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RESEARCH ARTICLE

# Factors Influencing Driver's Psychological Vulnerability Judgment When Sharing the Road With Driverless Vehicles

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**ABSTRACT** To determine whether drivers of manned vehicles sharing the road with driverless vehicles believe they are in a vulnerable state and to identify the factors that contribute to their feeling of ''driver's psychological vulnerability judgment'', this study conducted a questionnaire survey. The survey collected information on the attitudes, perceived usefulness, trust, perceived risk, and demographic characteristics of drivers in a hypothetical situation where they drive on the same road as driverless vehicles. The aim of the survey was to identify areas where drivers feel more vulnerable to poor psychological judgment. A total of 945 valid questionnaires were collected through the Credamo questionnaire survey platform. The results indicated that 43.7% of the respondents believed they would be in a vulnerable state in mixed traffic competition, while 30.2% of respondents did not know if they would feel vulnerable. Moreover, women, people with higher education, those with more aggressive driving personalities, older people, and those with more driving experience were less inclined to think they would be in a vulnerable state. Attitude, trust, and perceived usefulness had positive impacts on the driver's psychological vulnerability judgment, while perceived risk had a negative impact. Therefore, early promotion of driverless technology should target people with higher education, more driving experience, older age, and more aggressive driving personality. The focus should be on attitudes toward this technology, as well as perceived usefulness, trust, and perceived risk.

**INDEX TERMS** Driver's psychological vulnerability judgment, driverless technology, mixed traffic competition, questionnaire survey.

## I. INTRODUCTION

Among all modes of transportation, highway transportation occupies an important position in society. However, highway transportation is inefficient [1], has a high accident rate, and has a serious influence on environmental pollution [2]. Driverless technology is expected to play an important role in improving transportation efficiency, reducing accident rates, improving ride comfort reducing carbon emissions, and facilitating the travel of people without a driver's license, including disabled and elderly people [3]. However, as a new technology, driverless driving technology is still immature. The casualties caused by collisions between Uber driverless test vehicles and pedestrians in the United States and the Tesla incident in China both show that driverless technology is still unstable. Further, as the prevalence of driverless technology increases, there will be a long period during which driverless and manned vehicles share the road [4], [5], and the uncontrollable nature of driverless vehicles may pose a threat to road co-users [6]. Therefore, driverless technology is a recent research focus. Although many researchers have examined attitudes toward driverless technology in road co-users, few studies have specifically explored their psychological state when sharing the road with driverless vehicles.

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Road co-users of driverless vehicles include pedestrians, non-motor vehicles and manned vehicles. At present, the research on the interaction between driverless vehicles and pedestrians is mainly divided into two aspects. The first is to qualitatively study the behavior characteristics of driverless vehicles and pedestrians from the perspective of simulation experiments [7], [8], and the second is to analyze the dynamic process and behavior evolution of the interaction between pedestrians and driverless vehicles from the perspective of evolutionary game. In terms of the conflict between driverless vehicles and non-motor vehicles, relevant research focuses mainly on the study of safety distance [9], especially at intersections. A left-turn motion planning model for driverless vehicles based on approximate grid risk assessment was proposed to ensure the safe interaction, efficient passage and driving comfort of driverless vehicles and non-motor vehicles [10]. However, there are few studies on the conflict between driverless vehicles and manned vehicles.

The biggest difference between driverless vehicles and human drivers in the face of conflict is the psychological change of human drivers, including trust and fear of driverless vehicles, which can also be regarded as the degree of acceptance of driverless technology. The more receptive you are, the more relaxed you will be in the face of driverless vehicles, and otherwise the more nervous you will be. At present, research on driverless technology acceptance has mainly been based on simulations and questionnaire surveys [11], [12], [13], [14], [15]. For instance, Bansal and Kockelman [12] and Talebian Mishra [13] studied autonomous vehicle acceptance in terms of price and willingness to pay through simulation methods. Using questionnaires, Schoettle and Sivak [16], [17] found that most respondents had positive attitudes towards driverless technology, and they hope to use vehicles with this technology in the future. However, respondents were also very concerned about the risks of driverless vehicles. Kyriakidis et al. [17], [18] found that concerns regarding driverless technology were mainly related to network security and legal issues. Edwards et al. [19], [20], [21] proposed that, in addition to network security, driverless technology carries engineering risks in terms of control technology and specific scene application. Besides legal concerns, there are also social risks related to ethics, psychology, and management [17].

The level of acceptance of driverless technology is highly dependent on personal factors. Many studies have analyzed the impact of gender, age, education, and living environment on the acceptance, perceived usefulness, and perceived risk of driverless technology [18], [22], [23], [24], [25]. It indicates that people who are enthusiastic about driverless vehicles are typically male, young, highly educated, and live in large urban areas. Researchers have further examined the attitudes of specific groups such as elderly individuals [26], [27], passengers of driverless vehicles and their families [28], and other road co-users [29], [30]. It is found that older drivers rated the SAE (Society of Automotive Engineers) level 2 vehicle highest and the fully automated vehicle (SAE level 5) lowest [26]. Family members of driverless vehicle passengers, especially parents, are not willing to let their children to take the driverless school buses, while other road co-users believe the risk of driverless vehicles is low, and almost no one has objected to their use. In addition, studies have assessed the willingness to pay (WTP) for driverless technology [14], [17], [31], [32], and the moral problems that driverless vehicles may face [21], [33]. These studies show that, higher-income, technology-savvy males, who live in urban areas, and those who have experienced more crashes have a greater interest in and higher WTP for new technologies [14], [31], [32]. Mentioning the development prospect of driverless vehicles, China's driverless consumers have more positive and open attitudes than many developed countries in Europe and America. Research on the ethics of driverless technology shows that there is general agreement that cars that give priority to ensuring the safety of passengers are on the road, but few are willing to ride such cars. The social impact of driverless technology and the role of public opinion have also been examined [34] to prove that the promotion of driverless technology is related to social acceptance.

