The obstacles of China's intelligent automobile manufacturing industry development

A structural equation modeling study

Yuhong Cao
School of Management, Shanghai University, Shanghai, China

Jianxin You
School of Economics and Management, Tongji University, Shanghai, China

Yongjiang Shi
Institute for Manufacturing, University of Cambridge, Cambridge, UK, and

Wei Hu
School of Economics and Trade, Shanghai Urban Construction Vocational College, Shanghai, China

Received 5 September 2017
Revised 2 August 2018
9 November 2018
28 June 2019
Accepted 4 August 2019

Abstract

Purpose – This paper aims to make a systematic study on the factors that hinder the development of China's intelligent automobile manufacturing industry; based on comprehensive understanding of these obstacles and by optimization means, ultimately, the healthy and sustainable development of intelligent automobile manufacturing industry in China can be promoted.

Design/methodology/approach – Based on a questionnaire survey of intelligent automobile manufacturing listed companies in China, first, fuzzy semantic scale was adopted to collect respondents' choices, the fuzzy score function is used to calculate the fuzzy score value and these data are used as the basis for subsequent model analysis. Then, structural equation modeling (SEM) was adopted to analyze the causal relationship between influencing factors to explore the main hinder factors.

Findings – It is found that, in the short term, the backwardness of technological industrialization is the main reason leading to low permeability of intelligent automobile; in the medium term, the imperfect industrial R&D ability and the insufficiency of infrastructure are major causes for high manufacturing cost and low competitiveness of intelligent automobile manufacturing industry; in the long term, the lack of national policy and industrial strategic planning is the main factors affect intelligent automobile manufacturing cost and the industry competitiveness.

Practical implications – The research conclusion has important policy implications for promoting intelligent automobile manufacturing sustainable development. In recent years, China's intelligent automobile manufacturing industry has gradually stepped out of breeding period; therefore, the role of government should be gradually transformed from participants to managers and regulators. Considering the fact that intelligent automobile cost is very high, and still higher than the cost of fuel vehicle, government should focus on the issues such as improving R&D capabilities, infrastructure construction, policy framework system, legal system and technological industrialization. Specifically, in short-term planning, improving technological industrialization level is the key to development; in medium-term planning, policymakers should focus on the improvement of R&D capabilities and infrastructure; considering the long-term development, establishing appropriate national policies and dealing with the adverse impact of imperfect strategic planning are the most sensible choice.

Originality/value – This paper analyzes the factors that hinder the development of China's intelligent automobile manufacturing industry for the first time, and provides the basic logic of integration factors at

Chinese Management Studies
Vol. 14 No. 1, 2020
pp. 159-183

1750-614X
DOI 10.1108/CMS-09-2017-0250

different levels with the development of intelligent automobile to reveal the uniqueness and facts of China's economic development.

Keywords Intelligent automobile manufacturing industry, Development obstacle, Structural equation modelling, Urbanization, Transportation, Institute of electrical and electronics engineers

Paper type Research paper

1. Introduction

In recent years, with the increasement of car ownership and road mileage, a series of problems that cannot be properly solved by traditional cars are increasingly prominent such as traffic congestion, accidents, pollution and land resource shortage. The development of intelligent vehicle technology, which is regarded as an effective solution, has attracted much attention. American Institute of Electrical and Electronics Engineers (IEEE) predicts that the proportion of automatic driving vehicles will reach 75 per cent by 2040. The automobile transportation system will usher in changes, and the intelligent automobile may subvert the current operation mode of automobile transportation industry.

Inspired by a variety of preferential policies, such as *China's manufacturing 2025* and *China's manufacturing 2025-technical road map in key areas*, China's intelligent automobile manufacturing had a very rapid development, and the permeability of intelligent driving assisted driving or partial autonomous driving (DA/PA) stage achieved about 16 per cent in 2016. The cost of each automobile, which is driven by intelligent driving, including hardware, software, electronics and communications system, increased about 20000-30000 Yuan. Combined with the expected annual growth rate of 3 per cent, intelligent driving market share is expected to achieve 35 per cent in the next five years, and it will exceed 230bn Yuan in 2020. All these phenomena seem to indicate that intelligent driving is about to develop at high speed at present in the entire Chinese automotive transportation system. However, because China's involvement in intelligent automobile industry is relatively late, the gap between the competitiveness of China and Germany or China and the USA is still large. China's auto industry still has to overcome many obstacles if they want to get further development, such as social obstacles and technical obstacles. Some related studies pointed out that although China have a huge market space, the successful development of intelligent vehicle still depends on the strong support by government and related industries, in the areas of improving car networking infrastructure ahead, policy planning, appropriate rewards and incentives, etc. Currently, China is not sufficiently developed in these areas. In addition, the lack of industrial innovation capacity, inadequate cost control and backwardness of the infrastructure also are the expected challenges for the future development of Chinese intelligent automotive industry.

Under the circumstances that the global trade barriers are reduced, a large number of overseas intelligent automobile manufacturers with significant competitive advantages (such as Tesla and Google) enter Chinese market,as well as consumers have gradually matured and rationalized, and some issues (like energy, transportation and safety) have become increasingly prominent, smart car industry development still faces many unfavorable factors, which may come from the economic field or policy field or technology and environmental field (Shang, 2017; Xu, 2016; Wong and Lee, 2014; Wu, 2009). But the upgrading of overall competitiveness still faces many unfavorable factors that emerge from different fields, such as economic sector, policy sector, social sector, technical and environmental sector and others fields.

In recent years, some related literature has noted that the development of intelligent vehicles in China and Europe and the USA is facing unfavorable factors. Serra (2013) and Rodrigo *et al.* (2014) have examined the institutional environment, relevant laws and regulations, environment and infrastructure of the intelligent automobile industry. Li (2015), Xu (2015), Meyer (2014) and Hevelke (2014) pointed out that, in addition to reducing vehicle costs to boost public demand, the future development of intelligent automobile largely depends on manufacturer's technical level and R&D capability. Dong and Sun (2016) and Naoum *et al.* (2019) pointed out that the realization of intelligent manufacturing needs related industries in industry chain to achieve the same production level. Yao *et al.* (2014) pointed out that the intelligent manufacturing capacity and level of relevant industries in China's automobile manufacturing industry chain are generally low. Without cross-industry cooperation (cooperation of parts manufacturers, network operators, platform operators, content providers, service providers, and transportation management departments), it may not be possible to realize the transfer of intelligent automobile technological innovation achievements and industrialization. Xu (2015) proposed that the development and popularization of intelligent automobile not only need the integration of intelligent automobile industry itself, but also need cross-industry and cross-sectoral integration, and hence merging the elements in technical chain and industrial chain is the basis for sustainable development of intelligent automobile industry and the key point to enhance the overall competitiveness of China's intelligent automobile industry. Alam and Saini (2015) believe that rigorous testing standards and procedures are indispensable to ensure the reliability of intelligent technology. Zhang and Li (2009) pointed out that to enhance intelligent automobile penetration rate, manufacturers should think from the perspective of market consumers, that is, in addition to economic factors, security and comfort, other factors need to be considered either. Qi (2019) proposes that technical safety is the most important factor that people should consider. Based on the research of Etzion (2007) and Cachon and Kok (2010), Xu (2015) divides the hinder factors of intelligent automobile penetration into four categories: technical constraints (such as lack of safety and a well-established navigation database), infrastructure constraints (such as lack of human–car–road interconnection and information intelligent roads), business model restrictions (such as lack of insurance of technical failure insurance and customization and personalization) and safety regulatory restrictions (such as how to identify technical risks and car traffic tort liability; otherwise, intelligent automobile manufacturers will face excessive legal liability). Chu *et al.* (2019) believe that the improvement of infrastructure is the key to the development of smart cars.

