UTAUT, Unified theory of acceptance and use of technology; TPB, Theory of planned behavior; U, Usefullness; S, Satisfaction; WTC, Willingness-to-change; WTP, Willingness-to-pay; BSD, Bllind spot detection; ADAS, Advanced driver assistance systems; ATI, Affinity for Technology Interaction; CIs, Confidence intervals; WLS, Weighted least squares; VIF, Variance inflation factor; RMSEA, Root mean square error of approximation; SRMR, Standardized root mean square residuals; CFI, Comparative fit index; TLI, Tucker-Lewis index; CR, Composite reliability; AVE, Average variance extracted.

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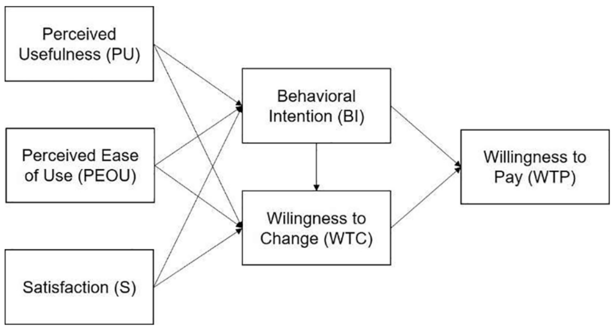

Fig. 1. Our research model adapted from TAM (Davis, 1989).

(Dillon and Morris, 1996). A model that is often used to conceptualize user acceptance is the technology acceptance model (TAM; Davis, 1989; Davis, Bagozzi, and Warshaw, 1989). In this model, users' behavioral intention to use a system (BI) is predicted by the perceived usefulness (PU), defined as "the degree to which a person believes that using a particular system would enhance his or her job performance", and by the perceived ease-of-use (PEOU), which refers to "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989, p. 320). PU and PEOU are believed to affect BI directly, and indirectly by users' attitudes towards technology use (Davis, Bagozzi, and Warshaw, 1989). The original TAM has been extended many times (Benbasat and Barki, 2007; Osswald et al., 2012; Venkatesh, 2000; Venkatesh and Bala, 2008; Venkatesh and Davis, 2000; Wixom and Todd, 2005). And it has been integrated in other models, such as the unified theory of acceptance and use of technology (UTAUT; Venkatesh et al., 2003).

Previous research has defined the valuation of a system as the price users would be willing to pay for this system (Huth and Gelau, 2013; Kaul et al., 2010; Kyriakidis et al., 2015; Liu et al., 2019; Souders et al., 2017; Viktorová and Sucha, 2018). Therefore, valuation will be termed willingness-to-pay (WTP) in the following. The aforementioned studies let their subjects either choose among predefined price ranges (Huth and Gelau, 2013; Kyriakidis et al., 2015; Liu et al., 2019; Viktorová and Sucha, 2018), or directly state a preferred price (Kaul et al., 2010; Schoettle and Sivak, 2014; Schulz et al., 2014). A notable exception is Souders et al. (2017), who used a staircase procedure. Subjects were presented with two different starting prices and then selected their most preferred price in four to five steps. In summary, subjects' WTP varied greatly. Depending on the starting price, the majority of subjects were willing to pay around 300 € or 700 € for a blind spot detection system. In other studies, subjects preferred to pay around 250 € for different ADAS, with large individual differences. Several subjects preferred to pay nothing and some were willing to pay more than 1000 € (Huth and Gelau, 2013; Kaul et al., 2010; Viktorová and Sucha, 2018).

1.2. Research model and prior expectations

Fig. 1 depicts the research model used in the following. We chose to include the constructs BI, PU, and PEOU of TAM, as proposed by Davis (1989). We did so for the following reasons. First, TAM has been used in many experiments examining acceptance of ADAS (Isa et al., 2015; Rahman et al., 2017; Rahman et al., 2020). Second, Rahman et al. (2017) compared TAM with UTAUT and the Theory of Planned Behavior (TPB; Ajzen, 1991) and found that TAM performed best in predicting acceptance of ADAS. However, we excluded attitude from the original model, since attitude only partially mediates the effect of PU on BI (Davis, 1989; Davis and Venkatesh, 1996; Marangunić and Granić, 2015; Venkatesh and Davis, 2000). This parsimonious TAM has been used before in the ADAS acceptance literature (Roberts et al., 2012; Tretten et al., 2011). Moreover, PEOU and especially PU have been repeatedly observed to be strong predictors for BI (King and He, 2006; Motamedi et al., 2021; Schepers and Wetzels, 2007; Turner et al., 2010). However, since TAM has been criticized for neglecting the hedonic determinants of BI (e.g. Benbasat and Barki, 2007), we have included satisfaction as additional predictor of BI, as proposed by Wixom and Todd (2005). To assess satisfaction, we used the van-der-Laan scale (van der Laan et al., 1997). This scale has been used earlier to conceptualize acceptance of ADAS (Beggiato and Krems, 2013). It has also been used frequently to assess the acceptance of different transportation systems (e.g. Huth and Gelau, 2013; Nordhoff et al., 2018; Roberts et al., 2012; Zoellick et al., 2021).

As shown in Fig. 1, two constructs were added to TAM in order to measure users' valuation of CMS. This approach follows the model proposed by Huth and Gelau (2013), who examined the acceptance and valuation of motorcycle assistance systems. The first construct represents the willingness to change (WTC) from conventional side-mounted rear-view mirrors to CMS. WTP represents the price users would be willing to pay for CMS (Huth and Gelau, 2013; Liu et al., 2019; Schulz et al., 2014; Souders et al., 2017). Note that we also explored the influence of demographic variables, such as age, gender, or technological affinity, but have not explicitly included them in the research model, as evidence for their effect is mixed at best (Bernhard et al., 2020; Huth and Gelau, 2013; Kyriakidis et al., 2015; Rahman et al., 2017; Schulz et al., 2014).