In traditional driving, drivers choose driving behaviors such as active overtaking or passive avoidance according to the state of their own vehicle and the surrounding driving environment. However, these choices are often based on the premise that all vehicles have roughly the same priority. In determining the rules and expectations for the roads used by both driverless vehicles and manned vehicles, the issue of priority must be addressed [35]. Specifically, drivers must answer the question "Which vehicle has a higher priority?" when traveling on roads used by both driverless vehicles and manned vehicles. This situation is known as mixed traffic competition.

In mixed traffic competition, drivers must fully consider driving safety. Because driverless vehicles are not subject to psychological state, drivers may feel psychologically vulnerable due to concerns about safety threats from driverless vehicles. Here, we used a questionnaire to investigate driver's psychological vulnerability judgment in a hypothetical mixed traffic competition. Our study addressed the following questions: (1) For a hypothetical situation involving drivers in mixed traffic competition, does the presence of driverless vehicles affect driver's psychological vulnerability judgment? (2) Which factors have the greatest impact? (3) How do these factors affect drivers' perceptions in terms of vulnerability psychology? Based on our research conclusions, we sought to provide directions for the future large-scale promotion of unmanned technology.

## II. RESEARCH HYPOTHESIS

Human driving behavior is affected by subjective factors such as emotional instability, psychological fatigue, and psychological frustration. In non-mixed traffic, drivers who drive in accordance with traffic rules and are not in a fatigued state are generally expected to have stable emotions and no driving-related psychological fatigue, and thus be able to drive safely [36]. However, in mixed traffic, drivers may experience a vulnerable psychological state. This could affect their driving psychology and behavior, thereby causing traffic problems [37]. This kind of anxiety, panic and psychological fatigue caused by driverless vehicles sharing the road, which the driver feels additionally, and considers himself in a vulnerability state under such complex road conditions, is called the driver's psychological vulnerability judgment in this paper.

Driver's psychological vulnerability judgment can also be viewed as the acceptance of unmanned driving technology. The higher the acceptance, the less driver's negative emotions will be generated. The Technology Acceptance Model (TAM) is often used to indicate the degree of acceptance [38], [39], [40]. The basic TAM consists of four factors, namely, perceived usefulness, perceived ease of use, attitude and intention to use. As shown in Fig. 1.

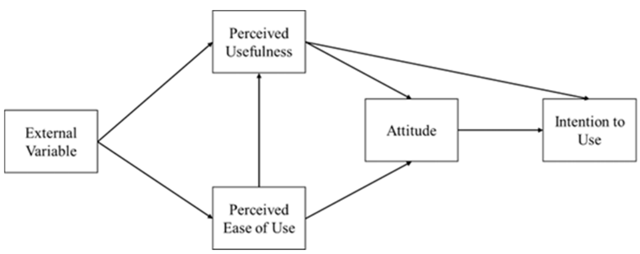


**FIGURE 1.** Technology Acceptance Model (TAM).

Use intention refers to the measurable degree to which users are willing to use the system [39], [41], [42]. However, the driver's use intention of driverless vehicles has nothing to do with this study. Since TAM allows the addition of extended variables, considering that the trust in driverless vehicles will also affect the driver's psychology, we add the driver's trust in driverless technology as a new factor. To understand the factors that affect vulnerability to a vulnerable psychological state in drivers, we established research hypotheses with four aspects: attitude, perceived usefulness, trust, and perceived risk [27], [43].

### A. ATTITUDE

Attitude refers to an individual's favorable or unfavorable evaluation of a specific object or behavior. A positive evaluation is expected to have a beneficial effect on psychological state [44], [45]. Rahman et al. tested whether attitude had a positive impact on behavior [27], and found that attitude had no significant effect on pedestrians or drivers, but that it positively influenced perceived usefulness. Based on the above, we generated the following hypotheses:

H1: attitude positively impacts driver's psychological vulnerability judgment;

H2: attitude positively impacts perceived usefulness;

H3: attitude positively impacts trust;

H4: attitude negatively impacts perceived risk.

### B. PERCEIVED USEFULNESS

Perceived usefulness refers to the degree to which productivity improves when using an emerging technology [44]. Buckley et al. found that perceived usefulness positively impacted the passengers' acceptance of driverless [27], [46]. Based on the above, we have generated the following hypotheses:

H5: perceived usefulness positively impacts driver's psychological vulnerability judgment;

H6: perceived usefulness positively impacts trust;

H7: perceived usefulness negatively impacts perceived risk.

