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Factors Influencing the User Acceptance of Automated Vehicles Based on Vehicle-Road Collaboration

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ABSTRACT The development of smart highway and vehicle-road collaboration has stimulated the market applications of automated vehicles. However, consumer acceptance of automated vehicles will influence the time course of automated driving technology promotion. This research explores user acceptance and demand for automated vehicles based on vehicle-road collaboration and identifies which factors drive the acceptance of automated vehicles. A sample of 3900 questionnaires are obtained through classification sampling. The descriptive statistical analysis of 3594 effective multi-source sample data shows that the user acceptance of automated vehicles based on the vehicle-road collaborative environment is 70.94%. The results show that the five categories of groups have significant differences in the acceptance of automated vehicles, and the focus on individual variables is higher than the overall acceptance. Due to the contradiction and dependence among various variables, multiple regression analysis is introduced. The results show that the six variables of safety, practicability, economy, highly automated driving functions, vehicle-road collaborative fusion application, and after-sale service have a significant positive impact on the acceptance of automated vehicles. The reasons why these six factors affect user acceptance are then analyzed in depth. The fitting model and acceptance value range obtained by this research can be used for market research. The research findings provide data support and theoretical reference for the research and development, marketing, teaching, and servicing of autonomous driving technology.

INDEX TERMS Automated vehicles, vehicle-road collaboration, acceptance, market research, regression analysis.

I. INTRODUCTION

A. FUTURE ROAD TRAFFIC ENVIRONMENT

The development direction of intelligent transportation will be influenced by the application of next-generation information technology, including big data, the internet of things, mobile internet, cloud computing, and artificial intelligence. Such technology is stimulating the rapid development of smart highway and vehicle-road collaborative construction in which the integrated development of vehicles and roads will become an inevitable trend [1].

According to the digital transportation development plan issued by China's Ministry of Transport, the intelligence level of transportation infrastructure will be upgraded first. A transportation system based on digital acquisition and network transmission is projected to be built in 2025, followed by an integrated digital transportation network in 2035 [2]. As the intelligence of a single vehicle is not capable of supporting the implementation of a blueprint for automated driving, it must rely on smart roads and vehicle-road collaboration to improve its driving safety [3].

In recent years, smart highways have possessed the capabilities of road perception and information transmission, providing dynamic road condition information for autonomous vehicles [4]. The vehicle-road collaboration system can realize interconnection and intercommunication between road facilities and autonomous vehicles, and provide comprehensive assistance information for such vehicles. The coopera-

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tive system can therefore improve the ability of autonomous vehicles to cope with environmental uncertainties such as changeable weather conditions, road environments, and unpredictable vehicle behavior [5]–[7].

Automated driving based on vehicle-road collaboration is an important direction for the future development of intelligent transportation applications. It can provide safe, efficient, and green travel experiences and services [8], as well as promote increased development and widespread implementation of autonomous driving technology. The first vehicle-road collaborative test in an actual highway scenario in China was completed by Audi China in December 2018, including L4 level autonomous driving with a speed of 80 km/h [9].

While the promotion and application of higher-level automated driving in China is expected, the real demand and acceptance of vehicle-road cooperative automated driving by the Chinese public has not been anticipated. Research shows that to realize the benefits of automated vehicles (AVs), an equilibrium of technological maturity, policy support, and public acceptance and adoption of AVs is required [10]. Therefore, user acceptance is a significant factor affecting the promotion of AVs and is also an essential prerequisite for the realization of large-scale application of autonomous driving technology.

B. LITERATURE REVIEW OF AUTOMATED VEHICLES ACCEPTANCE RESEARCH

Established research on the public acceptance of AVs has been conducted by scholars in Europe and America, providing analysis and prediction of influencing factors of acceptance. Reported statistics have been obtained according to surveys on the views and attitudes of the public towards automated driving technology [11]–[14]. Scholars have also explored the impact of perception and trust on the acceptance of autonomous driving technology [15]–[19], finding both factors to be important in influencing the acceptance of autonomous vehicles. It has also been determined that autonomous driving systems can provide users with driving goals and vehicle operation information to increase trust. In addition, a number of researchers have analyzed the impact of personality traits, driving interest, usage scenarios, user experience, and potential individual differences on the acceptance of different levels of autonomous driving systems. The results show that these five elements have varying influences on the acceptance of autonomous vehicles [20]–[25].

The effect of vehicle performance attributes and policies on the acceptance of AVs has also been investigated. The studies have mainly analyzed the impact of the vehicle's own factors on user acceptance, including driving mode, safety, economy, vehicle perceived risk, and control ability. Such factors have been found to predict purchase intention [26]–[28]. In addition, a small number of studies have analyzed the impact of the driving environment on the acceptance of AVs. With a focus on the effect of mixed traffic and dedicated lanes on user acceptance in the general traffic environment, the results illustrate that people believe dedicated lanes are relatively safe [29]. In terms of policy, some experts have believed that legal liability, regulatory deployment, and acceptance will affect the realization of vehicle automation [30]. In addition, a few studies on acceptance show that the public in European countries and America have expressed concerns about relevant laws, such as accident liability [11], [14].

Few studies on the acceptance of automated driving technology have explored its variations among different countries. Existing results show that most respondents in different countries are generally interested in automated driving technology, but their attitudes and concerns about autonomous driving technology differ significantly. For example, respondents in the United States and Japan are more concerned about the security of the technology, such as data privacy, and the performance of autonomous vehicles in severe weather. However, Chinese and Indian respondents are more concerned about the development of autonomous vehicles [31]–[34].

At present, there is limited research available on the acceptance of AVs by Chinese consumers. The earliest investigation began in 2014 with B. Schoettle's self-driving car acceptance study, which was mainly used to analyze variation in public opinion in different countries [31]. In 2017, J. Yang conducted a survey on the prospects, perceptions, purchases, and intentions of Chinese consumers regarding autonomous vehicles [35]. R. Yang studied the public acceptance of highly autonomous and fully autonomous vehicles from a perception and trust perspective [36]. In addition, W. Huang investigated the factors affecting Chinese public acceptance of fully autonomous driving technology based on planned behavior theory and the technology acceptance model (TAM) [37]. The works mentioned above explored the influencing factors and prediction of acceptance of AVs from the perspectives of opinion, cognition, psychological factors, and behavior theory.