Consistent with previous research, we expected subjects to evaluate CMS positively, with ratings on the acceptance constructs above their respective midpoints (e.g. Beggiato and Krems, 2013; Bernhard et al., 2020; Roberts et al., 2012). Furthermore, we expected PU, PEOU, and satisfaction to significantly predict BI and WTC, BI to predict WTC, and both factors to account for a significant proportion of variance in WTP. Finally, we investigated how customization affects the acceptance and valuation of CMS. To this end, subjects could choose between different options to extend standard CMS. Previous research has found that customization can increase the acceptance of different systems, such as electric vehicle smart charging devices (Will and Schuller, 2016), control interfaces (Burkolter et al., 2014), or m-commerce applications (Kalinic and Marinkovic, 2016; Liébana-Cabanillas et al., 2017). Thus, we expected the acceptance and valuation ratings to increase for customized CMS, compared to standard CMS.

2. Methods

2.1. Sample description

Respondents were recruited with e-mail invitations distributed at four different universities in Germany (Johannes Gutenberg-Universität Mainz, Technische Universität Kaiserslautern, FernUniversität Hagen, Hamburger Fernhochschule) as well as in the personal network of the authors. University students received partial course credit as compensation for their participation. However, please mind that participation was voluntary and anonymous. To receive course credit, subjects could access another questionnaire at the end of the main questionnaire to provide necessary information for compensation (i. e. name, contact details). These data were separated from the responses to the main questionnaire and were deleted directly after subjects received compensation. Moreover, data were saved on secured servers in order to protect the respondent's privacy and to follow research ethics.

396 subjects completed the online questionnaire. Subjects were excluded if they did not agree with the processing of their data, had owned no valid driving license at the time of data collection, or did not answer all questions truthfully (see section 2.2). Moreover, subjects who completed the questionnaire in less than ten minutes were excluded, which was defined as the minimum completion time. Consequently, 364 subjects were included. 294 were female, 68 male, and two non-binary. Their age ranged from 18 to 77 years (M = 31.42 years, SD = 11.05 years).

253 subjects stated to have a monthly income of up to 3.000 €, 100

Table 1
Main questionnaire items.

Name	ID	(Example) Item	Scale
Demographics			
Age		How old are you?	Number entry
Gender		What gender are you?	M / W / D
Education		What is your highest educational qualification?	4-point scale
Income		What is your gross monthly income?	6-point scale
Driving Experience		How many years have you held your driving license?	Number entry
Car ownership		Do you own a vehicle?	Yes / No
Annual mileage		How many kilometers have you been driven in the last 12 months?	5-point scale
Affinity for Technology Interaction (ATI)	ATI 1-9	I like to occupy myself in greater detail with technical systems.	6-point scale (completely disagree – completely agree)
Driver assistance systems and mirrors			
ADAS Selection		Which of these assistance systems do you use regularly?	Multiple selection
ADAS Use	ADAS_U	If new assistance systems are available in my vehicle, I would use them.	7-point scale (strongly disagree – strongly agree)
ADAS Support	ADAS_S	Assistance systems support me while driving.	
BSD Use	BSD_U	Assuming my vehicle had a Blind Spot Detection system, I would use it.	
CMS			
CMS Use		Have you used a camera-monitor system before?	Yes / No
Usefulness (U)	U1-U5	A camera-monitor system is… Useful vs. Useless	Bipolar 5-point scale (−2 to 2)
Satisfaction (S)	S1-S4	A camera-monitor system is… Pleasant vs. Unpleasant	
Perceived Usefulness (PU)	PU1-PU3	Camera-monitor systems can help me in avoiding accidents.	7-point scale (strongly disagree – strongly agree)
Perceived Ease of Use (PEOU)	PEOU1-PEOU3	I think it would be easy to use a camera-monitor system	
Behavioral Intention (BI)	BI	Assuming my vehicle had a camera-monitor system, I would use it	
Willingness to Change (WTC)	WTC1-WTC3	I would replace the side mirrors with a camera-monitor system.	7-point scale (strongly disagree – strongly agree)
Willingness to Pay (WTP)	WTP1-WTP3	What is the maximum amount you would be willing to pay for it?	Number entry
CMS Customization			
Selection Camera / Monitor		Imagine that you could place the two cameras [monitors] of your camera-monitor system in one of the positions presented above. Which position would you choose?	Selection of one of five positions
Selection Zoom / Augment / Night		Would you integrate this option into your camera-monitor system?	Yes / No
Importance Camera / Monitor / Zoom / Augment / Night	I_c, I_m, I_z, I_a, I_n	How important is the position of the cameras in a camera-monitor system to you?	7-point scale (not important at all – very important)
Customized CMS			
Usefulness (U_c)	U_c1- U_c5	See above	
Satisfaction (S_c)	S_c1- S_c4		
Perceived Usefulness (PU_c)	PU_c1- PU_c3		
Perceived ease-of-use ($PEOU_c$)	$PEOU_c1$-$PEOU_c3$		
Behavioral intention (BI_c)	BI_c		
Willingness to Change (WTC_c)	WTC_c	I would replace the side mirrors with the configured camera-monitor system.	7-point scale (strongly disagree – strongly agree)
Willingness to Pay (WTP_c)	WTP_c	See above	
Truthfulness		Did you answer all the questions in this survey seriously and sincerely?	Yes / No

Note. English translations of the items are shown here. For the original German questionnaire, please refer to the supplementary material.

subjects earned between 3.001 and 7.000 € and eight subjects more than 7.000 € a month. 105 subjects held an university degree, 229 a high school graduation, 25 a higher secondary school graduation, and four a lower secondary school graduation. Subjects had owned a driving license for 13.03 years on average (SD = 10.64 years). 274 subjects also owned a vehicle. 164 subjects stated that they had driven up to 5.000 km in the past year, whereas 137 subjects had driven between 5.001 and 15.000 km. 55 subjects had driven more than 15.000 km in the past year. Finally, subjects reported a medium affinity for new technologies, with a mean rating of 3.63 (*SD* = 1.10) on the 6-point Affinity for Technology Interaction (ATI) scale (Franke et al., 2019).