### C. TRUST

Trust refers to the belief of a driver in a mixed traffic environment that driverless vehicles can respond in a timely manner to an adverse driving event. Deb et al. reported that trust had a significant impact on the acceptance of driverless vehicles [43]. Choi and Ji found that trust had a significant negative impact on perceived risk [47], and Mccloskey and Leppel reported that trust had a significant positive impact on perceived usefulness [48]. Based on the above, we have generated the following hypotheses:

H8: trust positively impacts driver's psychological vulnerability judgment;

H9: trust negatively impacts perceived risk.

### D. PERCEIVED RISK

Perceived risk refers to the experience a driver expects when sharing the road with driverless vehicles. Choi and Ji reported that perceived risk had no impact on drivers' subject behavior [47], while Liu reported that perceived risk had a negative impact on public behavioral intentions [49]. Based on the above, we have generated the following hypothesis:

H10: Perceived risk negatively impacts driver's psychological vulnerability judgment.

## III. QUESTIONNAIRE AND ANALYSIS

### A. QUESTIONNAIRE DESIGN

Based on the maturity scale, we designed a questionnaire to measure the expectations of drivers regarding their psychological state in a hypothetical mixed traffic competition. We conducted a pre-survey and revised the questionnaire accordingly. The final questionnaire was divided into three parts. The first part investigated driver's psychological vulnerability judgment according to attitude, perceived usefulness, trust, and perceived risk regarding sharing the road with driverless vehicles. These items were measured using a Likert scale with 5 levels, ranging from 1 (strongly disagree) to 5 (strongly agree). In the second part of the questionnaire, we collected demographic information about the respondent, including gender, age, education, occupation, driving experience, and driving personality [27]. Among them, driving personality refers to the attitude of the driver in the process of meeting other vehicles, generally conservative, moderate and radical. Driving experience is measured by investigating the length of driving time for drivers, typically measured in years. The third part of the questionnaire was a question that enabled us to examine the correlation between driver's psychological vulnerability judgment and the responses to other items. The questionnaire items are shown in Table 1

**TABLE 1. The measurement of driver's psychological vulnerability judgment.**

| Variable | Items |
|---|---|
| Attitude | Q1 As a driver, I think I can accept driverless technology<br>Q2 As a driver, I think the development prospect of driverless technology is very good<br>Q3 As a driver, I am concerned about the fact that driverless vehicles and manned vehicles mix on the road.<br>Q4 As a driver, I would rather ride in a driverless vehicle than drive my own. |
| Perceived usefulness | Q5 As a driver, I think driverless technology can effectively reduce the occurrence of traffic accidents.<br>Q6 As a driver, I think driving automation can effectively reduce vehicle congestion.<br>Q7 As a driver, I believe that driving automation can effectively improve the comfort of driving.<br>Q8 As a driver, I think that driverless vehicles are more environmentally friendly.<br>Q9 As a driver, I think that driverless vehicles are more economical than manned cars. |
| Trust | Q10 As a driver, I believe that driverless vehicles can detect my vehicle and its driving state in time.<br>Q11 As a driver, I think that driverless vehicles will actively avoid my vehicle during driving.<br>Q12 As a driver, I think driverless vehicles will be able to respond to unsafe driving conditions much faster than human drivers. |
| Perceived risk | Q13 I would be nervous if my children, spouse, parents, or other loved ones were traveling in my vehicle and encountered a driverless vehicle on the road.<br>Q14 If I encounter driverless vehicles on the road, I plan to drive more intently.<br>Q15 I think that I will get increasingly nervous as a driverless car approaches my car.<br>Q16 I would be very concerned if a driverless vehicle suddenly changed its driving behavior (speeding up, slowing down, changing lanes, etc.).<br>Q17 While driving, I worry that driverless vehicles will have equipment or system failures and hit my car. |
| Perception of expected psychological vulnerability | Q18 I feel like I belong to vulnerable groups when I drive my vehicle together with driverless vehicles on the road. |

### B. RELIABILITY AND VALIDITY TESTS

#### 1) RELIABILITY ANALYSIS

Reliable scales are expected to pass reliability and validity tests. A reliability analysis is used to test the internal consistency of a questionnaire and to determine whether the results of the questionnaire are reliable. Cronbach's $\alpha$ and combined reliability (CR) are commonly used as criteria for reliability analyses. The Cronbach's $\alpha$ is judged as follows [50]: if $\alpha > 0.9$, the internal consistency of the scale is very high; if $0.7 < \alpha < 0.9$, the internal consistency of the scale is good; if $\alpha < 0.7$, the inconsistency between the items in the scale is high, and the scale needs to be revised. As shown in Table 2, the Cronbach's $\alpha$ for the four latent variables, i.e., attitude, perceived usefulness, trust, and perceived risk, were between 0.782 and 0.874. This indicates that internal consistency among latent variables was good. The total Cronbach's $\alpha$ between the four latent variables was 0.814, indicating that the overall internal consistency of the scale was good. Thus, the reliability of this scale was acceptable, and the survey data had strong reliability.