This paper aims to investigate user acceptance of AVs and its influencing factors in the intelligent transportation environment of vehicle-road collaboration. A classified survey is conducted among the groups involved in the construction and operation of vehicle-road collaboration, and user concerns and overall acceptance are obtained through data statistics. Six key influencing factors of acceptance are then obtained, and a fitted model is formulated to predict acceptance through regression analysis. The research conclusions provide a theoretical reference for the development, marketing, teaching, and service of autonomous vehicles.

II. METHOD

A. MEASUREMENT DEVELOPMENT

The purpose of this study is to determine the influencing factors that motivate users to accept AVs operating in a vehicle-road cooperative traffic environment. A questionnaire survey method was employed to collect relevant user reflection data on the entire process of research and development, production, use, and after-sale of AVs.

TABLE 1. Ordered classification for acceptance data collection of automated vehicles.

Main topic	Variable	Option definition of item
User acceptance	Y	From 1(fully unacceptable) to 5 (fully acceptable)
User personal characteristics	A1	0: Male, 1: Female
	A2	0: 18-44, 1: 45-59
	A3	0: Other, 1: Bachelor and above
	A4	0: No , 1: Yes
Driving environment condition for Automated vehicle	B1	From 1(very bad) to 5（very good)
	B2	From 1(very bad) to 5（very good)
	B3	From 1(very bad) to 5（very good)
	B4	From 1(very bad) to 5（very good)
Functions of Automated driving	C1	From 1(very unconcerned) to 5(very concerned)
	C2	From 1(very unconcerned) to 5(very concerned)
	C3	From 1(very unconcerned) to 5(very concerned)
	C4	From 1(very unconcerned) to 5(very concerned)
Attributes of Automated vehicle	D1	From 1(very low) to 5(very high)
	D2	From 1(very low) to 5(very high)
	D3	From 1(very low) to 5(very high)
	D4	From 1(very low) to 5(very high)
	D5	From 1(very low) to 5(very high)
Services for Automated vehicle	E1	0: No, 1: Yes
	E2	0: No, 1: Yes
	E3	From 1(very unconcerned) to 5(very concerned)

The questionnaire consisted of the following six research topics and corresponding 21 items (see Table 1).

1) Personal characteristics of users, including gender (A1), age (A2), education level (A3), and travel demand for the AVs (A4).
2) Driving environment conditions of the automated vehicle, including the ability to respond to dangerous road sections (B1), ability to respond to severe weather (B2), the anti-jamming capability of moving vehicles (B3), and vehicle-road collaborative fusion applications (B4).
3) Functions of automated driving, including integrated cruise assistance (C1), scenario-based autopilot (C2), high automation (C3), and full automation (C4).
4) Attributes of AVs, including safety (D1), comfort (D2), practicability (D3), economy (D4), and aesthetics (D5).
5) Regional after-sale service, including the market promotion of automated driving (E1), automated driving experience (E2), and after-sale service for automated driving (E3).
6) User acceptance of AVs (Y).

This questionnaire did not include legal issues concerning AVs. The data gathered from a small-scale pilot questionnaire survey showed that Chinese respondents did not pay much attention to legal issues related to AVs, but were more concerned about customer benefits provided by the technology. This is consistent with the results of some domestic and foreign investigations [31], [35]. Furthermore, the results indicated that the cognition level of users toward legal issues concerning AVs was not high. This may be due to the fact that the ownership of AVs in the Chinese market is smaller, the level of automation is lower, and the number of traffic accidents related to AVs is very low. Therefore, no related problems regarding legal issues were listed in the questionnaire.

The difference between the questionnaire in this study and those of the previous studies is that the two new topics of driving environment and automobile service were added to the questionnaire to reflect the user acceptance more accurately. The questionnaire design was based on existing literature and subsequent input by the automotive industry to improve the validity of the questionnaire. The item for measuring acceptance was adapted from the work of Fraedrich and Lenz [38]. To measure the adaptability of AVs to driving environment conditions such as dangerous road sections, severe weather, the anti-jamming capability of moving vehicles, and vehicle-road collaborative fusion applications, items adapted from the "Guidelines for the Construction of the Internet Standard System of the Chinese Automotive Industry" were employed [39]. The three variables of market promotion, driving experience, and after-sale service for the AVs were assessed using items adapted from the management documents of a Chinese brand automobile 4S shop. Items with other variables were adapted from existing literature on AVs [11], [14], [40], [41].

The definitions of all variable values are shown in Table 1. Acceptance is defined as the respondents' intention to use AVs, where the types of usage are divided into the purchase of a private AV and the hire of an AV. The five-point Likert scale was used to define acceptance, after-sale service, and all variables involved in the three topics of driving environment, unique functions, and attributes of AVs.

B. CATEGORICAL SAMPLING

The sampling of data was carried out by the equal proportion of classification survey method, to ensure that the samples truly reflected the social groups. In this work, a classification survey refers to conducting a questionnaire survey among five categories of groups related to automated driving technology of vehicle-road collaboration. Classified sampling divides the respondents into the following five categories:

1) The main body of road construction, collecting what kind of road sharing information the smart highway can provide for the vehicle-road system.
2) Automobile research institutes, collecting scientific research and the direction of development for the performance of autonomous vehicles. This information can be used to evaluate the development focus for the overall performance of vehicles.
3) Automobile manufacturing enterprises, collecting worker understanding of the technical and performance

indicators of autonomous driving. This information is used as the basis for the capital investment and human resource reserve of the production line.

4) Colleges and universities, collecting teacher and student awareness of autonomous driving technology. This information is used to formulate certain publicity indicators for automobile production, operation, sales, and service as a way to improve serviceability and service level.
5) Other users in the market, collecting individual attention to AVs to obtain important indicators for research and development, production, and services that guide technological development and improve the development direction of the process.

It is necessary to ensure that the proportion of various populations in the total sample is balanced so that the sample data is complete in variety and structure [42]. Therefore, the surveyed samples with equal proportion were extracted from five categories of groups related to AVs according to different industry fields. The sample data incorporating these five groups reflect the attention given to AVs from different perspectives. The classification structure of the samples reflects the real needs of multiple groups in society to improve the accuracy of the estimation effectively.