2.2. Questionnaire

The main questionnaire items are presented in Table 1 and the entire questionnaire can be found in the supplementary material. It consisted of five sections. In the *first section*, subjects received a short introduction and gave their written informed consent to participate. Afterwards, demographic information (see Table 1) was collected. Subjects also completed the ATI (Franke et al., 2019).

The *second section* focused on the knowledge and use of ADAS (Table 1). Subjects received general information about state-of-the-art rear-view mirrors and blind spot detection (BSD) systems, and assessed the perceived support and willingness to use these systems (ADAS_U, ADAS_S, BSD_U in Table 1).

The *third and main section* focussed on CMS. Subjects first received general information on standard CMS, including a demo video of the new Honda e (https://www.youtube.com/watch?v=Urf9JK5Szn8&ab_channel=HondaVideo) and several advantages and disadvantages of CMS, which were derived from the literature (Schmidt et al., 2016; Terzis, 2016; see supplementary material). The demo video was chosen among other alternatives based on the independent review of two co-authors. We decided to use this demo video as it gives a realistic and vivid impression of CMS and as it describes different advantages of CMS. Then, subjects rated the 9-item van-der-Laan scale (van der Laan et al., 1997; U1-U5 and S1-S4 in Table 1) and seven items assessing PU, PEOU, and BI (Davis, 1989; Davis et al., 1989; PU1-PU3, PEOU1-PEOU3, BI in Table 1). The van-der-Laan scale assumes a two-factor structure of acceptance. The factors are the usefulness and satisfaction of new technology. Whereas the usefulness factor is rather similar to the factor PU, the satisfaction factor focuses on users' pleasantness and hedonic quality (van der Laan et al., 1997). As the hedonic quality has been neglected in TAM (Benbasat and Barki, 2007; Wixom and Todd, 2005), we decided to include the van-der-Laan scale in our questionnaire. The framing of the TAM items was based on the ADAS acceptance literature (e.g. Biassoni et al., 2016; Rahman et al., 2017; Rahman et al., 2020;

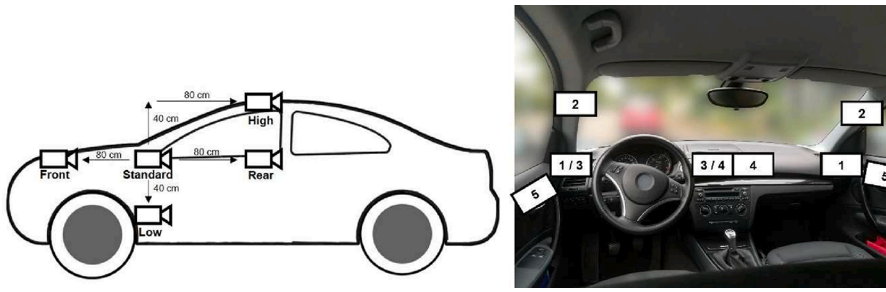

Fig. 2. Different configurations of the exterior cameras (left panel) and the in-vehicle monitors (right panel). Numbers in the left panel show the amount of displacement from the standard camera / mirror position. Monitor positions in the right panel: 1 = standard, 2 = high, 3 = close, 4 = middle, 5 = door.

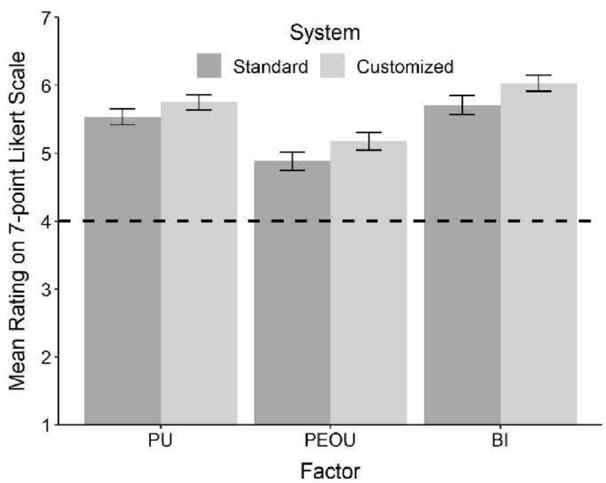

Fig. 3. Mean ratings on perceived usefulness (PU), perceived ease-of-use (PEOU), and behavioral intention-to-use (BI). The ratings were provided on a 7-point scale (1: strongly disagree, 7: strongly agree), with 4 representing a neutral position. Error bars show 95 % between-subjects confidence intervals. N = 364.

Roberts et al., 2012), but was adapted to CMS. At the end of this section, three mirror replacement scenarios were described to assess subjects' willingness-to-change (WTC) and willingness-to-pay (WTP). In these scenarios, subjects could choose between standard CMS and side-mounted rear-view mirrors (scenario 1), between standard CMS and side-mounted mirrors equipped with BSD (scenario 2), or between standard CMS and CMS equipped with BSD (scenario 3). Subjects rated WTC on a 7-point scale (WTC1-WTC3 in Table 1). Moreover, subjects entered the maximal price they would be willing to pay for the respective replacement option (WTP1-WTP3 in Table 1). We had chosen this method rather than a categorical rating to avoid anchor effects, which have been observed in Souders et al. (2017).