**TABLE 2. Reliability test.**

| Classification | Cronbach's α | Number of terms |
|---|---|---|
| Attitude | 0.867 | 4 |
| Perceived usefulness | 0.836 | 5 |
| Trust | 0.782 | 3 |
| Perceived risk | 0.874 | 4 |
| Review | 0.814 | 17 |

#### 2) VALIDITY ANALYSIS

Validity analysis is a process of argumentation wherein the publisher of a scale collects relevant theoretical information and empirical evidence to show that the measurement can effectively measure the target construct. The accuracy and validity of the measurement increases with the validity of the measurement. There are two types of validity analysis: exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) [51]. Generally speaking, if a scale is not divided into dimensions, EFA should be used for dimension division and preliminary analysis, and then CFA can be used to test whether results of the EFA are correct. This paper has assumed the structure of the questionnaire, so EFA is used directly for testing. Validity analysis can test three types of validity, namely construct validity, convergent validity, and discriminant validity [52].

Before conducting EFA, the suitability of the scale should be assessed with respect to the specific analysis. This process requires the Kaiser-Meyer-Olkin test (KMO) and Bartlett's test of sphericity. If the result of the KMO is greater than 0.6 and the significance of Bartlett's test of sphericity is less than 0.05, the scale is considered suitable for EFA [53], [54].

The test results are shown in Table 3. After testing, KMO value of the scale was equal to 0.932, which is greater

**TABLE 3. The KMO test and Bartlett's test of sphericity.**

| Test | | Numerical outcome |
|---|---|---|
| The KMO test and Bartlett's test of sphericity for sample suitability quantification | | 0.932 |
| Bartlett's test of sphericity | The approximate chi-squared test | 8515.155 |
| | Degrees of freedom | 136 |
| | Significance | 0.000 |

than 0.6. The significance of Bartlett's test of sphericity was less than 0.05, indicating that the scale could be used for EFA.

After EFA, the component values of each question were greater than 0.5. This indicated that each question was well designed and that there was no need to delete any questions.

CR is another indicator of reliability that is used to measure the reliability of combined variables. Generally, CR value must exceed 0.6 [55], and larger values are preferable. The average variance extracted (AVE) is also required to exceed 0.5, which means that the latent variable has good convergence validity. The factor load (estimate) is required to be greater than 0.5, which indicates that the corresponding latent variables belonging to the questionnaire items are highly representative.

As shown in Table 4, the data factor loadings obtained in this survey were all greater than 0.5, AVE was greater than 0.5, and CR was greater than 0.6. Thus, the aggregation effect of the survey data was good.

**TABLE 4. Convergence validity of measurement variables.**

| Path | | | Estimate | AVE | CR |
|---|---|---|---|---|---|
| Q4 | <--- | F1 | 0.846 | | |
| Q3 | <--- | F1 | 0.812 | 0.629 | 0.871 |
| Q2 | <--- | F1 | 0.721 | | |
| Q1 | <--- | F1 | 0.789 | | |
| Q9 | <--- | F2 | 0.775 | | |
| Q8 | <--- | F2 | 0.756 | | |
| Q7 | <--- | F2 | 0.684 | 0.504 | 0.835 |
| Q6 | <--- | F2 | 0.688 | | |
| Q5 | <--- | F2 | 0.639 | | |
| Q12 | <--- | F3 | 0.733 | | |
| Q11 | <--- | F3 | 0.708 | 0.544 | 0.782 |
| Q10 | <--- | F3 | 0.771 | | |
| Q18 | <--- | F4 | 0.732 | | |
| Q17 | <--- | F4 | 0.637 | | |
| Q16 | <--- | F4 | 0.858 | 0.586 | 0.875 |
| Q15 | <--- | F4 | 0.811 | | |
| Q14 | <--- | F4 | 0.772 | | |

To summarize, the reliability and validity of the data obtained met the requirements. The model fit was good and the data reliability was strong. Thus, we expect this data to truly reflect driver personality, perceived usefulness, trust, and perceived risk with respect to driverless vehicles.

## IV. STATISTICS AND ANALYSIS

### A. DESCRIPTIVE STATISTICS

The questionnaires were distributed online, a total of 945 valid questionnaires were recruited through Credamo website (https://www.credamo.com/home.html) for the questionnaire survey. We analyzed data obtained in terms of gender, age, education, occupation, driving experience, driving personality, and psychological vulnerability. These data are shown in Table 5. The study participants were mainly people under the age of 50 who had received a bachelor's degree or above. Among them, 95.8% of the respondents held a driver's license, indicating that the study population was generally well equipped to consider a driver's perspective. The results of the survey showed that in terms of driver's psychological vulnerability judgment, 43.7% of the respondents believed that they would be vulnerable in a mixed traffic competition; 30.2% of the respondents could not judge whether they would be vulnerable; and 26.1% of the respondents did not consider themselves vulnerable. Thus, the participants who clearly did not expect that they would be vulnerable to a vulnerable psychological state in a mixed traffic competition formed a minority of the participant group, this phenomenon was more pronounced among women, young people, business people, undergraduates, and those with less than 5 years of driving experience.