It can be found from the above literature review that most existing research focus on qualitative description of intelligent automobile development or the constraints encountered in infrastructure and technical levels, and the largest proportion of literature only identifies the individual factors' adverse effects on the development of intelligent automobile industry. There are few literatures analyzed the influencing factors systematically and multi-angled, and less literature study on the interrelationship between various influencing factors. However, the comprehensive and in-depth discussion of the obstacles in different fields and the relationship between these obstacles not only help improve Chinese public's awareness and participation in intelligent automotive development, but also help Chinese Government to develop corresponding strategy. The comprehensive and in-depth discussion of the obstacles in different fields and the relationship between these obstacles not only help improve Chinese public's awareness and participation in intelligent automotive development, but also help Chinese Government to develop corresponding strategy.

Based on the structural equation modeling (SEM), this paper makes an empirical analysis of how different factors affect the development of China's intelligent vehicle industry. The research results show that policy factors (the lack and imperfect of national policies) are the main factor affecting intelligent vehicle development and other factors; the factors which lead to the lack of industrial R&D capabilities include the lack of cooperation between industry–universities–research institutes and safety supervision, especially the vague concept of safety supervision, leads to developers not knowing enough about the many issues involved in the process of *common control*, thereby reducing the effect of industrial R&D capabilities, this kind of effect is bigger than the impact of industry–university–research cooperation on industrial R&D capabilities, so to improve the R&D capability, priority should be given to improving the meaning and scope of safety supervision and the related supporting technologies needed; the impact of early planning on the development of intelligent vehicle mainly comes from its influence on the promotion of technology industrialization; the early planning itself does not directly affect intelligent vehicle industry development; because of the high manufacturing cost, the price of intelligent vehicle is somewhat beyond people's expectations, which seriously hinders the further development of the intelligent vehicle industry; therefore, effectively controlling the manufacturing cost will help promote intelligent vehicle industry to further development.

Compared with the previous researches at home and abroad, the contributions of this paper mainly include the following. First, this paper explores the obstacles of intelligent vehicle further development from multiple perspectives. Shang (2017), Shah *et al.* (2017), Meyer (2014) and Hevelke (2014) all made a qualitative analysis of the affecting factors; this paper is a quantitative study and it is more objective. In addition, the factor analyzed in this paper is more comprehensive, including not only the policy and technical, but also the environmental and industrial chains, and thus, it has more practical significance. Second, this paper draws on the idea of Balanced Scorecard; introduces the concept of multidimensional and mutual influence; and establishes a path analysis framework based on SEM. Under this framework, the obstacles from different fields and different levels have been investigated; how these influences produced have been examined; and how these factors made a mutual interaction and restriction have been tested. Based on this, policy suggestions to promote China's intelligent automobile industry development have been put forward. The research in this paper has a certain reference value for developing intelligent automobile in China and other countries; at the same time, it contributes to the further study of collaborative development theory. The paper's structure is arranged as follows: in Section 2, SEM establishment and research hypothesis setting are discussed; the questionnaire design and delivery, as well as the research methods and data sources, are described in Section 3; in Section 4, case analysis is provided; research conclusions and policy recommendations are given in Section 5.

2. Theoretical analysis and research hypothesis

Regarding the factors affecting China's intelligent automobile industry development and their relationship, based on the literatures related to industrial development (Joseph and Wilson, 2018), strategic management and competitiveness theory (Fang *et al.*, 2016; Wang *et al.*, 2016), this paper made a theoretical analysis and hypothesis deduction from the followings four dimensions and nine items.

2.1 Policy dimension factor research hypothesis

2.1.1 Lack of national policy (P1). Without effective national policy planning, or different policy planning cannot be well coordinated, it may hinder the development of intelligent automobile industry (Xu, 2015). Lack of national policy made it difficult to promote the effective coordination of relevant departments and improve technology chain, industrial chain and value chain; it also brought difficulty to build a complete intelligent network of automotive eco-chain, for example, a sound legal and regulatory system (Gibson, 2015). The lack of relevant policies will result in the inability to effectively integrate the existing social resources, prevent the automotive industry, communications industry, the Internet industry, the transportation sector, and universities and scientific research institutions from forming a true alliance, thereby hindering a win-win cross-sector innovation development model formation (Li, 2015). Thus, this paper presents the following hypothesis:

H1. Lack of national policy has a significant direct effect on industry–university–institute, cross-industry collaboration and laws and regulations.

2.1.2 Lack of early strategic planning for intelligent automobile manufacturing (P2). Government should formulate national strategic planning in the early stages of intelligent automobile development to clear objectives, timetables and technical lines and form a certain consensus. It should also provide financial support to accelerate the transformation of key innovative technology at different times. Especially, government should invest more in the areas related to the connection of traffic environment, to establish a favorable environment for the development and rapid application of intelligent network vehicles from the perspective of building greater traffic environment (Li, 2015). Reasonable government planning and leadership can form an efficient industry-university-research cooperation mechanism, promote resource sharing, and promote large-scale intelligent connected car demonstration projects, finally, a win-win cross-disciplinary innovation and development model can be formed (Dai and Li, 2015). Thus, this paper presents the following hypothesis:

H2. Lack of a reasonable early intelligent automobile strategic planning has a significant direct effect on technological industrialization and cost control.

2.2 Environmental dimension factor research hypothesis

2.2.1 Imperfect infrastructure (E1). Intelligent automobile does not just mean automatic driving; it refers to the automatic driving based on configuration of various types of smart sensors and intelligent road (Weiß, 2011). To achieve this function, intelligent automobile should be equipped with a comprehensive navigation information database: first, including the information of domestic real-time highway, national road, city road, various units and various service facilities (food and entertainment, gas stations, tourist attractions, accommodation, etc.); second, with GPS satellite positioning system to accurately locate the vehicle's current location, match the information with navigation information in database and determine the follow-up trip according to the match result; third, it needs to be equipped with a real-time road condition system, in which the traffic control center timely feeds back the real-time road conditions of each road section, such as construction, accidents, traffic jams, etc., and provides the driver with suggestions for changing the driving route in advance. In addition, it is also necessary to configure vehicle collision avoidance system (including radar detection system, vehicle emergency control system and information sharing system), wireless communication system, automatic driving control system, etc. (Zhang and Li, 2009). Therefore, the cost of intelligent vehicle includes the vehicle itself and related test and test expenses. In addition to increasing the R&D process and reducing the cost of components through upgrading the technology level, domestic cost control can also learn from the experience of H0QISNS0 project in Germany, and establish a database containing different driving scenarios to find more effective methods for testing. Perfect intelligent automobile infrastructure can increase productivity and energy efficiencies while reducing overall costs. Thus, this paper presents the following hypothesis:

H3. Imperfect intelligent automobile infrastructure has a significant direct effect on cost control of intelligent vehicle manufacturing.

2.2.2 Lack of laws and regulations (E2). It is more difficult to improve vehicles safety performance through technology alone; we should also promote the establishment and improvement of relevant technical standards and industry standards in intelligent automobile development process. We should also develop and improve the intelligent network of automotive-related technical standards and industry standards system around the intelligent network of automotive architecture and related industry development goals, and actively participate in the development of relevant international standards. Fu Bingfeng, a minister of Planning department of FAW group, believes that the construction and further improvement of standard regulations is an important link in the development of intelligent networked vehicles, and also a necessary condition for industrialization (2017). Only focusing on vehicle information security technology development and the formulation and implementation of related standards, laws and regulations can ensure the sustainable development of intelligent automobile industry (Weiß, 2011). Thus, this paper presents the following hypothesis:

H4. Lack of laws and regulations has a significant direct effect on cross-industry synergy and technological industrialization.

2.3 Industry chain dimension factor research hypothesis

2.3.1 Cross-industry synergy lag (C1). Different from the traditional automobile enterprises to strictly control the upstream and downstream industrial chain, in the development process of smart cars, the coordinated development between different industries has become crucial. Gao Wen, a professor at Peking University, believes that, the perfect cross-industry collaboration not only contributes to the research and development of smart car technology, but also promotes its industrialization level and improves market penetration (2017). On the contrary, if there is lack of mutual coordination among the industry, vehicle manufacturers, parts suppliers, mobile operators, research institutions, government departments and industry associations and other organizations, which makes the industry unable to make a whole plan, this will affect China manufacturing intelligent automobile's later attained advantages (Xu, 2015). Thus, this paper presents the following hypothesis:

H5. The lag of cross-industry collaboration has a significant direct effect on the research and development of smart car technology and its industrialization.