C. DATA COLLECTION

The data collection process employed in this work was to provide accessible scientific works and user experiences before filling in the questionnaire. This worked to accurately reflect user acceptance of AVs and ensure the validity and representativeness of the survey data. This data collection process provided the following advantages:

1) Relevant scientific information and user experiences were provided to ensure that the users could clearly recognize the concept of vehicle-road collaborative environment and automated driving, and perceive the functional distinctions of different levels of automated driving, use scenarios, and customer benefits before they participated in the questionnaire survey. This process effectively improved the respondents' perception of AVs.
2) Comprehensive coverage of the survey scope. In the selection stage of the questionnaire survey scope of this study, the differences in economic condition, climatic characteristics and geographical environment for the surveyed area were comprehensively considered. Based on the above selection principle, the same number of cities involved in smart highway pilot provinces were selected from the southern and northern regions of China. Those sampling areas covered some first-tier cities and towns with different economic conditions in China. Since the regional variable was automatically identified through the network questionnaire system, it was not reflected in the questionnaire.

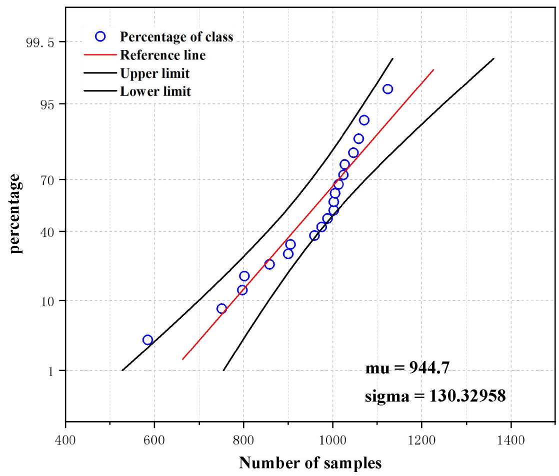

FIGURE 1. Probability distribution of variable proportion.

3) The difference in sampling methods between this study and previous studies was that the classified sampling survey was adopted.
4) Data collection adopted a combination of network surveys and on-site questionnaires.

The above content ensured the integrity, balance and representativeness of the data in terms of the survey content, scope, and sampling population. As a result, the aggregated sample data more closely reflected society. In this work, a total of 3900 questionnaires were distributed, and 3594 valid multi-source data were obtained. The effective recovery rate for the survey was 92.2%.

D. MODEL SELECTION

The logistic regression model was chosen to process and analyze the data as a preliminary analysis. The model determined the sample data to have the following characteristics: (1) The independent variables and acceptance were numerical data. The independent variables were independent of each other, and all independent variables had a linear relationship (see Fig. 1); (2) The collected data was entered in order, and the dependent variable showed a binomial distribution.

In summary, the collected data met the application conditions of the logistic regression model. The logarithmic probability regression formula was then used to process data, as shown in Eq. (1) and Eq. (2) [43].

$$\ln\left(\frac{p}{1-p}\right) = \alpha_j + \sum_{i}^{k} \beta_{ij} x_{ij} \tag{1}$$

$$p\left(y < j \mid x_j\right) = \frac{\exp\left(\alpha_j + \sum_{i}^{k} \beta_{ij} x_{ij}\right)}{1 + \exp\left(\alpha_j + \sum_{i}^{k} \beta_{ij} x_{ij}\right)} \tag{2}$$

where y represents the subject's acceptance of AVs, j is the classification of the dependent variable y, and the

TABLE 2. Classification statistics of sample data.

Sampling population	Acceptance	Acceptance rate	Completely willing	Very willing	willing
Main body of highway construction	534	71.26%	17.26%	26.54%	27.46%
Research institutes	543	75.42%	43.79%	19.58%	12.05%
Colleges and universities	507	70.42%	9.01%	33.64%	27.77%
Automobile manufacturers	549	76.25%	55.27%	13.02%	7.96%
Other users	438	61.34%	21.09%	25.86%	14.39%
Total sample	2571	70.94%	29.28%	23.73%	17.93%

corresponding levels of y are represented by 0 and 1. In addition, x represents factors affecting acceptance, k is the number of independent variables x, α is the intercept parameter, and β is the cumulative probability of the regression variable at different levels.

III. FEATURE ANALYSIS OF SAMPLES

A. CATEGORICAL STATISTICAL ANALYSIS OF SAMPLE DATA

The classification statistics of the sample data work to illustrate the acceptance of AVs in five categories of groups to accurately reflect the general acceptance of the groups involved in the construction of vehicle-road collaboration. The sample data was classified and aggregated according to the category of groups and then statistically analyzed (see Table 2). Finally, the characteristics of different categories of groups that were willing to accept AVs and the differences in their concerns were obtained.

As shown in Table 2, 71.3% of the samples of the main body of highway construction accept AVs, of which 17.26% are completely willing to use it, 26.54% are very willing to use it, and 27.46% are willing to use it. This group of people are more concerned with vehicle-road collaboration, the ability to cope with dangerous roads and severe weather, and practicality.

Among the samples of automobile research institutes, 75.4% are willing to accept automated driving technology (completely willing: 43.79%; very willing: 19.58%; willing: 12.05%). The education level of this group of people is mostly bachelor's degree and above, and they are more concerned about vehicle-road collaborative fusion, highly automated driving technology, the anti-jamming capability of moving vehicles, scenario-based autopilot, and safety.

In the sample of colleges and universities, 70.4% of people accept AVs, of which 9.01% are completely willing, 33.64% are very willing, and 27.77% are willing. Teachers and students are more concerned with highly automated driving technology, safety, aesthetics, and economy.

In addition, 76.3% of the automobile manufacturers sampled accept self-driving cars (completely willing: 55.27%; very willing: 13.02%; willing: 7.96%). They are more concerned with vehicle-road collaborative fusion, integrated cruise assist functions, highly automated driving technology, safety, market promotion of automated driving, and the popularity of the automated driving experience.