**TABLE 5. Demographic variables.**

| Variable | | Whether you think you are vulnerable | | | Total amount | |
|---|---|---|---|---|---|---|
| | | Yes | Vague | No | Quantity | Proportion |
| Gender | Male | 193 | 158 | 167 | 518 | 54.8% |
| | Female | 220 | 127 | 80 | 427 | 45.2% |
| Age | Under the age of 30 | 199 | 152 | 111 | 462 | 48.9% |
| | 30–39 | 161 | 102 | 111 | 374 | 39.6% |
| | 40–49 | 41 | 19 | 19 | 79 | 8.4% |
| | 50–60 | 12 | 12 | 5 | 29 | 3.1% |
| Educational background | High school, technical secondary school, and below | 43 | 30 | 14 | 87 | 9.2% |
| | Undergraduate /Junior College | 319 | 206 | 201 | 726 | 76.8% |
| | Postgraduate and above | 51 | 49 | 32 | 132 | 14.0% |
| Professional | Cadres of government departments, political parties, government organs, enterprises, institutions, and public organizations | 93 | 72 | 31 | 196 | 20.7% |
| | Professional and technical personnel | 73 | 55 | 64 | 192 | 20.3% |
| | Company employees | 139 | 87 | 88 | 314 | 33.2% |
| | Business people | 56 | 45 | 36 | 137 | 14.5% |
| | Students | 12 | 6 | 9 | 27 | 2.9% |
| | Freelancers | 40 | 20 | 19 | 79 | 8.4% |
| Driving experience | 1 year or less | 81 | 55 | 22 | 158 | 16.7% |
| | 1–5 years | 169 | 117 | 94 | 380 | 40.2% |
| | 5–10 years | 109 | 75 | 102 | 286 | 30.3% |
| | More than 10 years | 37 | 21 | 23 | 81 | 8.6% |
| | No driver's license | 17 | 17 | 6 | 40 | 4.2% |
| Driving personality | Conservative | 272 | 117 | 82 | 471 | 49.8% |
| | Moderate | 128 | 155 | 145 | 428 | 45.3% |
| | Radical | 13 | 13 | 20 | 46 | 4.9% |
| Vulnerable mentality | Number | 413 | 285 | 247 | 945 | —— |
| | Proportion | 43.7 % | 30.2 % | 26.1 % | 1 | —— |

### B. CORRELATION ANALYSIS

Correlation analyses are conducted to analyze the correlation between two or more variables. They are usually used to determine whether changing trends in two or more groups of data are consistent. Here, we conduct Pearson correlation analyses for nine factors: attitude, perceived usefulness, trust, perceived risk, gender, age, education, driving experience, and driving personality. As a result, we obtained four main findings, as follows. The data are shown in Table 6 and Table 7.

#### 1) THE RELATIONSHIP BETWEEN ATTITUDE AND OTHER VARIABLES

We found significant correlations between attitudes and perceived usefulness, trust, perceived risk, education, and driving personality. Among them, we found a significantly positive correlation between attitude and perceived usefulness (0.754), a significantly positive correlation between attitude and trust (0.646), a significantly negative correlation between attitude and perceived risk (−0.32), and a significantly negative correlation between attitude and perceived risk (−0.32). Further, we found a significantly positive correlation between attitude and educational background (0.101), and between attitude and driving personality (0.186).

#### 2) THE RELATIONSHIP BETWEEN PERCEIVED USEFULNESS AND OTHER VARIABLES

In addition to a significantly positive relationship between perceived usefulness and attitude, we found significant relationships between trust, perceived risk, education, and driving personality. Among these, we found a significantly positive correlation between perceived usefulness and trust (0.700), a significantly negative correlation between perceived usefulness and perceived risk (−0.246), and a significantly positive correlation between perceived usefulness and education (0.099). We also found a significantly positive correlation between perceived usefulness and driving personality (0.189).

#### 3) THE RELATIONSHIP BETWEEN TRUST AND OTHER VARIABLES

In addition to a significantly positive relationship between trust, attitude, and perceived usefulness, we found a significantly negative relationship between trust and perceived risk (−0.233), and a significantly positive relationship between trust and driving personality (0.151).

**TABLE 6. Correlation coefficients between latent variables.**

| | Attitude | Perceived usefulness | Trust | Perceive d risk |
|---|---|---|---|---|
| Attitude | 1 | | | |
| Perceived usefulness | 0.754** | 1 | | |
| Trust | 0.646** | 0.700** | 1 | |
| Perceived risk | -0.32** | -0.246** | -0.233** | 1 |

**TABLE 7. Correlation coefficients between latent variables.**

| | Attitude | Perceived usefulness | Trust | Perceived risk |
|---|---|---|---|---|
| Gender | -0.030 | -0.041 | 0.035 | -0.017 |
| Age | -0.022 | 0.011 | 0.051 | -0.166** |
| Education | 0.101** | 0.099** | 0.038 | 0.070* |
| Profession | -0.076* | -0.058 | -0.053 | -0.016 |
| Driving experience | 0.043 | 0.049 | 0.062 | -0.148** |
| Driving personality | 0.186** | 0.189** | 0.151** | -0.176** |

**The correlation is significant at the 0.01 level (two-tailed).
*The correlation is significant at the 0.05 level (two-tailed).

#### 4) THE RELATIONSHIP BETWEEN PERCEIVED RISK AND OTHER VARIABLES

In addition to being significantly negatively correlated with attitude, perceived usefulness, and trust, perceived risk was also significantly correlated with age, education, driving experience, and driving personality. Among these, we found a significantly negative correlation between perceived risk and age (−0.166), a significantly positive correlation between perceived risk and education (0.070), a significantly negative correlation between perceived risk and driving experience (−0.148), and a significantly negative correlation between perceived risk and driving personality (−0.176).