2.3.2 Lack of industry–university–institute cooperation (C2). To promote intelligent transportation industry level and strengthen intelligent transportation technology innovation system construction, the most effective way is to adapt industry–university–institute cooperation co-innovation (Wu, 2009). A complete cooperation of industry–university–institute can not only combine backbone vehicle enterprises, research institutions and universities to develop the core resources of intelligent automobile industry, but also actively promote the transfer and industrialization of intelligent automobile technology innovation. Simultaneously, cross-industry and cross-sectoral cooperation in government, industry and research also contributes to the overall planning of road and communication infrastructure construction and the improvement of supporting management mechanisms (Yao *et al.*, 2014). Thus, this paper presents the following hypothesis:

H6. The lack of industry–university–institute cooperation has a significant direct effect on the research and development of smart car technology and the infrastructure.

2.4 Technology dimension factor research hypothesis

2.4.1 Insufficient R&D capacity (T1). For the development of intelligent automobile, R&D support provided by government and enhancement of cooperation and innovation ability of industry–university–institute are the important factors which will contribute to the upgrading of intelligent automobile technology level (Fontelap and Mielgo, 2007; Chen, 2012). If domestic industry lacks R&D capacity, it may lead to import main parts or accessories of intelligent automobile from overseas, which will increase expenditure cost indirectly. On the contrary, enhancing domestic industry R&D level can significantly reduce the manufacturing cost and enhance the overall competitiveness level of the industry (Wu, 2009). Thus, this paper presents the following hypothesis:

H7. The lack of industry R&D capacity has a significant direct effect on manufacturing cost.

2.4.2 Lower technological industrialization level (T2). The operation of intelligent vehicles requires supporting transportation infrastructure, and the current infrastructure construction will no longer be applicable. Therefore, the continuous improvement of the industrialization of intelligent vehicles can greatly promote the construction and improvement of road traffic (Xu, 2015). At the same time, the industrialization of intelligent driving technology, especially the industrialization of key technologies in key areas, can realize intelligent manufacturing and digital management of production processes, which not only improves the level of product consistency, but also reduces manufacturing costs (Shah *et al.*, 2017). If R&D institutions do not have appropriate technology transformation measures and plans and neglect the transfer of results according to market demand, it may lead to the separation of R&D and application, which will weaken the cooperation within and outside the industry, and ultimately affect the construction of cross-industry industrial chain of intelligent vehicles (Roeglinger, 2017). Thus, this paper presents the following hypothesis:

H8. Lower technological industrialization level has a significant direct effect on manufacturing cost and infrastructure, and may reduce the level of cross-industry collaboration.

2.4.3 Inadequate cost control (T3). Strong cost control ability is a very important factor for reducing vehicle cost and improving market penetration. However, excessive cost control, especially the reduction of technology R&D cost, will reduce the overall R&D level and ultimately affect the level of industrialization (Rodrigo *et al.*, 2014). It should be noted that the quality of the main parts and components of smart cars in China is not up to the first-class international level, so the lack of high-quality main parts and components will greatly increase the manufacturing cost of smart cars, while the lack of professional maintenance companies will also increase the operating cost of enterprises, which will ultimately affect the operation mode of smart car manufacturing enterprises. At the same time, the lack of professional maintenance companies will also increase the operating cost of enterprises and ultimately affect the operation mode of intelligent automobile manufacturing enterprises (Liu, 2015). Thus, this paper presents the following hypothesis:

H9. The inadequate cost control capabilities have a significant direct effect on R&D, and may reduce the level of technological industrialization.

Based on theoretical analysis and hypothesis deduction, the structural equation theoretical model has been built (see Figure 1).

From Figure 1 and related hypotheses, the following possible conclusions can be drawn. First of all, in this model, cost control ability (T3) is the main dependent variable; early strategy planning (P2) and industry–university–institute cooperation (C2) are the main independent variables, that is, the lack of P2 and C2 is the reason for the change of other factors; and low-cost control (T3) is the result of all factors eventually lead to. Second, early strategy planning (P2) will have a direct impact on cost control (T3), and have an indirect impact on cost control through variables such as cross-industry collaboration, R&D level and intelligent driving regulations, and hence these variables can be considered as mediators variables for early strategy planning (P2). Similarly, in the theoretical model, other factors may also act as independent or dependent variables or intermediary variables in the interaction.

3. Samples and research methods

3.1 Questionnaire design and delivery

All the data used in this study are from the questionnaire survey on the factors affecting intelligent automobile manufacturers' development. Because the large-scale survey of company senior managers is very difficult, it is not easy to conduct a complete random sampling in China. Drawing on the research methods of Zhang and Li (2009) and Steden (2011), this paper adopts the principle of convenient sampling. First, after reviewing the literature on industrial development, intelligent automobile manufacturing and industrial competitiveness, the initial questionnaire was designed according to the above theoretical framework. Then, in the process of modifying the questionnaire, the necessary steps such as expert review, simulated test filling, face interview and preliminary test were taken to

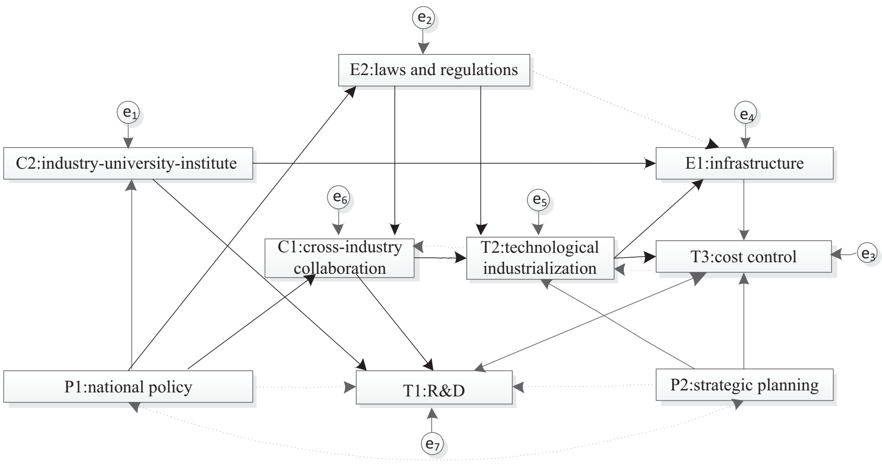

Figure 1.
Schematic diagram of the theoretical model

ensure questionnaire quality. To improve the response rate, this research questionnaire is mainly for the management personnel of intelligent automobile manufacturing enterprises. A total of 430 questionnaires were issued and 243 were returned; among them, 197 were valid. The actual recovery rate was 45.81 per cent. The total number of questionnaires recovered and the actual recovery rate met the research requirements (Yao *et al.*, 2014). According to this research's statistics, a total of 67 listed companies across the country were involved in the production of intelligent automobile, and all questionnaires were distributed among these 67 companies which ensured research findings are highly targeted. Most of the sample companies are large and medium-sized enterprises, and the company with more than 500 employees accounted for 55.3 per cent. The majority of the respondents were middle and senior managers which accounted for 85.4 per cent, and 76.9 per cent of the respondents had been in the company for more than 3 years. This indicates that the respondents have rich work experience and are familiar with the basic content, and hence the accuracy of their responses will be higher.

To assess the potential response bias, the basic characteristics of early responders and late responders were compared. By comparing the similarities and differences between the two in terms of enterprises size and various factors, it is possible to assess whether the potential response bias exceeds an acceptable level. Of the total of 197 valid questionnaires, 128 (about 65 per cent) were directly collected without being urged – this article defines it as an early responder, and the remaining 69 were collected under urge via phone or e-mail after the predetermined deadline, which is defined as late responder (for specific samples' demographic statistics, refer to Appendix 2).