In the *fourth section*, subjects could customize their CMS. We first presented a video and a picture demonstrating five camera mounting positions (standard, high, low, front, rear; see Fig. 2, left panel). Please note that only mounting positions on the vehicle's side were shown as this survey focused on the replacement of traditional *side-mounted* rear-view mirrors with CMS. Moreover, pictures of five different monitor positions were presented (standard, high, close, middle, door; see Fig. 2, right panel). Subjects selected their preferred positions and rated the overall importance of camera and monitor placement (I_c, I_m in Table 1). Moreover, they could choose to include three extensions and rated their respective importance (I_z, I_a, I_n in Table 1). The extensions included a zoom function (flexible shift of image section, zoom in or out), augmentation (highlighting an approaching vehicle, its distance, or speed in the monitor), and a night vision system (using infrared cameras to record the rearward scene in darkness). Each extension was introduced with a short description and an example picture (see supplementary material).

In the *last section*, subjects received a summary of their customized CMS and again completed the van-der-Laan scale (U_c1- U_c5, S_c1-S_c4 in Table 1) and TAM items (PU_c1-PU_c3, $PEOU_c$1-$PEOU_c$3, BI_c in Table 1). They also rated their WTC and WTP for replacing the side-view mirrors with their customized CMS (WTC_c, WTP_c in Table 1). Finally, subjects stated whether they had answered all questions truthfully. The original questionnaire was presented in German. It was created and hosted with the online platform LimeSurvey, could be accessed via a web link, and took 22.03 min on average (SD = 12.24 min) to complete.

2.3. Data analysis

The factors used in the further analysis (PU, PEOU, U, S, PU_c, and $PEOU_c$) were first examined regarding their reliability and validity. Inverse items were recoded. We conducted confirmatory factor analyses separately for each factor, using the R software package lavaan (Rosseel, 2012). Items were modelled as endogenous variables and factors as exogenous variables. Note that we measured the items on scales with up to seven categories. In this case, modelling item-level variables as continuous can lead to biased parameter estimates in factor analysis, especially when using Maximum Likelihood (ML) estimation (DiStefano, 2002; Flora et al., 2012; Kline, 2011; Li, 2016; Wirth and Edwards, 2007). Instead, estimators are recommended that can handle ordered-categorical data, such as robust weighted least squares (WLS) estimation (Flora et al., 2012; Flora and Curran, 2004; Li, 2016; Wirth and Edwards, 2007). Therefore, we employed WLS estimation with a mean- and variance-adjusted test statistic and robust standard errors in our factor analyses (Flora and Curran, 2004; Muthén et al., 1997). No issues with multicollinearity were observed for the different scales (Variance Inflation Factor (VIF) $\leq$ 2.53). Items with low standardized factor loadings (<0.65) were excluded. The results of the confirmatory factor analyses are presented in the Appendix.

Next, items were mean aggregated into their respective factors. In the further analysis, we conducted pairwise comparisons with either two-sided paired-sample *t*-tests or Wilcoxon signed rank tests. If significant, d_z for *t*-tests or *r* for Wilcoxon tests are reported as measures of effect size. Figures depict 95 % between-subjects confidence intervals (CIs). All analysis were performed in R version 4.0.3 and were interpreted on a significance level of $\alpha = 0.05$.

3. Results

3.1. Attitudes towards advanced driver assistance systems (ADAS) and camera-monitor systems (CMS)

First, we briefly summarize the results regarding ADAS and blind spot detection (BSD) systems that were assessed on 7-point scales, with a value of 4 representing neutral responses. In comparison, subjects were rather inclined to use ADAS (ADAS_U: M = 5.07, SD = 1.39) and

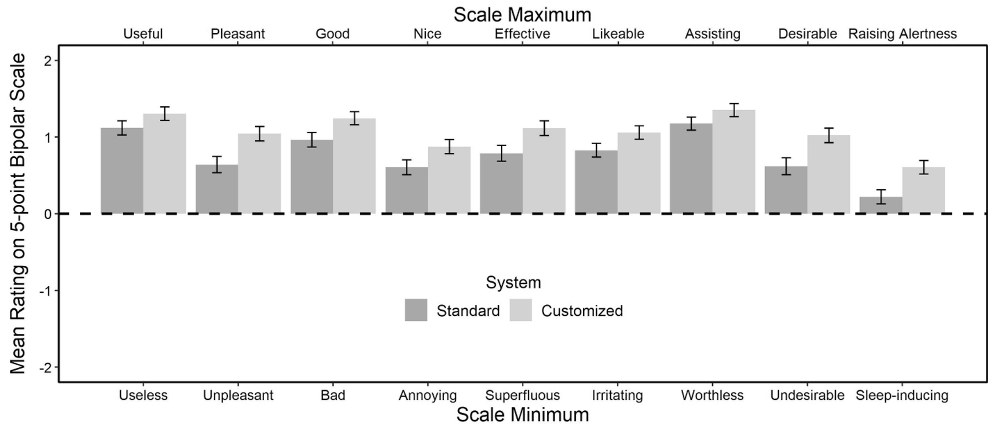

Fig. 4. Mean ratings on the nine van-der-Laan-scale items. Inverse items were recoded prior to the data analysis. Error bars show 95 % between-subjects confidence intervals. N = 364.