### C. ORDERED LOGISTICS REGRESSION ANALYSIS

Logistic regression analysis is used to test whether a dataset has multicollinearity. Multicollinearity refers to whether explanatory variables in a linear regression model are distorted or difficult to estimate accurately because they are precisely correlated or highly correlated with explanatory variables [56]. The presence of a multicollinearity problem can be determined by the tolerance and variance inflation factor. The dataset is generally considered to have a multicollinearity problem if the variance inflation factor is greater than 10 or the tolerance is less than 0.1 [56]. Here, we analyzed the collected data and found the variance inflation factor and tolerance to range from 1.051–2.855 and 0.350–0.952, respectively. Thus, the data meet the requirements, and there is no evidence of a multicollinearity problem. Accordingly, logistic regression analysis can be performed.

The independent variables (attitude, perceived usefulness, trust, and perceived risk) and dependent variables (driver's psychological vulnerability judgment) in this study were all ordinal variables. Therefore, we were able to analyze the data using ordinal logistic regression. When analyzing data using logistic regression analysis, it is first necessary to consider whether the data passes the parallelism test. If the degree of freedom of the parallelism test is greater than 0.05, then the data pass the parallelism test. This indicates that

**TABLE 8. Factors influencing driver's psychological vulnerability judgment.**

| Latent variables | B | Wald | Sig | OR | 95% confidence interval | |
|---|---|---|---|---|---|---|
| | | | | | Floor | Ceiling |
| Attitude | 0.269 | 5.496 | 0.019* | 1.308 | 0.044 | 0.493 |
| Perceived usefulness | -0.087 | 0.440 | 0.507 | 0.916 | -0.346 | 0.171 |
| Trust | 0.371 | 10.691 | 0.001*** | 1.450 | 0.149 | 0.594 |
| Perceived risk | -0.787 | 86.383 | 0.000*** | 0.455 | -0.952 | -0.621 |

***P < 0.001, **P < 0.01, *P < 0.05. Instances in which P > 0.1 are not shown in this table.
B value refers to the regression coefficient and intercept.
Wald is a chi-square value, equal to the square value of B divided by its standard error.
OR is defined as odds ratio, which ranges from 0 to infinity and cannot be negative.

ordered logistic regression can be used for analysis. The degree of freedom of the parallelism test in this study is 0.174. Since this is greater than 0.05, the data were considered to pass the parallelism test. In addition, when the model fits ($p < 0.05$) and the goodness of fit ($p > 0.05$), an orderly logistics regression analysis can be carried out. The ordinal logistic regression analysis indicated that for a hypothetical situation in which participants were drivers of manned vehicles in a mixed traffic competition, the main factors influencing expected psychological state were attitude, trust, and perceived risk. Among these, attitude ($P = 0.019$, $B = 0.269$, Wald $= 5.496$, OR $= 1.308$) and trust had a significantly positive impact on driver's psychological vulnerability judgment ($P = 0.001$, $B = 0.371$, Wald $= 10.691$, OR $=$ 1.450), and perceived risk had a significantly negative impact on driver's psychological vulnerability judgment ($P = 0.001$, $B = -0.787$, Wald $= 86.383$, OR $= 0.455$). Details are shown in Table 8.

## V. DISCUSSION

### A. DEMOGRAPHIC DATA

The participant scores for the items measuring attitudes about autonomous driving, perceived usefulness, and trust were all between 3 and 4, indicating that respondents had neutral and positive attitudes toward driverless technology. Previous work by Schoettle supports this view [16]. The average score for the items measuring the perceived risk of driverless vehicles was 3.70, indicating that respondents believed driverless technology was associated with increased risk. This was consistent with the conclusions of Choi and Ji [47].

### B. INFLUENCE OF LATENT VARIABLES ON PSYCHOLOGICAL VULNERABILITY

We measured the impact of four latent variables (attitude, perceived usefulness, trust, and perceived risk) on driver's psychological vulnerability judgment our data confirmed our hypothesis about the relationship between the four latent variables and driver's psychological vulnerability judgment, as follows (Fig. 2):

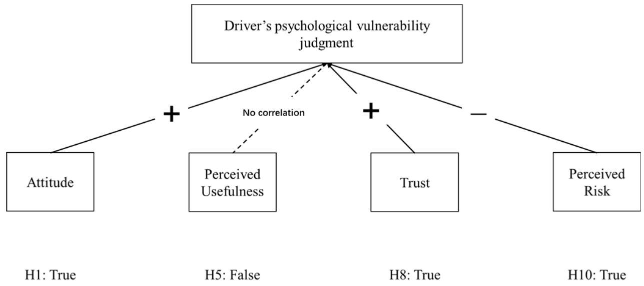


**FIGURE 2. The relationship between driver's psychological vulnerability judgment and latent variables.**

Attitude significantly and positively impacted driver's psychological vulnerability judgment, supporting H1;

Perceived usefulness had no significant effect on driver's psychological vulnerability judgment, indicating that hypothesis H5 is false;

Trust significantly and positively impacted driver's psychological vulnerability judgment, supporting H8;

Perceived risk significantly and negatively impacted driver's psychological vulnerability judgment, supporting H10.

In the Fig. 2-7, '+' represents a positive correlation, '−' represents a negative correlation, and the dotted line represents no correlation.