The independent chi-square test (p = 0.3810) indicates that there is no significant difference in the early and late responders. The mean value of lack of national policies, lack of early planning, imperfect infrastructure construction, lack of smart driving laws and regulations, lag in cross-industry collaboration, lack of cooperation between industry–universities–research institutes, insufficient R&D capabilities, lower technological industrialization level, lack of cost control, imperfections of after-sales service and lack of safety supervision given by the early responders are 6.0875, 6.2684, 5.6632, 6.0242, 6.3314, 6.0934, 6.3224, 5.4432 and 6.0531, respectively; the mean value of these factors given by the late responders are 6.2287, 6.3362, 5.7641, 6.2353, 6.0332, 6.1234, 6.0924, 5.5422 and 6.4521, respectively (the p value of these factors obtained by the t-test is 0.2207, 0.8236, 0.7641, 0.5623, 0.4632, 0.3234, 0.2932, 0.3422 and 0.2542, respectively). There were no significant differences between them, which indicates that there is no serious self-selection problem in the sample of this paper.

3.2 Research methods and data sources

For the theoretical model proposed in this paper, the SEM is a suitable testing tool. The traditional path analysis consists of multiple linear regression equations. It can only test the relationship between specific index variables (direct observation variables), whereas the SEM integrates path analysis and factor analysis, which can simultaneously detect the relationship between the observed variable, the latent variable and the error variable in the model. At the same time, it also can obtain the direct effect, indirect effect and total effect of the independent variable on the dependent variable. Therefore, the SEM is a more effective test method for the hypothesis put forward in this paper. To guarantee the practical characteristics of the research, all the factors and data in the theoretical model are obtained through investigation. Because all influencing factors belong to observed variables, the theoretical model in this paper can be regarded as the path analysis, and because of the two-way causal relationship among the factors, for example, the two-way causal relationship between C_1 and T_2, so the theoretical model belongs to non-recursive model. This article used AMOS22.0 for path analysis.

Before experts judge the status of indicators, they should read listed companies' annual report and enterprise development situation analysis report first, so, most indicators level was evaluated based on quantitative data, for example, R&D capacity, experts will judge its level based on R&D investment and patent quantity. The data needed by this article are from the listed automobile manufacturing enterprises involved in intelligent automobile manufacturing. Because data of listed companies have usually been audited and supervised by independent third parties, they are highly representative and with high accuracy.

The data measurement method is to modify traditional five-point Likert scale into fuzzy semantic scale, that is, use fuzzy mathematical characteristics in fuzzy theory to describe the different semantic vocabulary variables, such as

(1) very much agree (5);
(2) agree (4);
(3) common (3);
(4) do not agree (2); and
(5) very much disagree (1).

After that, under the condition that the total percentage of semantic vocabulary variables is 100 per cent, according to the description of influence factors, and referring to the description of influence factors in the existing literature, the corresponding percentage scores are given to each semantic vocabulary variables. Finally, the fuzzy membership score is weighted by fuzzy membership function and used as the data for model analysis (for specific information collection methods, refer to Appendix 3).

The problem of common method variance (CMV) is easy to appear when all questions are filled by the same people in questionnaire survey. A common method for detecting homology deviations is the Harman-based one-factor detection method recommended by Podsakoff and Organ (1986): all the questionnaire items are factored together, and the first principal component obtained when not rotated reflects the amount of CMV. In this paper, all the obstacles factors in the questionnaire are factored together. The first principal component obtained when not rotating accounts for 40.32 per cent of the load, and does not account for the majority, so the homology deviation is not serious.

4. Empirical results and analysis

4.1 Descriptive statistical analysis of measurement models

The descriptive statistics and correlation analysis of the variables are shown in Tables I and II, respectively. This paper first conducted a multi-collinear diagnosis of the independent variables, and the analysis result is proved by collinearity test. Then, the data were analyzed by descriptive statistics and correlation analysis. According to the results shown in Table II, we can know that there is a significant correlation between all the other variables and T2 (technology industrialization level).

4.2 Structural equation modeling path analysis results

The analysis results of theoretical model are shown in Figure 2 and Tables III-Table VI. Results in Table III show that, except five paths (C1 → T1, P2 → T3, T2 → T3, B2 → T3, C1 → T2) that did not reach the significance level of 5 per cent (where C1 → T1, C1 → E1

Variable	Implication	Mean	Variance	Minimum value	Maximum value
P1	National policy lacking	1.211948	1.116871	0	3.22
P2	Strategic planning lacking	1.142231	1.021338	0	3.21
T2	Low technological industrialization level	1.179123	1.002126	0	3.17
E2	Laws and regulations lacking	1.171343	0.889657	0	3.24
C1	Cross-industry collaboration lacking	0.695322	0.862818	0	2.64
T1	Insufficient R&D capacity	0.801321	0.768902	0	2.98
C2	Industry–university–institute cooperation lacking	0.837645	1.091704	0	3.68
E1	Imperfect infrastructure	0.501425	0.960213	0	3.77
T3	Low cost control level	1.049204	0.901122	0	3.09

Table I.
Descriptive statistics of major variations

Variable	P1	P2	E1	E2	C1	C2	T1	T2	T3
P1	1.0000								
P2	0.6205*	1.0000							
E1	0.3601*	0.3704*	1.0000						
E2	0.0721	−0.0014	0.2398*	1.0000					
C1	0.3247*	0.2417*	0.2899*	0.2798*	1.0000				
C2	0.0342	0.0899	0.3698*	0.4101*	0.3099*	1.0000			
T1	0.2703*	0.4476*	0.4589*	0.2715*	0.3781*	0.1299	1.0000		
T2	0.2443*	0.2711*	0.3102*	0.3699*	0.5401*	0.2306*	0.5948*	1.0000	
T3	0.0631	0.1029	0.1035	0.5068*	0.2092*	−0.0141	0.3706*	0.2713*	1.0000

Note: *Represents a significant level of 5%

Table II.
Correlation analysis between variables

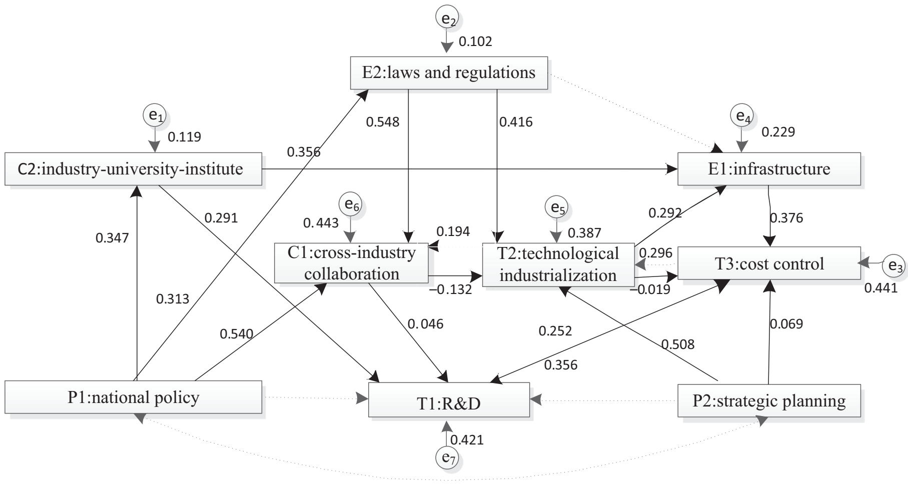

Figure 2.
Path analysis results of theoretical model

Table III.
Structural equation model path coefficient regression results

Structure model path		Standardized path coefficients	Standard error	Critical value	p-Value
P1	→ E2	0.313	0.078	3.480	***
E2	→ C1	0.548	0.067	7.075	***
P1	→ C2	0.347	0.077	4.020	***
C2	→ T1	0.291	0.072	3.61	***
P1	→ C1	0.540	0.061	7.414	***
P2	→ T2	0.508	0.074	6.492	***
E2	→ T2	0.416	0.079	4.672	***
T1	→ T3	0.356	0.065	2.732	***
C1	→ T2	−0.132	0.068	−1.820	0.067
T2	→ C1	0.194	0.071	3.225	***
T2	→ E1	0.292	0.078	3.705	***
C2	→ E1	0.356	0.073	4.413	***
T2	→ T3	−0.019	0.075	−0.227	0.801
T3	→ T2	0.296	0.067	2.103	***
P2	→ T3	0.069	0.075	0.873	0.364
E1	→ T3	0.376	0.065	4.943	***
C1	→ T1	0.046	0.105	0.545	0.566
T3	→ T1	0.252	0.088	2.876	0.003