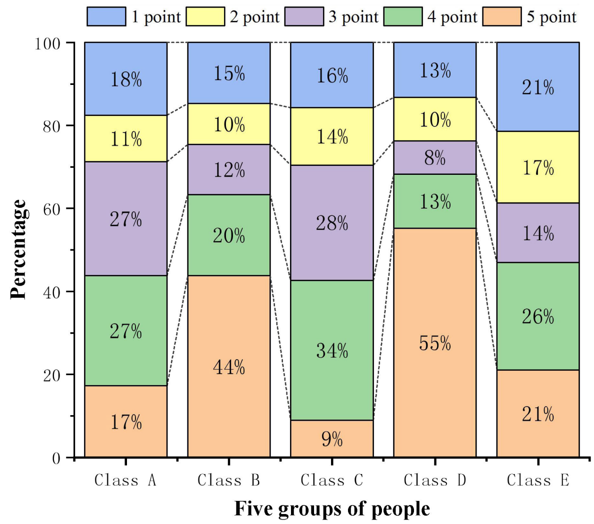

FIGURE 2. Acceptance distribution map of five categories of groups.

The rate of active acceptance by other users is 61.3% (completely willing: 21.09%; very willing: 25.86%; willing: 14.39%). This group of people are more concerned about highly automated driving technology, safety, economy, practicality, aesthetics, and after-sale service.

The acceptance distribution of the five categories of groups is shown in Fig. 2. The general acceptance rate in the entire sample is 70.94% (completely willing:29.28%; very willing:23.73%; willing: 17.93%). The differences between groups are as follows: a) The acceptance of different groups is distinct. The automobile manufacturers have the highest acceptance rate. Acceptance by those involved in the main body of highway construction and scientific research institutes is the next highest. Then, the acceptance of those in colleges and universities is at a medium level, and the acceptance of other users is lowest; b) There are also obvious distinctions in the focus on AVs. The main body of highway construction pays more attention to the driving environment conditions, while research institutes are more concerned about the unique attributes and grade differences of the vehicles themselves. In addition, the functions of automated driving and driving safety are the focus of all respondents.

Among those who accept AVs, 1792 respondents are willing to pay to purchase AVs, and 779 respondents are willing to pay to use shared or pooled automated vehicles. Figure 3 shows that respondents who purchase AVs have large differences in their willingness to pay for different levels of AVs. The technical cost of AVs with Level 2 or higher is considered, so the price option below \$10,000 is not set. Within the same price range, respondents are more inclined to buy higher-level automated driving functions, but in the purchase options of L4 and L5, they are more likely to buy L4 automated driving functions.

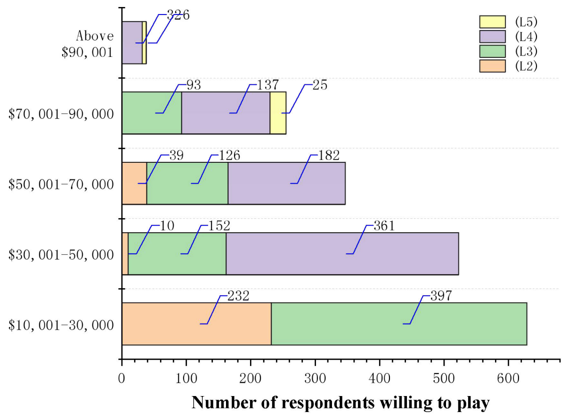

FIGURE 3. Distribution of respondents' willingness to pay for AVs with different levels.

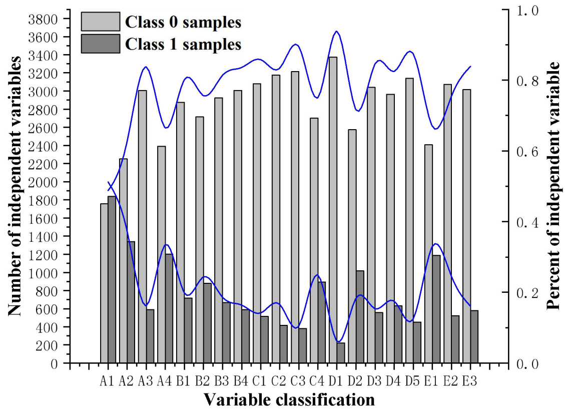

FIGURE 4. Comparative analysis of sample numerical characteristics.

B. ANALYSIS OF THE PROPORTION OF INFLUENCING FACTORS ON SAMPLE DATA

Ranking the attention degree of AVs was carried out by analyzing the sample attributes of the 3594 samples. The characteristics of sample value are presented in Table 3, in which the attention to individual variables is ranked in descending order of safety, highly automated driving functions, vehicle-road coordination, scenario-based autopilot, practicality, after-sale service, and aesthetics. These findings can provide theoretical guidance for the promotion of precise policies for autonomous vehicles.

As shown in Fig. 4, the results indicate that attention to a single variable is much higher than the overall acceptance, and there are dependencies and contradictions between the variables. For example, safety is the foundation of other characteristics, but there are contradictions between economics, practicality, and aesthetics. Moreover, the analysis demonstrates that the ranking of the above-mentioned variables' attention degree only represents a single focus point of the sampling population and cannot be used as influencing factors of acceptance.

TABLE 3. Statistical description of sample value characteristics.

IV	Value	Sample size	Proportion of total	IV	Value	Sample size	Proportion of total
A1	Male	585	48.80%	C3	Yes	1071	89.4%
	Female	613	51.20%		No	127	10.6%
A2	18-44	751	62.70%	C4	Yes	900	75.13%
	45-59	447	37.30%		No	298	24.87%
A3	Bachelor	1002	83.70%	D1	Yes	1124	93.80%
	Other	196	16.30%		No	74	6.20%
A4	Yes	797	66.50%	D2	Yes	858	71.60%
	No	401	33.50%		No	340	18.40%
B1	Yes	959	80.10%	D3	Yes	1013	84.60%
	No	239	19.90%		No	185	15.40%
B2	Yes	905	75.60%	D4	Yes	988	82.50%
	No	293	24.40%		No	210	17.50%
B3	Yes	975	81.40%	D5	Yes	1047	87.40%
	No	223	18.60%		No	151	1260%
B4	Yes	1002	83.60%	E1	Yes	802	67.00%
	No	196	16.40%		No	396	33.00%
C1	Yes	1027	85.80%	E2	Yes	1024	75.50%
	No	171	14.20%		No	174	24.50%
C2	Yes	1059	83.40%	E3	Yes	1005	83.90%
	No	139	16.60%		No	193	16.10%