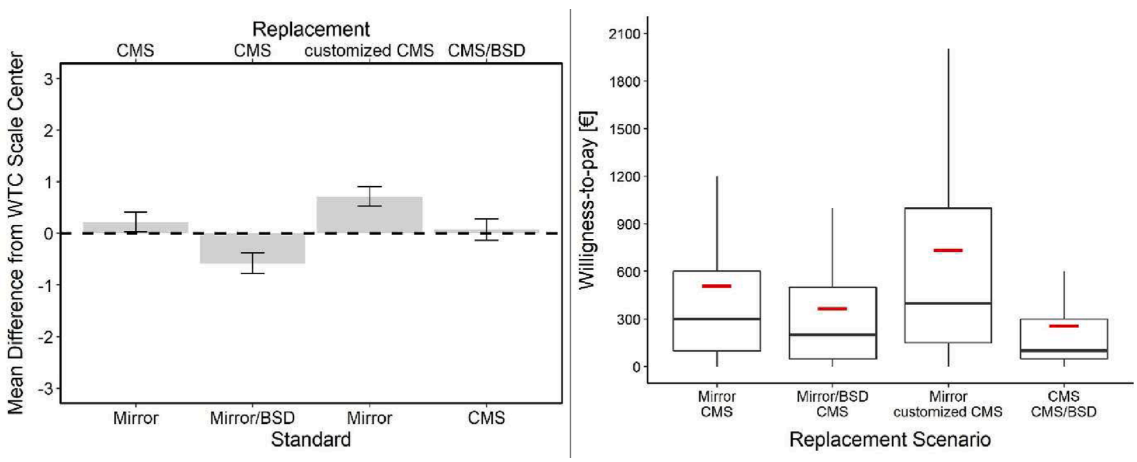

Fig. 5. Left panel: Mean differences of WTC ratings from the scale center. A negative value indicates a preference for the standard system, a positive value indicates a preference for the respective CMS or enhancement. Right panel: WTP as a function of the system options. The values indicate the price subjects were willing to pay for the system indicated by the bottom word on the x-axis, as compared to the top word. The fat solid lines represent the median (black) and mean (red) price, respectively. The error bars represent the 1.5 interquartile range below the 25% and above the 75% quartile. Outliers larger than 1.5 times the interquartile range are excluded to improve readability. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

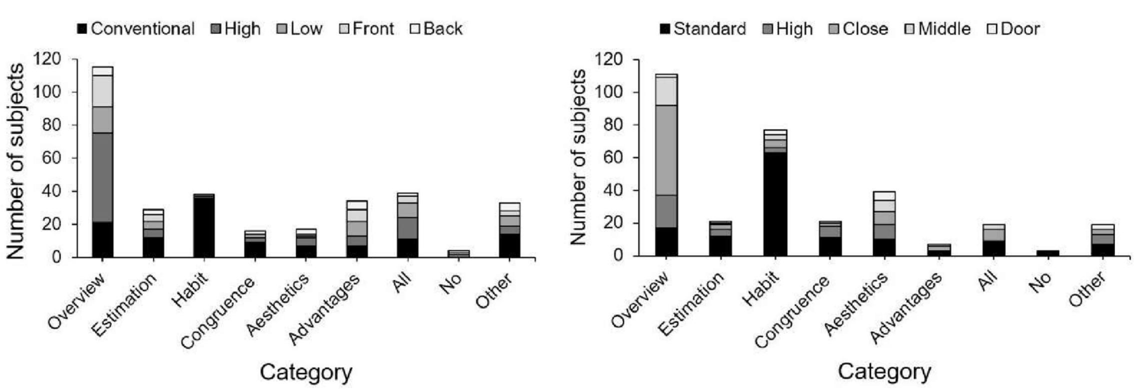

Fig. 6. Reasons for choosing a specific camera position (left panel) and monitor position (right panel). The y-axis depicts the number of subjects grouped into each category. N = 364.

perceived them as supportive while driving (ADAS_S: $M = 5.08$, $SD = 1.39$). Likewise, subjects evaluated their usage intention of BSD (BSD_U) positively, with a mean rating of 6.14 ($SD = 1.27$).

Fig. 3 depicts the mean ratings on the TAM factors together with their between-subjects CIs for both the standard and the customized CMS. Subjects evaluated CMS positively – all ratings were well above their respective midpoints. Moreover, the ratings increased slightly when subjects evaluated their customized CMS, in comparison to the standard CMS. These differences were significant for all factors (PU: $t(363) = 5.04$, $p < .001$, $d_z = 0.26$; PEOU: $t(363) = 5.57$, $p < .001$, $d_z =$

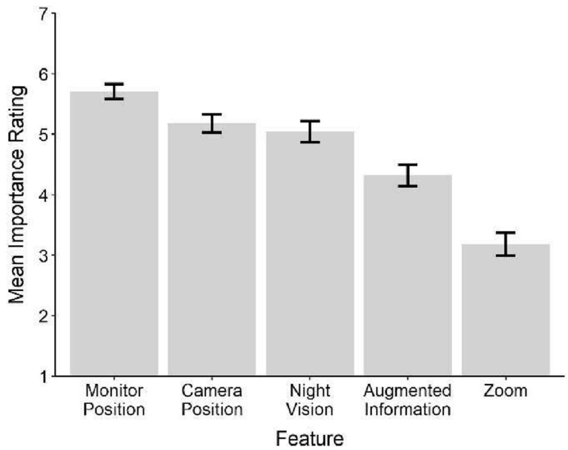

Fig. 7. Mean importance ratings as a function of CMS feature. The importance was rated on a 7-point scale (1 = not important at all, 7 = very important). Error bars show 95 % between-subjects confidence intervals. N = 364.

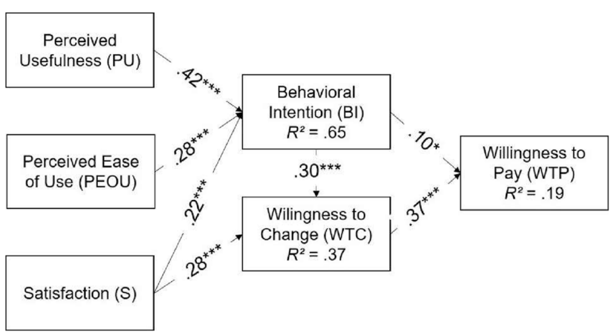

Fig. 8. Path analysis model of the variables perceived usefulness (PU), perceived ease-of-use (PEOU), satisfaction (S), and the criterion variables behavioral intention (BI), willingness-to-change (WTC), and willingness-to-pay (WTP). Coefficients represent standardized path coefficients. *p < .05. **p < .01. ***p < .001.

0.29; BI: t (363) = 5.94, $p < .001$, $d_z = 0.31$).