Note: ***Indicates $p < 0.001$

Table IV.
The standardized total effect of external variables on internal variables

Variable	P2	P1	E2	C2	C1	T1	T2	E1
E2	0.000	0.309	0.000	0.000	0.000	0.000	0.000	0.000
C2	0.000	0.347	0.000	0.000	0.000	0.000	0.000	0.000
C1	0.000	0.602	0.072	0.077	0.013	0.255	0.000	0.000
T1	0.000	0.241	0.276	0.305	0.0584	0.015	0.000	0.000
T2	0.507	0.013	0.282	−0.013	−0.134	−0.034	0.000	0.000
E1	0.143	0.132	0.079	0.353	−0.042	−0.013	0.301	0.000
T3	0.126	0.119	0.161	0.179	−0.005	0.146	0.085	0.374

Notes: Column is external variable; line is internal variable

Table V.
The standardized direct effect of external variables on internal variables

Variable	P2	P1	E2	C2	C1	T1	T2	E1
E2	0.000	0.313	0.000	0.000	0.000	0.000	0.000	0.000
C2	0.000	0.347	0.000	0.000	0.000	0.000	0.000	0.000
C1	0.000	0.540	0.000	0.000	0.000	0.252	0.000	0.000
T1	0.000	0.000	0.000	0.302	0.0585	0.000	0.000	0.000
T2	0.511	0.000	0.416	0.000	−0.138	0.000	0.000	0.000
E1	0.000	0.000	0.000	0.356	0.000	0.000	0.312	0.000
T3	0.074	0.000	0.000	0.000	0.000	0.000	−0.025	0.376

Notes: Column is external variable; line is internal variable reached a significant level of 10 per cent), other pathways reached 5 per cent significance level.

In terms of model fitting degree (see Figure 2), Chi-square = 42.46, p = 0.147 > 0.05, GFI = 0.941 > 0.90, CFI = 0.965 > 0.90, RMSEA = 0.041 < 0.05. The results show that theoretical model fits the sample data well. The overall model's ability to interpret endogenous variables is as follows: laws and regulations (R^2 = 0.102), industry–university–institute cooperation (R^2 = 0.119), R&D (R^2 = 0.421), cross-industry collaboration (R^2 = 0.443), technological industrialization (R^2 = 0.387), infrastructure (R^2 = 0.229) and cost control (R^2 = 0.441).

4.3 Analysis of the causal relationship between influencing factors

First, analyze the path that does not reach 10 per cent significance level, and the results are shown in Table III and Figure 2. First, previous studies suggest that technological industrialization can significantly affect cost control. Weiß (2011) pointed out that low-level technological industrialization will increase imported intelligent systems price, and thus improve the overall cost of intelligent automobile. However, the empirical results in this research show that low-level technological industrialization does not have a significant direct impact on the overall cost of intelligent automobile (p = 0.801), but only produce an indirect impact through infrastructure (the path is T2 → E1 → T3; the path coefficient is 0.292 × 0.376 = 0.109). That is, because low-level technological industrialization led to imperfect infrastructure, and imperfect infrastructure will improve the cost of intelligent automobile, low-level technological industrialization indirectly improves intelligent automobile cost. Second, in terms of the relationship between strategy planning and cost control, lack of early strategic planning does not affect inadequate cost control (p = 0.364) significantly; this result is inconsistent with many previous documents. Even though lack of early strategic planning can affect inadequate cost control, according to path coefficient, the impact of infrastructure on cost control is higher than on early strategy planning. Therefore, in terms of efficiency and effectiveness, improved infrastructure can reduce intelligent automobile cost significantly. As for the impact of early planning on the development of intelligent automobile, it mainly comes from its impact on the level of technology industrialization. Therefore, through the interrelationship's analysis among influencing factors, it is possible to clarify that strategy planning is not a major factor which hinders China's intelligent automobile development.

From the paths which reach 10 per cent significance levels, we get the following result. First, national policy is the direct cause of problems including industry–university–institute cooperation, laws and regulations and cross-industry coordination, and also the indirect cause of other problems. However, the direct effect of national policy on cross-industry

Variable	P2	P1	E2	C2	C1	T1	T2	E1
E2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C1	0.000	0.059	0.064	0.073	0.0163	0.003	0.000	0.000
T1	0.000	0.224	0.276	0.004	0.001	0.013	0.000	0.000
T2	0.000	0.011	−0.125	−0.012	−0.004	−0.035	0.000	0.000
E1	0.152	0.129	0.084	−0.005	−0.039	−0.011	0.000	0.000
T3	0.044	0.115	0.153	0.175	−0.005	0.153	0.114	0.000

Notes: Column is external variable; line is internal variable

Table VI. The standardized indirect effect of external variables on internal variables synergy is higher (path coefficient = 0.540), indicating that when the national policy obtains a standard deviation improvement, cross-industry synergy lag can be improved by 0.540 standard deviation units. This effect is higher than national policy on laws and regulations (path coefficient = 0.313) and national policy on industry–university–institute cooperation (path coefficient = 0.347). Second, in terms of R&D capacity, the empirical results show that industry–university–institute cooperation is the main affect factor, this conclusion is consistent with practice. Third, in terms of technology industrialization (T2), the research shows that there are many factors affecting it, such as: the lack of early planning (P2), the lack of laws and regulations (E2), the lack of cross industry coordination (C1) and the lack of safety supervision (B2), but P2 is the root cause which the technology industrialization level lies in. This result is beyond our expectations, because many literatures point out that R&D capability is the major factor limiting technology industrialization. For this result, this paper argues that the lack of strategic planning will limit decision-makers' perception on market and technology application direction, and its effect will be higher than that of R&D. Therefore, it is the foundation for China to enhance the level of technology industrialization to carry out strategic planning from the national level and formulate clear objectives and technical routes. Finally, based on infrastructure analysis, this paper found that the main factor affecting infrastructure is industry–university–institute cooperation, rather than the technology industrialization, as also pointed out in previous literatures. The explanation for this is that the lack of industry-university-research cooperation may cause local governments to lag behind in infrastructure construction due to incomplete construction plans or construction plans, and this effect will be higher than the impact caused by the low level of technological industrialization. Therefore, the key for the Chinese government to solve the problem of local infrastructure is to establish relevant research platforms or build industrial think tanks, and make detailed planning of industrial development strategies and measures that government departments should take.

4.4 Path analysis of the interaction between factors

In addition to exploring the path coefficients and significance among factors, we also need to analyze the action path among them. This will help decision-makers to plan for intelligent automobile's sustained development.

First of all, the most important direct factor that leads to imperfect infrastructure is the lack of cooperation between industry, universities and research institutes ($C2 \rightarrow E1 = 0.356$). Therefore, in theory, decision-makers can take in hand upgrading the level of cooperation between industry, universities and research institutes as the focus of short-term development. In addition, it is worth noting that the improvement of technical industrialization ($T2 \rightarrow E1 = 0.292$) is also worthy of the attention of policymakers. The improvement of one standard deviation unit infrastructure can increase the infrastructure level by 0.386 standard deviation units, which is equivalent to 82 per cent of the impact of cooperation between industry, universities and research institutes. Therefore, in terms of intelligent automobile manufacturing short-term planning, decision-makers can focus on the improvement of cooperation between industry, universities and research institutes and technical industrialization.