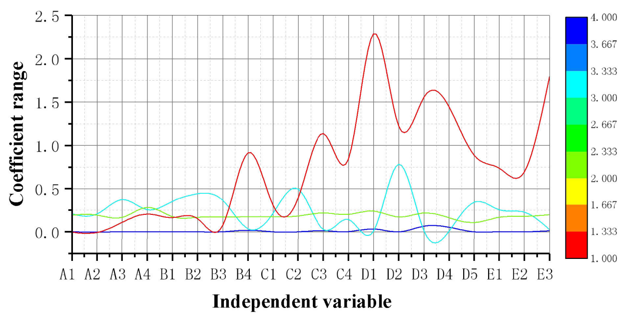

FIGURE 5. Numerical comparison of initial regression models.

IV. INFLUENCING FACTOR ANALYSIS

A. DATA PROCESSING

The 3594 samples were further processed to identify the key factors affecting user acceptance of autonomous driving. The preliminary results of the regression analysis of the sample data were calculated by selecting a logistic model in IBM SPSS Statistics V22.0 (see Fig. 5).

For the first step of single-factor regression analysis, the correlation value between a single factor and acceptance was obtained through the statistical analysis of a single factor and acceptance one by one. The second step of multivariate regression analysis worked to verify the results of the statistical analysis of sample data. The overall statistical analysis of multiple factors and acceptance was then used to verify the correlation between the sample data and obtain the significance value between the data.

While the results of the two statistics are not exactly the same, the six independent variables with p values less than

TABLE 4. Statistical analysis of the multiple regression model with ordered parameters.

IV	multi-factor analysis				Single factor analysis		
	Coefficient estimation	Standard error	P value	Marginal effect	Coefficient estimation	Standard error	P value
A1	-0.0058	0.1933	0.2071	-0.0009	-0.0032	0.1949	0.0069
A2	-0.0069	0.1924	0.2079	-0.0031	-0.0136	0.1828	0.0079
A3	0.1096	0.1665	0.3724	0.0008	0.0693	0.1659	0.3724
A4	0.2061	0.2829	0.2549	0.0006	0.0032	0.2742	0.5549
B1	0.1640	0.1747	0.3537	0.0003	0.0445	0.1659	0.8537
B2	0.1522	0.1682	0.4421	0.0007	0.0325	0.1697	0.8421
B3	0.0751	0.1696	0.3639	0.0009	0.0456	0.1533	0.7639
B4	0.9139	0.1746	0.0342	0.0179	0.0237	0.1721	0.0381
C1	0.3076	0.1745	0.2140	0.0009	0.0174	0.1738	0.2136
C2	0.3987	0.1834	0.4948	0.0008	0.2016	0.1798	0.5948
C3	1.1365	0.2168	0.0281	0.0124	0.8363	0.1964	0.0179
C4	0.8459	0.2021	0.1424	0.0019	0.1462	0.2043	0.0024
D1	2.2882	0.2391	0.0082	0.0326	0.5284	0.2193	0.0015
D2	1.2232	0.1729	0.7833	0.0006	0.6239	0.1684	0.0436
D3	1.5580	0.2170	0.0091	0.0639	0.6583	0.2175	0.0083
D4	1.4439	0.1620	0.0063	0.0527	0.3461	0.1649	0.0247
D5	0.8841	0.1072	0.3435	0.0007	0.0145	0.1517	0.0439
E1	0.7368	0.1687	0.2561	0.0014	0.4788	0.1612	0.2566
E2	0.6929	0.1805	0.2273	0.0009	0.2336	0.1768	0.2757
E3	1.7935	0.1976	0.0256	0.0134	0.7651	0.1902	0.0394

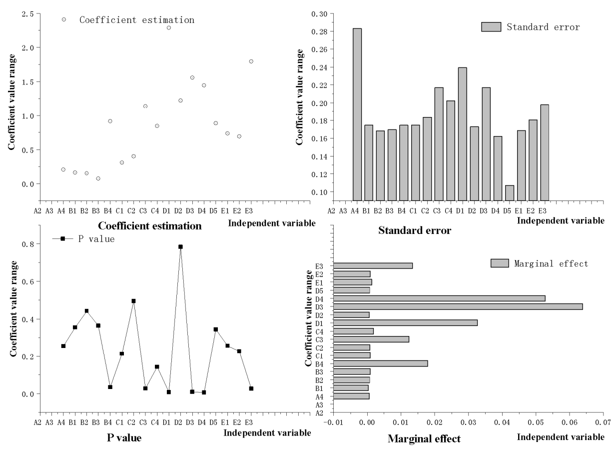

FIGURE 6. Multiple regression parameters.

0.05 are the same (see Table 4). According to the value of multi-element correlation, the six independent variables with high significance are safety ($p = 0.025$), practicability ($p = 0.019$), economy ($p = 0.034$), highly automated driving functions ($p = 0.018$), vehicle-road collaboration ($p = 0.033$), and after-sale service ($p = 0.036$).

As shown in Fig. 6, the result indicates that the above six factors have a positive impact on the acceptance of AVs and reflect the core concerns of Chinese respondents to AVs operating in the vehicle-road collaborative traffic environment.

B. ANALYSIS OF POSITIVE IMPACT FACTORS

Through the above-mentioned verification of the critical impact factors and the impact analysis of classified sampling, six key factors were determined to affect the acceptance of AVs. These factors are safety, practicability, economy, highly automated driving functions, vehicle-road collaborative fusion application, and after-sale service.

Such results indicate that Chinese respondents pay more attention to safety, practicality, and economy in terms of the unique attributes of AVs. In China, AVs are expected to become a practical and competitive new vehicle, combining the functions of traditional cars with the comfort and timeliness of high-speed rail, while maintaining economy and flexibility. The above six attributes are thus determined to directly influence the choice of AVs.