In addition, Fig. 4 illustrates the ratings on the nine items of the van-der-Laan scale. CMS was again evaluated positively – ratings were well above zero. Only the last item received ratings close to zero. Importantly, the ratings for the customized system were significantly higher than for the standard system (all $p < .001$, d_z greater than 0.19), especially for the items pleasantness, effectiveness, desirability, and alertness.

3.2. Valuation of CMS

Fig. 5 illustrates the direct comparison of the different rear-view systems with respect to WTC and WTP. In the left panel, WTC is depicted as the mean difference of the ratings from the midpoint of the 7-point scale. Subjects were rather undecided about replacing their conventional side-view mirror with the standard CMS. They slightly preferred CMS, as the 95% between-subjects CIs did not overlap with zero. However, subjects preferred a mirror with BSD in comparison to the standard CMS. This difference was significant (Mirror-CMS vs. Mirror/BSD-CMS: t (363) = 11.20, $p < .001$, $d_z = 0.59$). Thus, the willingness to change to CMS decreased if the mirror was enhanced by a BSD. WTC ratings increased again if subjects could choose between a normal mirror and their customized CMS. They preferred their customized system more than the standard CMS (Mirror-CMS vs. Mirror-customized CMS: t (363) = 7.12, $p < .001$, $d_z = 0.37$). Finally, subjects were undecided about switching from CMS to CMS with BSD.

Subjects would be willing to pay a median price of 300 € for CMS, assuming their vehicle is already equipped with a normal rear-view mirror (Fig. 5, right panel). The maximum price was 5000 €. 39 subjects (10.71 %) were not willing to pay for CMS at all. When the normal mirror system was additionally equipped with BSD, the willingness to pay for CMS decreased (Median = 200 €). This difference was significant ($Z = 9.02$, $p < .001$, $r = 0.47$). The median price increased if the mirror was replaced with a customized CMS. The subjects were willing to pay a higher price for their customized system than for a standard CMS ($Z = 8.69$, $p < .001$, $r = 0.46$). Finally, subjects were willing to pay a median price of 100 € to enhance their CMS with a BSD.

3.3. System customization

In the fourth section of the questionnaire, subjects could choose between different features to customize CMS. They also rated the importance of each feature. Regarding the camera position, 130 subjects (35.71 %) chose the standard position and 106 subjects (29.12 %) the high position. The other positions were less preferred (low: 54, 14.84 %; front: 49, 13.46 %, back: 25, 6.87 %). Regarding the monitor position, 154 (42.31 %) chose the standard position on the dashboard, close to the traditional mirror location. In contrast, 101 subjects (27.75 %) chose a monitor position close to the steering wheel, 56 (15.39 %) the high position, 38 (10.44 %) the position in the middle console, and only 15 (4.12 %) the door position. We categorized the reasons for these decisions. Fig. 6 depicts the categories. Subjects chose the conventional camera position (left panel) and the standard monitor position (right panel) mostly out of habit. In contrast, the high camera and close monitor positions were chosen because of the improved overview on the traffic or in the cockpit. Several subjects had no clear preference for either position (categories "All" and "No"). Only a few subjects justified their decision with the improved estimation of distance or speed. Finally, several subjects chose the camera or monitor position for other reasons, such as practical intuition or based on the occlusion of the outside scene. Some also highlighted that their choice would depend on the type of vehicle.

Furthermore, 137 subjects (37.64 %) would add a zoom function, 261 (71.70 %) augmented information, and 298 (81.87 %) a night vision system to their customized CMS. Fig. 7 depicts the mean importance ratings for each feature. Apparently, the monitor position was of prime

Table 2
Unstandardized and standardized coefficients of the path model.

Criterion	Predictor	Unstandardized Coefficient	Standardized Coefficient	SE	Z Value	p
BI	PU	0.64	0.42	0.08	8.31	<0.001
	PEOU	0.37	0.28	0.06	5.99	<0.001
	S	0.47	0.22	0.10	4.78	<0.001
WTC	PU	0.01	0.01	0.08	0.17	0.866
	PEOU	0.09	0.09	0.06	1.44	0.151
	S	0.46	0.28	0.09	5.03	<0.001
	BI	0.23	0.30	0.05	4.41	<0.001
WTP	BI	0.08	0.10	0.04	2.01	0.044
	WTC	0.40	0.37	0.03	13.94	<0.001

importance in the camera-monitor tandem, it was rated higher than the camera position, $t\,(363) = 7.3$, $p < .001$, $d_z = 0.38$. The camera position and night vision system were perceived as equally important ($p = .21$). Augmented information was also judged as important, but the ratings were smaller than for the night vision system, $t\,(363) = 6.53$, $p < .001$, $d_z = 0.34$. Finally, the zoom function was perceived as least important, the ratings were significantly smaller in comparison to the augmented information, $t\,(363) = 10.6$, $p < .001$, $d_z = 0.56$.

3.4. Exploring the relationship between acceptance and valuation of CMS

In a final step, we modelled user acceptance and valuation using a recursive path analysis model (Fig. 1) to explore the relationship between the TAM factors PU, PEOU, and BI, the van-der-Laan satisfaction subscale (S), as well as WTC and WTP for the comparison between rear-view mirror and standard CMS. The item-level variables BI and WTC were again included as ordered categorical variables. We employed WLS estimation with a mean- and variance-adjusted test statistic and robust standard errors (Flora and Curran, 2004; Muthén et al., 1997). WTP was rescaled in order to prevent an ill-scaled covariance matrix (Kline, 2011). The VIF was not larger than 1.99, indicating an absence of collinearity. Table A2 in the Appendix depicts a correlation matrix for the included factors. Fig. 8 depicts the significant standardized path coefficients. All unstandardized and standardized coefficients can be found in Table 2. The overall model fit was acceptable ($X^2(3) = 4.58$, $p = .205$, CFI = 0.99, TLI = 0.99, RMSEA = 0.04, SRMR = 0.02). PU, PEOU, and S were significantly associated with BI ($p < .001$). The explanatory power for BI was high ($R^2 = 0.65$). Furthermore, BI and S were significantly related to WTC ($p < .001$). PU and PEOU only had indirect effects on WTC. The fit was acceptable ($R^2 = 0.37$). All path coefficients were positive, indicating that an increase in PU, PEOU, S, and BI was associated with an increase in BI and WTC, respectively. Finally, BI and WTC were significantly associated with WTP ($p < .05$). However, the fit was low ($R^2 = 0.19$). We also explored the role of demographic information or affinity for technology (ATI) in the prediction of BI, WTC, or WTP. However, no significant effects were observed.