We found that attitude had a significantly positive effect on driver's psychological vulnerability judgment, such that a more positive attitude decreased the likelihood that the participants' psychological vulnerability judgment. Perceived usefulness had no significant effect on driver's psychological vulnerability judgment, indicating that whether or not the participants believed that driverless technology was useful did not influence their psychological vulnerability judgment when encountering driverless vehicles on the road. Trust had a significantly positive impact, indicating that a higher degree of trust decreased the chance that the participants' psychological vulnerability judgment. Perceived risk had a negative impact on psychological vulnerability judgment Thus, a higher perceived risk was associated with a greater chance that the participants psychological vulnerability judgment.

### C. RELATIONSHIPS BETWEEN LATENT VARIABLES

While the four latent variables (attitude, perceived usefulness, trust, and perceived risk) impacted participant's psychological vulnerability judgment, they also influenced one another. The mutual influence of these latent variables could indirectly affect driver's psychological vulnerability judgment [56]. We have summarized the relationships between the four variables below, and generated the following conclusions (Fig. 3):

Attitude was significantly positively correlated with perceived usefulness, which supported H2;

Attitude was significantly positively correlated with trust, which supported H3;

Attitude was significantly negatively correlated with perceived risk, which supported H4;

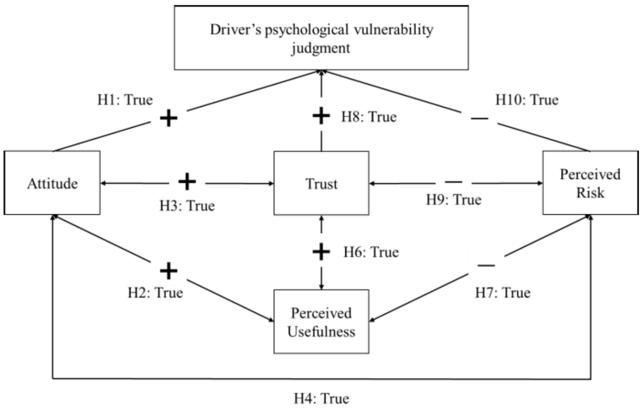


**FIGURE 3.** The influence of the relationship between latent variables on psychological vulnerability.

Perceived usefulness was significantly positively correlated with trust, which supported H6;

Perceived usefulness was significantly negatively correlated with perceived risk, which supported H7;

Trust was significantly negatively correlated with perceived risk, which supported H9.

According to the relationships between the latent variables and driver's psychological vulnerability judgment, perceived usefulness did not directly affect driver's psychological vulnerability judgment. However, from the relationship between the latent variables, we found a significant correlation between perceived usefulness and attitude, trust, and perceived risk, which indicates that perceived usefulness could indirectly affect driver's psychological vulnerability judgment by affecting the other three latent variables. The directionality of this influence was as follows:

First, a higher degree of perceived usefulness was positively correlated with stronger attitudes and trust. Further, driver's psychological vulnerability judgment was positively correlated with trust and attitude. Therefore, improved perceived usefulness can effectively reduce driver's psychological vulnerability judgment, which is indirectly achieved by influencing attitudes and trust.

Second, we found a significantly negative correlation between perceived usefulness and perceived risk, i.e., a higher perceived usefulness was associated with a lower perceived risk. Perceived risk was negatively correlated with driver's psychological vulnerability judgment. Thus, improved perceived usefulness can indirectly influence driver's psychological vulnerability judgment by reducing perceived risk.

### *D. RELATIONSHIP BETWEEN LATENT VARIABLES AND OTHER FACTORS*

In addition to the direct influence of the three latent variables (attitude, trust, and perceived risk) and the relationships between the four latent variables, driver's psychological vulnerability judgment was also indirectly influenced by other factors such as educational background and driving personality. These other factors (education, driving experience, driving personality, and age) affected driver's psychological vulnerability judgment via a direct and significant correlation with the four latent variables, and indirectly affected driver's psychological vulnerability judgment by influencing the four latent variables (only considering significant correlations at the 0.01 level). Details are as follows:

#### 1) THE INFLUENCE OF THE RELATIONSHIP BETWEEN ATTITUDE AND OTHER FACTORS ON DRIVER'S PSYCHOLOGICAL VULNERABILITY JUDGMENT

Educational background and driving personality had a significant positive impact on attitude. A higher educational background or more aggressive driving personality led to a more positive driving tendencies, and a decreased inclination to driver's psychological vulnerability judgment (Fig. 4).

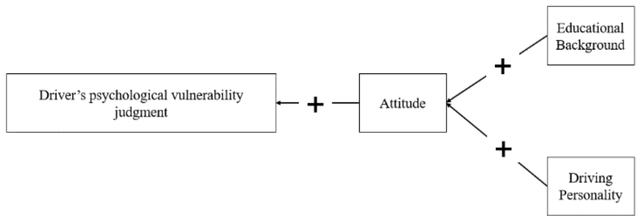


**FIGURE 4.** The influence of the relationship between attitude and other factors on driver's psychological vulnerability judgment.