Chinese consumers are highly concerned about the driving environment of AVs, especially the vehicle-road collaborative environment. The function of smart roads to provide driving assistance has been the basis for the promotion of autonomous driving technology. Therefore, in areas where smart road construction and vehicle-road collaboration platform environments are prominent, people are more willing to choose AVs for travel.

For autonomous vehicles running in a vehicle-road collaborative traffic environment, Chinese users prefer highly automated driving. The vehicle-road collaboration system provides a safe driving guarantee for autonomous vehicles. Furthermore, people are willing to use highly autonomous driving technology to ease the pressure of travel, believing that it can relieve driving fatigue, improve driving safety, and reduce psychological stress.

The after-sale service of AVs is another critical factor affecting Chinese consumer choice. By referring to the after-sale service quality of traditional cars and the after-sale service during the pilot operation of autonomous vehicles, the majority of market users require excellent after-sale service to ensure the daily use of autonomous vehicles. Users who choose autonomous driving hope that converged hardware and software services can provide functions such as free maintenance and rescue.

C. ESTABLISHMENT OF ACCEPTANCE PREDICTION MODEL

The accuracy of the acceptance prediction model mainly depends on the influence factors and their correlations. First, this study employed the technology acceptance model (TAM) as a reference. TAM can be used to model how users come to accept and use a technology [44]. In this work, acceptance was measured by the respondents' intention to use AVs and usage intention was employed to characterize the user's behavior intention. Using behavioral intention as the dependent variable is particularly useful to examine the acceptance of technical products at an early stage [45], [46]. Second, taking the six positive factors identified by the above analysis as the object, the correlation coefficient between positive factors was obtained by linear regression analysis. Finally, the acceptance prediction model was revised according to the statistical principle.

Based on the verification results of statistical analysis of the sample data, user acceptance of AVs was predicted by the fitting method of multiple regression analysis. As shown in Eq. (3), a prediction model of user acceptance was thus constructed. The model characterizes the linear relationship between acceptance, the six positive factors, and the weight of the positive factors as:

$$\mathbf{Y} = \mathbf{0.133B_4} + \mathbf{0.143C_3} + \mathbf{0.150D_1} + \mathbf{0.135D_3} + \mathbf{0.132D_4} + \mathbf{0.134E_3} \quad (3)$$

where B4, C3, D1, D3, D4, and E3 represent the acceptance for a single variable of vehicle-road collaborative fusion, highly automated driving function, economy, safety, practicability, and after-sale service, respectively.

Moreover, the value range of acceptance obtained at a 95% confidence interval is from 0.673 to 0.757, which is the value range of the market acceptance for AVs under the vehicle-road cooperative traffic environment.

In previous studies, conceptual structure models were used to predict acceptance and were presented in the form of diagrams. However, the acceptance prediction model of this study is presented using a more intuitive data fitting formula, and the value range of acceptance is given. It can be directly utilized for the market acceptance prediction of AVs, and possesses good portability.

V. DISCUSSION AND CONCLUSION

This study aimed to explore users acceptance, identify the factors affecting acceptance, and clarify the correlation between these factors. In this study, user acceptance of AVs was 70.9% under the conditions of vehicle-road coordination, providing helpful information for manufacturers to grasp the overall level of user acceptance of AVs. This result implied that user acceptance of AVs is higher than that of other studies on this subject available in China [34]–[36]. On the one hand, this result was attributed to the provision of relevant scientific information and user experiences before the questionnaire survey, which effectively improved respondents' cognitive levels for AVs. On the other hand, it was due to ensuring that the respondents understood that AVs will be running in the intelligent transportation environment of vehicle-road coordination and that improvement of the driving environment will enhance the safety of AVs. Furthermore, the survey results of willingness to pay for different levels of AVs illustrated the demand distribution and purchasing capability of users for AVs, and provided guidance for automobile companies to conduct market layout of automated driving products and pricing.

Research analysis revealed that different groups had different concerns about AVs. However, safety, practicability, economy, highly automated driving functions, vehicle-road collaborative fusion application, and after-sales service were identified as important factors that affect the acceptance of different groups in different economic regions. The six positive factors that influenced acceptance are helpful for enterprises to improve user acceptance and adjust the direction of autonomous driving technology research and development.

The difference between the questionnaire in this study and those of previous studies was that seven problem items were added from the perspective of the driving environment and automated vehicles service. The results showed that the vehicle-road collaborative application and after-sales service were the key factors that affected the acceptance and purchase options for automated driving functions. In the context of vehicle-road collaboration, Chinese users were more willing to choose Level 4 AVs to travel. Besides, the focus of after-sales service reflects users' real expectation for automobile companies in improving the after-sales service quality of AVs. It also implied that when making AVs purchase choices, after-sales issues will be considered, such as software service fees for automated driving and vehicle failure service. Thus, it is recommended that car companies and internet service providers improve the overall service level and their abilities to meet users' expected needs. For example, remote service and intelligent travel services for automated driving should be considered for inclusion in after-sales service to eliminate users' concerns about usage problems. In summary, the research findings for the respondents on the focus of automated vehicles and the service expectations provide practical guidance for product promotion and the formulation of marketing strategies, so as to enhance the perceived value of customers and expand the acceptance range.

The acceptance prediction model expressed by a mathematical fitting formula was able to intuitively characterize the relationship between positive factors and acceptance. Compared with the conceptual structure models in previous studies, this model has intuitive, digital, and powerful transplantable features. The range of acceptance values with a confidence interval of 95% was given, making it easier for statistical applications and technical exchanges. Furthermore, the acceptance prediction model can be used to evaluate the market acceptance of autonomous driving products or technologies. The built-in method of the acceptance prediction model in this study can broaden the expression form of the acceptance prediction model and increase its ease of use.

The following aspects of this work require further study. First, with the growth in the number of high-level automated vehicles and the number of accidents caused by these vehicles in the future in China, it is necessary to consider the impact of the legal issues of AVs on acceptance. Second, after-sales service should be further studied to determine the main factors affecting respondents' acceptance. Finally, the payment issue for shared or pooled automated vehicles is not covered in this study and needs to be further explored to improve the acceptance of this specific group.