4. Discussion

Overall, the more than 300 drivers we polled were positive about camera-monitor systems and stated a high intention to use them. This is consistent with the overall positive attitude towards new technologies, which has been observed earlier (e.g. Beggiato and Krems, 2013; Bernhard et al., 2020; Roberts et al., 2012). Despite their positive evaluation and high usage intention, subjects were rather reluctant to replace conventional side-view mirrors with standard CMS. Their willingness to change and pay for a CMS depended on the sophistication of the rear-view system. Subjects were rather undecided about replacing their conventional side-view mirror with CMS. WTC even dropped further when the mirror was additionally equipped with a BSD system (replacement scenario 3). This was reflected in subjects' willingness to pay for CMS, which decreased if the mirror was already equipped with a BSD system. The subjects' high intention to use BSD indicates that they have an interest in improving their rearward perception. However, it seems that they do not consider CMS as the favorite solution. A combination of side-view mirror and BSD could have been taken as sufficient support for safe driving. Supposedly, subjects were unsure whether CMS offered them advantages over a BSD.

The price subjects were willing to pay (median: 200 € for a standard to 400 € for a customized CMS) was low, compared to the current market price of CMS (e.g. 1540 € for a CMS in Audi eTron; Audi, 2021). Interestingly, it was rather close to the preferred price for BSD and other ADAS reported in earlier studies, which was about 250 € (Huth and Gelau, 2013; Kaul et al., 2010; Souders et al., 2017; Viktorová and Sucha, 2018). Mind that our subjects were informed about the potential advantages of CMS. These advantages alone might not have been sufficient to increase the perceived value of CMS in comparison to the BSD-enhanced mirror. However, the low price may merely reflect the characteristics of our sample, which contained many low-age and low-income subjects.

Importantly and consistent with our expectations, the opportunity to customize CMS raised the acceptance and valuation of CMS significantly. The customized system was rated higher on its perceived usefulness, its perceived ease-of-use, and on all items of the van-der-Laan scale. When customizing their CMS, subjects rated the position of the in-vehicle monitor as the most important feature, followed by the camera position and the night vision system. The monitor positions close to the standard mirrors and close to the steering wheel were most preferred. Subjects justified the preference for the position close to the steering wheel with a better overview in the cockpit. This is in accordance with results from previous experimental studies on monitor placement (Beck et al., 2017; Large et al., 2016; Murata and Kohno, 2018). Regarding the camera position, the high position was the most preferred alternative to the conventional position, because of the improved overview over the rearward scene. However, note that our subjects did not experience the different camera positions during driving, as had been the case in our recent driving simulator experiment (Bernhard et al., 2021). There, the high camera position had been preferred to the conventional position by an even larger margin. The flexible adjustment of the monitor image, in terms of a zoom function, was judged to be least important.

When taking a closer look at the path analysis, the following picture emerges: Behavioral intention (BI) was rather well explained by the TAM factors PU and PEOU, as expected (see e.g. Davis, 1989; King and He, 2006; Marangunić and Granić, 2015; Rahman et al., 2017; Schepers and Wetzels, 2007). Satisfaction (S) was also significantly associated with BI, highlighting the importance of hedonic aspects to predict usage intention (Benbasat and Barki, 2007). The model fit was high ($R^2 = 0.65$), indicating that BI can be reliably predicted with only three determinants. Moreover, BI and S, but not PU or PEOU, had a direct effect on WTC. The variance accounted for was acceptable ($R^2 = 0.37$). Note that a direct effect of PU and PEOU on WTC was observed when BI was excluded from the analysis, indicating that BI mediated the effect of PU and PEOU on WTC. Moreover, WTP was significantly associated with WTC and BI, but not with any other predictor. A similar relationship had been assumed earlier (Huth and Gelau, 2013). However, the fit was low ($R^2 = 0.19$). In contrast to WTC, the association of WTP with determinants of system use appears to be on shakier ground. This has also been observed by Liu and colleagues, who predicted WTP with the perceived benefit (Liu et al., 2019). The fit in that study was rather low ($R^2 = 0.15$) and comparable to the current fit. Future research should investigate in more detail to what extent WTP depends on psychological determinants of system use.

4.1. Limitations

Our sample tended to be comparatively young, female, and consisted largely of students. Therefore, not all results might generalize to the ageing population of drivers. In particular, the absolute price subjects were willing to pay for CMS was surely affected by the limited income characteristics of our sample. However, we take that the observed relative differences between the different rear-view systems can still apply to a larger population of drivers. To verify this, we have applied the reported tests and statistics separately to a subset of our subjects, with age higher than 30 years and monthly income higher than 3000 € ($n = 74$). The results were largely consistent with the effects reported earlier. Subjects were willing to pay a median price 300 € to replace their standard mirrors with CMS, 250 € if their mirrors were enhanced by a BSD, and 400 € for the customized CMS. Subjects' WTC also decreased if the mirrors were additionally equipped with a BSD and increased if the mirror was replaced with customized CMS. With respect to the customization, adapting the monitor position was still perceived as the most important option, as was the camera position and night vision system. The zoom function was perceived to be least important.