Second, imperfect infrastructure is the main reason leading to high intelligent automobile's cost. In theory, lifting one standard deviation unit of infrastructure level can reduce 0.376 standard deviation units manufacturing cost. Even higher than the improvements of R&D capacity on manufacturing costs 0.099 ($T1 \rightarrow C1 \rightarrow T2 \rightarrow T3 = 0.101$, $T1 \rightarrow C1 \rightarrow P2 \rightarrow E1 \rightarrow T3 = 0.002$, $0.101\text{-}0.002 = 0.099$). Therefore, in terms of intelligent automobile manufacturing medium-term planning, decision-makers can focus on the improvement of R&D ability and infrastructure.

In terms of intelligent automobile manufacturing long-term development, previous literature has pointed out that we must provide importance to improve national policies, including establishing competent authorities, right and responsibilities coordination among departments, development planning and corresponding law. This view is confirmed in the research. That is, lack of national policy does lead to other problems and indirectly affect cost control through other factors. By calculation, we found that one unit standard deviation national policy improvement can improve 0.085 standard deviation units cost control level ($P1 \rightarrow C2 \rightarrow E1 \rightarrow T3 = 0.048$, $P1 \rightarrow E2 \rightarrow T2 \rightarrow E1 \rightarrow T3 = 0.013$, $P1 \rightarrow C1 \rightarrow T2 \rightarrow E1 \rightarrow T3 = -0.008$, $P1 \rightarrow C2 \rightarrow T1 \rightarrow C1 \rightarrow T2 \rightarrow E1 \rightarrow T3 = -0.0004$). In addition, previous literature also points out that the role of strategy planning in other intelligent automobile manufacturing countries mainly impacts the technology industrialization and cost control. In this paper, regardless of $P2 \rightarrow T3$ path or $P2 \rightarrow T2 \rightarrow T3$ path, all are not significant, so the impact of the above path is statistically zero. However, it should be noted that, from a long-term perspective, each standard deviation unit improvement of P2 can reduce 0.056 standard deviation units manufacturing cost control ($P2 \rightarrow T2 \rightarrow E1 \rightarrow T3$), the influential impact being equivalent to 56 per cent national policy impact. Therefore, in terms of long-term development, we should pay more attention to the establishment of national policy and appropriate framework system; at the same time, we should also properly cope with the adverse impact of lacking strategy planning on intelligent automobile manufacturing development.

5. Research conclusions and policy recommendations

5.1 Research conclusions

To promote China's intelligent automobile manufacturing development and enhance its overall competitiveness, we need to have a clear quantitative understanding of the hinder factors. To deepen analysis of these factors and their relationship, based on the sample of intelligent automobile manufacturing listed companies, this paper analyzes the factors that hinder the development from aspects of policy, environmental, industrial chain construction and technical. From the above empirical results and analysis, the following information can be obtained.

5.1.1 Policy factors. Lack of national policy is the main factor affecting the development of intelligent automobile. It is not only the direct cause of factors such as industry–university–research cooperation, laws and regulations and cross-industry synergy, but also the main reason that affects other factors, and finally indirectly affects cost control through other factors. Therefore, *H1* has been confirmed. However, *H2* has not been fully confirmed; early strategic planning has a low degree of direct and indirect impact on inadequate cost control, but the empirical results show that early strategic planning has a high degree of influence on industrialization level, which is the most important factor affecting the technology industrialization level of China's intelligent automobile. Therefore, in terms of the development plan, policymakers should pay attention to both national policies and appropriate framework systems. At the same time, they should also properly cope with the adverse effects of the lack of early development plans on the manufacturing development.

5.1.2 Environmental factors. H3 and *H4* have been confirmed. The social environment for the development of smart cars is not yet available, with the imperfect laws and infrastructure. This is not a problem that the automotive industry can solve; it needs government's top-level design and strategic planning. At the same time, empirical research also found that the lack of infrastructure is greatly affected by the cooperation of industry–universities–research institutes. The reason is that the lack of industry–universities–research institutes may cause the local government to lag behind the possible infrastructure construction for the lack of perfect planning, and this effect will be higher than the influence brought about by the low level of technical industrialization. Although infrastructure is mostly affected by other factors, it has a huge impact on costs improvement. Therefore, it is necessary for policymakers to focus on the construction of research platforms or industry think tanks, detailed plans for industrial development strategies and layouts, etc., which can be the first choice for improving local infrastructure issues.

5.1.3 Industry chain factors. H5 and *H6* have been confirmed. The lack of appropriate cross-industry synergy and industry–university–research cooperation will directly or indirectly affect other influence factors. For example, form the empirical results we can know that cross industry synergy and industry–university–research cooperation have a positive impact on the technical industrialization level, cost control and infrastructure. At the same time, it is also found that the lack of industry–university–research cooperation is the main factor affecting the lack of infrastructure. Unlike traditional automotive companies that strictly control only the upstream and downstream industrial chains, the coordinated development of different organizations has become the key to smart automotive companies, because whether it is an automotive network or artificial intelligence, it is necessary to develop technology alliances to achieve industrial transformation and upgrading. At the same time, the empirical evidence also shows that the government's guiding role in industrial integration and coordinated development through policy and strategic planning are indispensable, mainly because intelligent automobile involves the application of lots of new technologies, such as artificial intelligence, information communication, satellite positioning and navigation, big data and cloud computing. It is difficult for the automobile manufacturing industry to carry out such a large-scale cross-border integration in the short term by virtue of its own strength.

5.1.4 Technical factors. H7 and *H9* have been confirmed. *H8* has not been confirmed. The research found that low-level technology industrialization does not directly affect the cost of automobile manufacturing, it only indirectly affects cost through the infrastructure, this also shows from another angle that in addition to improve the technical level, cost control can also be performed from multiple perspectives. Technical factors are the most intricate of all the factors affecting the automobile manufacturing industry. In this study, we also found a slightly different conclusion from previous studies: the main factor that affects the technology industrialization level is not the R&D capability, but the lack of the early planning. The reason for this result may be that in the current development practice, the lack of strategic layout and planning for industry development will limit the decision-makers' perception of the direction of market and technology applications, and the effect is even higher than the lower R&D level.

5.2 Policy implications

These research conclusions have important policy implications for promoting intelligent automobile manufacturing sustainable development. In recent years, China's intelligent automobile manufacturing industry has been greatly developed; the industry has gradually matured, and the role of government should gradually shift from early players to current managers and regulators. Considering the fact that intelligent automobile cost is very high and the price of intelligent automobile is still higher than that of fuel vehicle, to promote the sustainable development of intelligent automobile manufacturing industry, government should focus on the issues such as improving R&D capabilities, infrastructure construction, policy framework system, legal system and technological industrialization. Specifically, action can be taken from the following aspects.

5.2.1 In terms of short-term development of intelligent automobile manufacturing. The resources of scientific research institutions should be integrated and optimized, and the integration of government, industry, university and research should be actively promoted, such as speeding up the construction of research center of intelligent driving engineering technology, accelerating the construction of key laboratory of intelligent driving, establishing innovative research and development platform, strengthening the construction of academician workstation, realizing major breakthroughs in key common technologies through multi-type alliances and then driving the rapid development of intelligent automobile industry. On the basis of alliance, an innovative operation system led by core manufacturing enterprises will be formed. A platform for cooperation among innovators should be provided, so that they can quickly and accurately find organizations complementary to their own strengths, carry out efficient cooperative R&D activities, realize the integration and optimal allocation of all kinds of innovative resources in the ecosystem and enable innovative resources to flow freely between different regions.

The transformation of innovation achievements should be accelerated and the integration of technology, market and capital should be promoted. The low conversion rate of autopilot technology achievements is still a prominent shortcoming in the development of China's smart automobile industry. The research achievements of R&D institutions lack the connection with manufacturing enterprises. Even if there are some good technical achievements, they are often not mature enough because of the lack of testing links, and the companies are afraid of taking risks, so the production design is very cautious, resulting in many results being shelved. Getting through the "transformation channel" to make autopilot technology achievements no longer constrained is the key to the development of the smart car industry. Whether it is a university, a scientific research institute or an automobile manufacturing enterprise, the research direction should focus on market application. The government should adopt post-subsidy and other means to support the transformation of results, encourage enterprises to actively participate in the test and open up the channels for the transformation of scientific and technological achievements.