REFERENCES

[1] B. Ran, "World intelligent transportation progress and trends," *China Highway*, no. 14, pp. 22–23, Jul. 2018.

[2] T. Department, "Outline of digital transportation development planning," *World Shipping*, vol. 42, no. 9, p. 48, Sep. 2019.
[3] E. Journal, "A summary of aca-demic research on China's automotive engineering 2017," *China J. Highway Transp.*, vol. 30, no. 6, pp. 1–197, Jun. 2017.
[4] J. S. Zhang, B. Li, X. J. Wang, F. Zhang, and X. L. Sun, "Smart expressway architecture and development path design," *Highway Transp. Sci. Technol.*, vol. 35, no. 1, pp. 88–94, Jan. 2018.
[5] Z. P. Yu, X. Y. Xing, and J. Y. Chen, "Progress of testing technology and application of autonomous vehicles," *J. Tongji Univ.*, vol. 47, no. 4, pp. 540–547, May 2019.
[6] *Taxonomy and Definitions for Terms Related to Dr-Iving Automation Systems for On-Road Motor Vehicles: Standard J*, SAE International, Warrendale, PA, USA, Sep. 2016, pp. 1–30.
[7] X. M. Xiong, X. Yang, Z. L. Liu, and X. T. Zhu, "Research on the cloud-end architecture and service of vehicle-road collaboration," *Electron. Technol. Appl.*, vol. 45, no. 8, pp. 14–18, Aug. 2019.
[8] CCID Consulting, "The acceleration of China's intelligent and connected automobile industry," New Energy Auto News, Ministry Ind. Inf. Technol., China, Beijing, Tech. Rep. 010, Nov. 2019. [Online]. Available: https://kns.cnki.net/KCMS/detail/detail.aspx?dbcode=CCND&dbname=CCNDLAST2019&filename=XNQC201911250100&uid=WEEvREcwSlJHSldRa1FhcEFLUmViNWx0NHBnMi92YXZZakVXVndSMCt6OD0=$9A4hF_YAuvQ5obgVAqNKPCYcEjKensW4IQMovwHtwkF4VYPoHbKxJw!!&v=MTczMDhuajk4VG5qcXF4ZEVlTU9VS3JpZlplWnZFU3ZuVTdmTklGb1ZQU1BhYmJHNEg5ak5ybzFBWk9vUERCTkt1aGRo
[9] P. Team, "Huawei joined hands with sf group and audi China to realize the country's first demonstration of vehicle-road collaborative intelligent driving in actual highway scenarios," *Electron. Meas. Technol.*, vol. 41, no. 24, p. 45, Dec. 2018.
[10] N. Merat and D. de Waard, "Human factors implications of vehicle automation: Current understanding and future directions," *Transp. Res. F, Traffic Psychol. Behaviour*, vol. 27, pp. 193–195, Nov. 2014.
[11] M. Kyriakidis, R. Happee, and J. C. F. de Winter, "Public opinion on automated driving: Results of an international questionnaire among 5000 respondents," *Transp. Res. F, Traffic Psychol. Behav.*, vol. 32, pp. 127–140, Jul. 2015.
[12] B. Schoettle and M. Sivak, *A Survey of Public Opinion About Autono-Mous and Self-Driving Vehicles in the U.S. the U.K. and Australia*. A-nn Arbor, MI, USA: University of Michigan, Jun. 2014. [Online]. Available: https://de-epblue.lib.umich.edu/bitstream/handle/2027.42/108384/103024.pdf?
[13] W. Payre, J. Cestac, and P. Delhomme, "Intention to use a fully automated car: Attitudes and a priori acceptability," *Transp. Res. F, Traffic Psychol. Behaviour*, vol. 27, pp. 252–263, Nov. 2014.
[14] S. V. Casley, A. S. Jardim, and A. M. Quartulli, *A study of public a-cceptance of autonomous cars (Bachelor of Science)*. Worcester, MA, USA: Worcester Pol-ytechnic Institute, Mar. 2013. [Online]. Available: https://web.wpi.edu/Pubs/E-project/Available/E-project-043013-155601/unrestricted/A_Study_of_Public_Acceptance_of_Autonomo-us_Cars.pdf
[15] D. Howard and D. Dai, "Public perceptions of self-driving cars: The c-ase of Berkeley, California," in *Proc. 93rd Annu. Meeting*, vol. 14, Jan. 2014, p. 4502.
[16] Z. Zhang, Y. Guo, W. Yuan, and C. Wang, "The impact of cognitive distraction on driver perception response time under different levels of situational urgency," *IEEE Access*, vol. 7, pp. 184572–184580, 2019.
[17] L. M. Hulse, H. Xie, and E. R. Galea, "Perceptions of autonomous vehicles: Relationships with road users, risk, gender and age," *Saf. Sci.*, vol. 102, pp. 1–13, Feb. 2018.
[18] F. M. F. Verberne, J. Ham, and C. J. H. Midden, "Trust in smart systems: Sharing driving goals and giving information to increase trustworthiness and acceptability of smart systems in cars," *Hum. Factors, J. Hum. Factors Ergonom. Soc.*, vol. 54, no. 5, pp. 799–810, Oct. 2012.
[19] J. K. Choi and Y. G. Ji, "Investigating the importance of trust on adopting an autonomous vehicle," *Int. J. Hum.-Comput. Interact.*, vol. 31, no. 10, pp. 692–702, Jul. 2015.
[20] C. Rödel, S. Stadler, A. Meschtscherjakov, and M. Tscheligi, "Towards autonomous cars: The effect of autonomy levels on acceptance and user experience," in *Proc. 6th Int. Conf. Automot. User Interface Interact. Veh. Appl.*, 2014, pp. 1–8.
[21] R. Fu, T. Liu, Y. X. Guo, S. W. Zhang, and W. D. Cheng, "A case stud-y in China to determine whether GPS data and derivative indicator can be used to identify risky drivers," *J. Adv. Transp.*, vol. 2019, pp. 1–16, Nov. 2019.
[22] J. Helgath, P. Braun, A. Pritschet, M. Schubert, P. Böhm, and D. Isem-ann, "Investigating the effect of different autonomy levels on user acceptance and user experience in self-driving cars with a VR Dri-ving simulator," in *Proc. Int. Conf. design, user Exper.*, vol. 10920, Jun. 2018, pp. 247–256.