Furthermore, as typical when acquiring opinions about sophisticated emerging technologies from a large sample of subjects, we could not provide our subjects with the opportunity of first-hand experience of CMS during driving. We provided our subjects with several sources of information, such as demo videos, images, detailed descriptions, and lists of potential strength and weaknesses. This was deemed important since CMS are offered only by a few manufacturers and for selected models. This way, all subjects had detailed information about CMS and were encouraged to amply reflect the potential benefits and limitations. We could not expect that subjects were already experienced with CMS. Indeed, only two subjects stated to have ever used a comparable system before. In contrast, 37 subjects had used rear-view cameras, as included in many parking assistant systems. However, these camera systems are in no way comparable to CMS. In this sense, our results represent the first comprehensive impression of the emerging technology CMS, in the absence of first-hand experience. As typical for new technologies, such experience is likely to boost user acceptance considerably. For instance, passenger acceptance of an autonomous bus was greatly increased after subjects had the opportunity to hitch a ride (Bernhard et al., 2020). Thus, CMS acceptance is likely to receive an additional boost, as these systems become more readily available. Nonetheless, our findings should be validated by further research assessing acceptance after first-hand experience with CMS.

Conclusion

Replacing standard rear-view mirrors with CMS is desirable, as these systems have a great potential to increase road safety (Schmidt et al., 2016; Terzis, 2016). CMS have several advantages over standard rear-view mirrors, such as an increased field of view or fuel efficiency, and decreased drag (Terzis, 2016). Moreover, they offer a venue to enhance the mirror image and to incorporate assistive information into the mirror display, which traditionally requires dedicated assistance systems. However, our results suggest that mere awareness of these benefits by itself is not sufficient to motivate a change from conventional mirrors to CMS, especially if a vehicle is additional equipped with BSD. The current cost for installing CMS far exceeds our subjects' WTP. This indicates that subjects perceive CMS mostly as yet another assistance system, and not as the powerful substitute for mirror systems they could become. However, our results also indicate that acceptance, WTC, and WTP increase substantially if customers can customize their CMS. In this regard, the opportunity to adjust the monitor and camera position as well as adding a night vision system could represent a lever to increase the valuation and acceptance of CMS. As these systems become more common and less expensive to manufacture, their perceived value may exceed the price threshold of CMS.

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CRediT authorship contribution statement

Christoph Bernhard: Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Heiko Hecht:** Conceptualization, Methodology, Validation, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Results of the confirmatory factor analyses

Table A1 shows the included items for each model, together with their standardized factor loadings and their scale reliability and convergent validity measures. The fit of all models was deemed acceptable, with nonsignificant χ^2 test statistics ($p > .05$), the standardized root mean square residual (SRMR) $\leq .03$, the root mean square error of approximation (RMSEA) ≤ 0.07, the comparative fit index (CFI) ≥ 0.98, and the Tucker-Lewis index (TLI) ≥ 0.96 (Bagozzi and Yi, 2012). Moreover, all residual correlations were well below a value of 0.10 (Kline, 2011). As shown in Table A1, scale reliability was confirmed – all values of internal consistency (Cronbach's α) and composite reliability (CR) were below the criterion of 0.70. Moreover, the average variance extracted (AVE) exceeded the criterion of 0.50 for all factors, establishing convergent validity. Additionally, Table A2 depicts the correlation matrix of the measured factors. The square root of each AVE (diagonal elements) was greater than the associated inter-construct correlations for all factors, thus confirming discriminate validity (Anderson and Gerbing, 1988).

Table A1
Factor loadings, reliability and validity scores for the measured factors.

Factor	Item	M	SD	FL	α	CR	AVE
Perceived usefulness (PU)	PU1	5.57	1.27	0.73	0.77	0.77	0.63
	PU3	5.50	1.26	0.86			
Perceived ease-of-use (PEOU)	PEOU1	4.90	1.59	0.70	0.75	0.76	0.61
	PEOU3	4.87	1.34	0.86			
Usefulness (U)	U1	1.12	0.90	0.86	0.90	0.90	0.76
	U3	0.79	1.01	0.84			
	U4	1.18	0.82	0.92			
Satisfaction (S)	S1	0.64	1.02	0.76	0.84	0.85	0.58
	S2	0.61	0.94	0.74			
	S3	0.83	0.88	0.85			
	S4	0.62	1.07	0.70			
Perceived usefulness (PU_c)	PU_c1	5.86	1.15	0.81	0.83	0.83	0.72
	PU_c3	5.64	1.19	0.88			
Perceived ease-of-use ($PEOU_c$)	$PEOU_c1$	5.16	1.49	0.72	0.78	0.73	0.66
	$PEOU_c3$	5.19	1.35	0.90			

Note. M = Mean. SD = Standard deviation. FL = Standardized factor loadings. α = Cronbach's α. CR = Composite reliability. AVE = Average variance extracted. $N = 364$.

Table A2
Mean, standard deviation, and correlation coefficients for each measured factors and the dependent variables BI, WTC, and WTP.

Factor	M (SD)	PU	PEOU	U	S	PU_c	$PEOU_c$	BI	WTC
PU	5.53 (1.11)	(.79)							
PEOU	4.88 (1.29)	.64	(.78)						
U	1.03 (0.80)	.67	.56	(.87)					
S	0.67 (0.77)	.61	.62	.73	(.76)				
PU_c	5.75 (1.27)	.71	.60	.61	.54	(.85)			
$PEOU_c$	5.17 (1.27)	.54	.70	.48	.52	.70	(.81)		
BI	5.71(1.33)	.71	.65	.60	.61	.59	.57		
WTC	4.22 (1.86)	.46	.47	.49	.54	.50	.45	.51	
WTP	511.82(672.64)	.20	.21	.21	.16	.19	.22	.21	.30

Note. Standard deviations are in parentheses. The shown coefficients are Pearson correlation coefficients. Diagonal numbers in parenthesis are the square roots of the average variance extracted (AVE). $N = 364$.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2021.100512.

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