5.2.2 In terms of medium-term planning of intelligent automobile manufacturing. The regulations for the development of smart cars should be improved. In accordance with the principle of "comprehensive planning and moderate advancement", we should actively carry out the construction of a comprehensive standardization system and formulate uniform standards for smart car vehicle terminals, communication protocols, test evaluation, information security and other key technologies. Also, the revision of the road traffic regulations applicable to smart cars should be actively carried out, along with promoting the implementation of the amendments to the Law on Road Traffic Safety and other provisions; improving the laws and regulations on the identification of traffic accidents; and building smart cars and intelligent transportation laws in line with national conditions. The protection of intellectual property rights and patented technologies in the smart car industry should be strengthened, and the intelligent network link information and data security management mechanism should be improved.

Infrastructure construction should be strengthened. Infrastructure transformation is the basis for the rapid development of intelligent driving, and it is also the key point to greatly reduce the cost of automatic driving. New infrastructure construction needs new ways; the key elements of car, road, governance and society should be coordinated; and this kind of synergy mechanism should be guided by the government. At present, China has issued the documents such as *new generation artificial intelligence development plan*, *artificial* *intelligence three-year action implementation plan* and *traffic engineering technology 2035 strategy*; these documents are clearly deployed for the intelligent driving city and smart city involved in the intelligent transportation strategic layout. In the future, we should speed up the demonstration application of smart cars based on multiple scenarios, combine the use scenarios of smart cars, explore the construction of road traffic scene libraries and provide basic support for the development test, safety evaluation and capability evaluation of smart car products.

5.2.3 In terms of long-term planning for intelligent automobile manufacturing. The system innovation mode should be improved. In the field of intelligent driving, China is expected to achieve *curve overtaking*. At present, China's intelligent automobile industry needs to work hard to establish a technological innovation system, formulate technological innovation strategy and promote the rapid development of the industry through leading innovations in all aspects. First of all, to promote enterprises to become the core of the intelligent driving technology innovation ecosystem, the pace of system technology innovation should be accelerated, and the content of intelligent driving technology should be increased. Second, innovation in manufacturing technology and mode is required to improve the quality of intelligent vehicles. Third, business model innovation should be promoted. The future automobile industry will be an industry combining automobile and internet. The more intelligent and customized manufacturing development direction will bring a diversified automobile business model. The traditional way of "introducing automobile products and then competing sales" may be replaced in the near future.

The market consumption environment should also be improved. The increase in global car ownership and the diversification of consumer demand will also greatly promote the rapid development of the global smart car market. Therefore, per capita disposable income also affects the development of the smart car industry. At the same time, the smart car industry can promote the development of the overall industrial chain. The economic value and position created can increase per capita disposable income. The increase in per capita disposable income will further promote the sales of automobiles, and eventually form a benign ecological cycle. In terms of income level, China's per capita disposable income level has shown a sustained and steady growth trend, and there will be no sharp increase or decrease. At present, China's per capita disposable income is one-ninth of that of the USA, one-eighth of Germany and Japan and one-fourth of that of South Korea. There is still much room for development. On the other hand, the concept of Chinese consumers has always been conservative compared with other countries. We can draw lessons from the mature experience of foreign countries, set up a complete credit evaluation system by the government, bank and insurance companies or set up a credit company to share credit risks in automobile finance. On the premise of ensuring safety, we can encourage consumers to consume automobile products by reducing interest or exempting interest and prolonging the repayment period.

References

Alam, K.M. and Saini, M. (2015), "Toward social internet of vehicles: concept, architecture, and applications", *IEEE Access*, Vol. 3, pp. 343-357.

Cachon, G.P. and Kok, A.G. (2010), "Competing manufacturers in a retail supply chain: on contractual form and coordination", *Management Science*, Vol. 56 No. 3, pp. 571-589.

Chen, Z.X. (2012), *Study on the Test Effect of Automobile Test Field*, Jilin University, Changchun.

Chen, S.H. and Hsieh, C.H. (1999), "A model and algorithm of fuzzy product positioning", *Information Science*, Vol. 121 No. 1, pp. 61-82.

Chu, H.Q., Guo, L.L. and Yan, Y.J. (2019), "Energy-efficient longitudinal driving strategy for intelligent vehicles on urban roads", *Science China Information Sciences*, Vol. 62 No. 6, pp. 1-3.

Dai, Y.F. and Li, K.Q. (2015), "Analysis of the status quo and development trend of automotive intelligent network", *The Automobile Manufacturing Industry*, Vol. 18 No. 1, pp. 14-17.

Dong, Y.T. and Sun, C.Y. (2016), "Adaptive neural impedance control of a robotic manipulator with input saturation", *IEEE Transcations on Systems Man Cybernetics-System* Vol. 46 No. 3, pp. 334-344.

Etzion, D. (2007), "Research on organizations and the natural environment, 1992-present: a review", *Journal of Management*, Vol. 33 No. 4, pp. 637-664.

Fang, F., Dickson, K. and Wang, D. (2016), "The standardization model of innovation: case of high-technology enterprises", *Chinese Management Studies*, Vol. 10 No. 1, pp. 102-118.

Fontelap, S.A. and Mielgo, J. (2007), "Airport electric vehicle powered by fuel cell", *Journal of Power Sources*, Vol. 169 No. 1, pp. 184-193.

Gibson, T. (2015), "Virginia's smart road: where researchers make the extreme weather", *Weatherwise*, Vol. 68 No. 4, pp. 20-27.

Hevelke, A. (2014), "Responsibility for crashes of autonomous vehicles: an ethical analysis", *Science and Engineering Ethics*, Vol. 17 No. 1, pp. 41-52.

Joseph, J. and Wilson, A.J. (2018), "The growth of the firm: an attention-based view", *Strategic Management Journal*, Vol. 39 No. 6, pp. 1779-1800.

Li, K.Q. (2015), "Enterprise network and technology transformation of future car", *Science Chinese*, Vol. 10 No. 1, pp. 40-48.

Liu, Z.Y. (2015), *Global Energy Internet*, China Electric Power Press, Beijing.

Lu, L.R. (2014), *The Application of Electric Vehicle in Electric Power System*, Zhejiang University, Zhejiang.

Meyer, G. (2014), "City mobil2: challenges and opportunities of fully automated mobility, in road vehicle automation", *2nd Annual Workshop on Road Vehicle Automation, Stanford, CA*.

Naoum, T., Dimitrios, B. and Jagjit, S. (2019), "Intelligent autonomous vehicles in digital supply chains", *Business Process Management Journal*, Vol. 11 No. 3, pp. 414-437.

Podsakoff, P.M. and Organ, D.W. (1986), "Self-reports in organizational research: problems and prospects", *Journal of Management*, Vol. 12 No. 4, pp. 531-544.

Qi, F. (2019), "Simplifying coefficients in differential equations for generating function of Catalan numbers", *Journal of Taibah University for Science*, Vol. 13 No. 1, pp. 947-950.

Rodrigo, G.V., Joao, A.P. and Guo, C.L. (2014), *International Electrical Engineering Advanced Technology Translation: electric Cars into the Modern Power Grid*, Machinery Industry Press, Beijing, translation.

Roeglinger, M. (2017), "Maturing maturity models – a methodological extension using the analytical hierarchy process and Google PageRank", *Journal of Decision Systems*, Vol. 26 No. 4, pp. 307-327.

Serra, G. (2013), "The dissemination of economic ideas", *Journal of the History of Economic Thought*, Vol. 35 No. 4, pp. 558-561.

Shah, R., Ball, G.P. and Netessine, S. (2017), "Plant operations and product recalls in the automotive industry: an empirical investigation", *Management Science*, Vol. 63 No. 8, pp. 2439-2459.

Shang, H.Y. (2017), "An extended macro traffic flow model accounting for the driver's bounded rationality and numerical tests", *Physica a-Statistical and its Applications*, Vol. 468, pp. 322-322.

Steden, F. (2011), "Process integration of machine simulation for control program development in machine manufacturers", *12th Branch Meeting of the Measurement and Automation Technology - Automation, Baden Baden*.