[23] M. Körber and K. Bengler, "Potential individual differences regarding automation effects in automated driving," in *Proc. Int. Conf. Hum. Comput. Interact.*, 2014, pp. 1–7.
[24] A. H. Eichelberger and A. T. McCartt, "Toyota drivers' experiences with dynamic radar cruise control, pre-collision system, and lane-keeping assist," *J. Saf. Res.*, vol. 56, pp. 67–73, Feb. 2016.
[25] B. J. Lee, "Consumer Preference for Autonomous Vehicles and Chag-llenges in Transportation Planning," *KRIHS Policy Brief*, vol. 600, pp. 1–8, Jan. 2017.
[26] Y. S. Guo, Q. Y. Sun, R. Fu, and C. Wang, "Improved car-follo-wing strategy based on merging behavior prediction of adjacent vehicle from naturalistic driving data," *IEEE Access*, vol. 7, pp. 184572–184580, 2019.
[27] J. Lee, H. Chang, and Y. I. Park, "Influencing factors on social acce-ptance of autonomous vehicles and policy implications," in *Proc. Portl-Int. Conf. Manage. Eng. Technol.*, Aug. 2018, pp. 1–6, doi: 10.23919/PICMET.2018.8481760.
[28] N. Ostern, A. Eßer, and P. Buxmann, "Capturing users' privacy expe-ctations to design better smart car applications," in *Proc. PACIS*, Oct. 2018, p. 97.
[29] J. P. Zmud and I. N. Sener, "Towards an understanding of the travel behavior impact of autonomous vehicles," *Transp. Res. Procedia*, vol. 25, pp. 2500–2519, Oct. 2017.
[30] (2014). *Automated Vehicles Forecast: Vehicle Symposium Opinion Survey*. [Online]. Available: https://www.scienceopen.com/document?vid=e24fb7fe-9c7a-420d-bb14-8f6b1e984359
[31] B. Schoettle and M. Sivak, *Public Opinion About Self-Driving Vehicles in China, India, Japan, the US, the UK, and Australia*. Ann Arbor, MI, USA: University of Michigan, Oct. 2014. [Online]. Available: https://deepblue.lib.umich.edu/bitstream/handle/2027.42/109433/103139.pdf?sequence=1&isAllowed=y
[32] B. Brown, M. Drew, C. Erenguc, R. Hill, S. Schmith, and B. Ganula, *2014 Global Automotive Consumer Study*. New York, NY, USA: Deloitte Development LLC, 2014. [Online]. Available: https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-auto-global-automotive-consumer-study-100914.pdf
[33] P. Bazilinskyy, M. Kyriakidis, and J. de Winter, "An international crowd-sourcing study into People's statements on fully automated driving," *Procedia Manuf.*, vol. 3, pp. 2534–2542, 2015.
[34] S. Nordhoff, J. de Winter, M. Kyriakidis, B. van Arem, and R. Happee, "Acceptance of driverless vehicles: Results from a large cross-national questionnaire study," *J. Adv. Transp.*, vol. 2018, pp. 1–22, Oct. 2018.
[35] J. Yang and M. J. Shen, "Investigation of consumer market acceptance of automated vehicles in China," *J. Chang Univ.*, vol. 19, no. 6, p. 159, Nov. 2017.
[36] H. Liu, R. Yang, L. Wang, and P. Liu, "Evaluating initial public acceptance of highly and fully autonomous vehicles," *Int. J. Hum. Comput. Interact.*, vol. 35, no. 11, pp. 919–931, Jan. 2019.
[37] W. Huang, "Research on the acceptance of fully autonomous vehicle based on theory of planned behavior and technology acceptance model," Ph.D. dissertation, Jiangsu Univ., Zhenjiang, China, Jun. 2019. [Online]. Available: https://kns.cnki.net/KCMS/detail/detail.aspx?dbcode=CMFD&dbname=CMFD201902&filename=1019893737.nh&v=MTYwMDNVUjdxZllPUnNGeURtVjdySlZGMjZGN3V4SGRiUHFKRWJQSVI4ZVgxTHV4WVM3RGgxVDNxVHJXTTFGckM=
[38] E. Fraedrich and B. Lenz, *Societal and Individual Acceptance of Au-tonomous Driving*. London, U.K.: Springer, 2016, pp. 621–640, doi: 10.1007/978-3-662-48847-8_29.
[39] (Jun. 2018). *Guidelines for the Construction of the National Vehicle Connectivity Industry Standard System*. [Online]. Available: http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757016/c6223806/content.html.
[40] (Jul. 2019). *Safety First for Automated Driving*. [Online]. Available: https://www.daimler.com/innovation/case/autonomous/safety-first-for-automated-driving-2.html
[41] A. Eskandarian, *Handbook of Intelligent Vehicles*, vol. 1. London, U.K.: Springer-Verlag, 2012, pp. 117–138.
[42] T. Speed, "Statistics for experimenters: Design, innovation, and discovery," *Amer. Stat. Assoc.*, vol. 101, no. 476, pp. 23–36, Jun. 2006.

[43] A. Dean, D. Voss, and D. Dragulji, "Design and analysis of experim-ents," *Springer Texts Statist.*, vol. 42, no. 3, p. 308, Sep. 2017.

[44] F. D. Davis, R. P. Bagozzi, and P. R. Warshaw, "User acceptance of computer technology: A comparison of two theoretical models," *Manage. Sci.*, vol. 35, no. 8, pp. 982–1003, Aug. 1989.

[45] P. Y. K. Chau and P. J.-H. Hu, "Investigating healthcare professionals' decisions to accept telemedicine technology: An empirical test of competing theories," *Inf. Manage.*, vol. 39, no. 4, pp. 297–311, Jan. 2002.

[46] J.-H. Wu, W.-S. Shen, L.-M. Lin, R. A. Greenes, and D. W. Bates, "Testing the technology acceptance model for evaluating healthcare professionals' intention to use an adverse event reporting system," *Int. J. Qual. Health Care*, vol. 20, no. 2, pp. 123–129, Dec. 2007.

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