#### 2) THE INFLUENCE OF THE RELATIONSHIP BETWEEN PERCEIVED USEFULNESS AND OTHER FACTORS ON DRIVER'S PSYCHOLOGICAL VULNERABILITY JUDGMENT

Education and driving personality significantly and positively impacted perceived usefulness. A higher educational level or more aggressive driving personality was associated with enhanced perceived usefulness. Both the interaction between perceived usefulness and attitude and between trust and perceived risk had a positive impact on driver's psychological vulnerability judgment (Fig. 5).

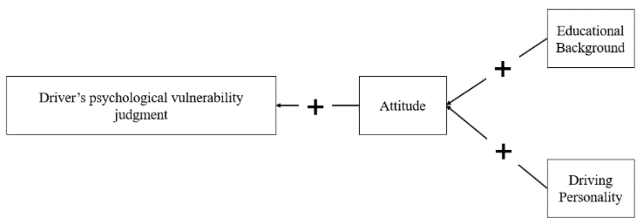


**FIGURE 5.** The influence of the relationship between perceived usefulness and other factors on driver's psychological vulnerability judgment.

#### 3) THE INFLUENCE OF THE RELATIONSHIP BETWEEN TRUST AND OTHER FACTORS ON DRIVER'S PSYCHOLOGICAL VULNERABILITY JUDGMENT

Driving personality had a significantly positive impact on trust. A more aggressive driving personality was associated with a higher level of trust, and in turn, decreased driver's psychological vulnerability judgment (Fig. 6).

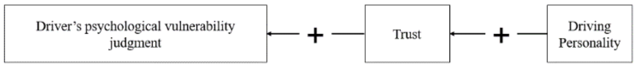


**FIGURE 6. The influence of the relationship between trust and other factors on driver's psychological vulnerability judgment.**

#### 4) THE INFLUENCE OF THE RELATIONSHIP BETWEEN PERCEIVED RISK AND OTHER FACTORS ON DRIVER'S PSYCHOLOGICAL VULNERABILITY JUDGMENT

Age, driving experience, and driving personality had significantly negative impacts on perceived risk. A higher age, longer driving experience, and a more aggressive driving personality was associated with a lower perceived level of risk. These factors decreased driver's psychological vulnerability judgment (Fig. 7).

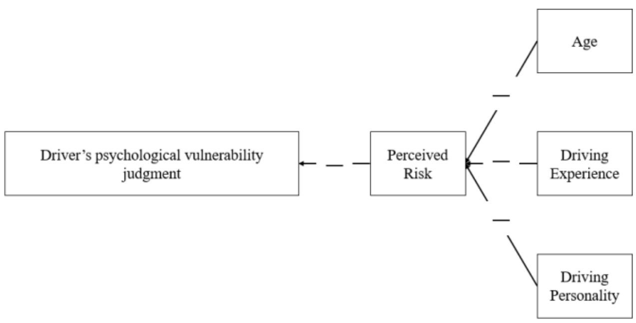


**FIGURE 7. The influence of the relationship between perceived risk and other factors on driver's psychological vulnerability judgment.**

Our data indicate that individuals with higher education, more driving experience, older age, and more aggressive driving personalities are less likely to consider themselves psychologically vulnerable when sharing the road with driverless vehicles. Thus, these groups are more likely to accept driverless technology. This can be explained as follows:

Highly educated individuals may be better able to understand the mechanisms of driverless technology, and be more receptive to emerging technologies. Further, experienced drivers may have accumulated more confidence in the process of driving, and thus be less concerned about the problems they may encounter during driving. Thus, these individuals may be less worried about whether other vehicles are driverless or manned. Older individuals may be both highly educated and experienced drivers, and may stand to gain more from emerging technologies such as driverless technology as they attempt to preserve freedom of travel as they age. Finally, aggressive drivers may also be more motivated to adopt emerging technologies, making them less fearful and more confident.

## VI. CONCLUSION

In this paper, a series of analysis was carried out on the results of the questionnaire survey. After ensuring the validity of the questionnaire data, the paper used Logistics regression analysis to conduct a detailed analysis on the factors affecting driver's vulnerable psychology. Finally, the results of Logistics regression analysis were discussed in detail and the final results were summarized as follows.

In summary, we detected the following relationships amongst the assessed factors influencing driver's psychological vulnerability judgment in a mixed traffic competition:

Attitude and trust significantly and positively impacted driver's psychological vulnerability judgment, while perceived risk significantly and negatively impacted predications regarding psychological vulnerability.

Perceived usefulness was positively correlated with attitude and trust. Attitude and trust had an indirect positive impact on driver's psychological vulnerability judgment. Perceived usefulness was negatively correlated with perceived risk, and perceived risk had an indirect positive impact on predictions regarding psychological vulnerability.

Educational background and driving personality were positively correlated with attitude and perceived usefulness, and had an indirect positive effect on driver's psychological vulnerability judgment by influencing trust and perceived usefulness.

Driving personality was positively correlated with trust, which had a positive impact on expectations of psychological vulnerability by influencing trust.

Age, driving experience, and driving personality were significantly and negatively correlated with perceived risk, and had a positive impact on expectations of psychological vulnerability by influencing perceived risk.

This paper makes an effective investigation on the factors affecting the promotion of driverless technology. According to these conclusions, researchers and market promoters of driverless technology can modify the existing shortcomings of driverless technology, and provide good help for the future promotion of driverless technology.

## CONFLICT OF 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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