Wang, X.J., Liu, J. and Ma, C. (2016), "A research on the cluster competitiveness evaluation of the Chinese automobile industry based on cuckoo-AHP", *Chinese Management Studies*, Vol. 10 No. 4, pp. 746-769.

Weiß, C. (2011), "V2X communication in Europe-from research projects towards standardization and field testing of vehicle communication technology", *Computer Networks*, Vol. 55 No. 14, pp. 3103-3119.

Wong, Y. and Lee, W. (2014), "An intelligent load management system and method for electric vehicle charging system and charging station system", *IEEE transcations on smart grid*, Vol. 5 No. 4, pp. 1969-1979

Wu, M.L. (2009), *Operation and Application of Structural Equation model-AMOS*, Chongqing University press, Chongqing.

Xu, F. (2016), "Internet collaborative governance based on evolutionary game", *Journal of Nanjing University of Science and Technology*, Vol. 40 No. 6, pp. 752-758.

Xu, N. (2015), "Internet + boost the auto industry intelligent transformation", *Industry*, Vol. 11 No. 4, pp. 34-43.

Yao, M.M., Wu, X.B. and Si, Y.J. (2014), "Matching of business model design and technology innovation strategy from the perspective of technology catching", *Management World*, Vol. 30 No. 10, pp. 24-32.

Zhang, Y.L. and Li, Q.W. (2009), "Corporate entrepreneurial orientation, ambidextrous competence and organizational performance", *Journal of Management Sciences in China*, Vol. 12 No. 1, pp. 137-152.

Further reading

Becker, J. (2014), "Bosch's vision and roadmap toward fully autonomous driving", *2nd Annual Workshop on Road Vehicle Automation, Stanford, CA*.

Cachon, G.P. and Olivares, M. (2015), "Drivers of finished-goods inventory in the US automobile industry", *Management Science*, Vol. 56 No. 1, pp. 202-216.

Chin, T. and Liu, R. (2015), "Understanding labor conflicts in Chinese manufacturing: a Yin-Yang harmony perspective", *International Journal of Conflict Management*, Vol. 26 No. 3, pp. 288-315.

Chin, T., Liu, R-h. and Yang, X. (2016), "Reverse internationalization in Chinese firms: a study of how global startup OEMs seek to compete domestically", *Asia Pacific Business Review*, Vol. 22 No. 2, pp. 201-219.

Ding, X.H. (2014), *Smart Grid Key Technology Series: Smart Grid and Electric Vehicle*, China Electric Power Press, Beijing.

Guangdong Grid Co (2012), "Research on the legal risks and Countermeasures of electric vehicle charging facilities", Law Press, Beijing.

Hui, J.Z., Sun, D.S. and Zou, Y. (2008), "Application of linear accumulated damage theory in the study of strength coefficient of automobile test site reliability test", *Journal of Engineering Design*, Vol. 28 No. 4, pp. 264-278.

Joao, V.F. (2013), *Electric Vehicle Technology, Policy and Market*, Mechanical Industry Press, Beijing.

Lu, J. and Yang, Z.W. (2015), "British new energy law and policy research", Wuhan University Press, Hubei, 2012.

Röglinger, S. (2011), "A methodology for testing intersection related vehicle- 2-X applications", *Computer Networks*, Vol. 55 No. 12, pp. 3154-3168.

Vander, W.A., Young, S.M. and Chen, C.X. (2005), "Assessing the quality of evidence in empirical management accounting research: the case of survey studies", *Accounting, Organizations and Society*, Vol. 30 No. 8, pp. 655-684.

Xu, K. and Xu, N. (2015), "A global perspective on the development path of intelligent network", *Chinese automobile industry review*, No. 9, pp. 14-23.

Appendix 1. Questionnaire on the factors affecting the development of intelligent automobile manufacturing enterprises

Part I Contents of measurement factors affecting the development of intelligent automobile manufacturing enterprises

Please objectively select the main measurement indicators included in each influencing factor according to the specific situation. The answer is multiple choices, no restrictions, and mark √ in □.

1. Influencing factors of policy dimension

(1) Lack of national policies

□Financial and taxation policy □Financial policy

□Research support policy □Intellectual property protection policy

(2) Lack of early planning

□Formulation of intelligent automobile technical standards □Industry planning

□Platform development strategy

2.Influencing factors of environmental dimension

(1) Incomplete intelligent automobile infrastructure construction

□Automotive network high-speed network □Construction of low-power Internet of Things

□Intelligent road □Parts and components enterprise

(2) Lack of intelligent driving laws and regulations

□Road test system □Insurance system

□Operation report system □Information security system

3.Influencing factors of industry chain dimension

(1) Lag of cross-industry collaboration

□Core technology synergy □Infrastructure intelligent construction synergy

□Operational supervision synergy

(2) Lack of cooperation between industry-university-research

□Investment in industry-university-research cooperation

□Output of industry-university-research cooperation

□Process management of industry-university-research cooperation

4.Influencing factors of technical dimension

(1) Insufficient R&D ability

□R&D investment □Number of patents

(2) Low level of technical industrialization

□Investment recovery period □Total foreign exchange earning

□Internal rate of return □Annual gross output value after project been put into production

□Investment profit rate

(3) Insufficient cost control ability

□Design cost □Production cost

□Process technology innovation cost □Budget formulation rules

□Cost management methods

(*continued*)

Part II Investigation on the relationship among the influencing factors

Please objectively judge the characteristics of the influencing factors at the current stage according to the specific circumstances, and give you the degree of consent to the following statements. The answers are divided into five levels: 1 = very disagree, 3 = basic consent, 5 = very agree.

1. Influencing factors of policy dimension

(1) Lack of national policies will lead to a lack of relevant fiscal incentives.

(2) Lack of national policies will lead to a lag in cross-industry collaboration.

(3) Lack of national policies will lead to inappropriate industrial development strategy planning.

(4) Lack of early planning will lead to imperfect smart car driving environment problems.

(5) Lack of early planning will lead to industrial synergy problems.

2. Influencing factors of environmental dimension

(6) Imperfect infrastructure will lead to low intelligent automobile penetration.

(7) Imperfect infrastructure will lead to insufficient effective coordination between relevant departments inside and outside the industry.

(8) Lack of intelligent driving laws and regulations will lead to the backward construction of intelligent automobile infrastructure.

(9) Lack of intelligent driving laws and regulations will lead to problems such as cross-industry synergy lag.

3. Influencing factors of industry chain dimension

(10) Lag of cross-industry collaboration will lead to the backward construction of intelligent automobile infrastructure.

(11) Lag of cross-industry collaboration will lead to imperfect infrastructure.

(12) Lack of cooperation between industry, university and research institutes will lead to the backwardness of intelligent automobile technology.

(13) Lack of cooperation between industry, university and research institutes will lead to low level of technological industrialization.

4. Influencing factors of technical dimension

(14) Lack of industrial R&D capacity will lead to higher costs of intelligent automobile and lower the overall industry competitiveness.

(15) Lack of technical industrialization will limit the level of R&D and collaborative innovation in industry, university and research institutes.

(16) Domestic low-cost control capability will lead to difficulties in the operation of intelligent automobile manufacturing industry.

Appendix 2

Order no.	No. of participants	Location of the unit	Position/Title
1	30	Beijing	Executive
2	45	Shanghai	Executive
3	27	Chongqing	Executive/R&D personnel
4	16	Shenzhen	Executive/sales people
5	33	Hefei	Executive
6	20	Xi'an	Executive
7	26	Hangzhou	Executive/staff in industrial platform

Note: Table background information of the participants involved in the survey

Table AI. The samples' demographic statistics

Appendix 3. The calculating process of fuzzy semantic scale

Step 1. Sorting out the questionnaires

Based on the survey results, the complete set of semantic phraseology is established:

$$X = \{x_1, x_2, \ldots, x_n\}$$

where x_n represents the semantic wording and n represents the number of words in the semantic cluster.

Because different respondents use different number of semantic words when filling in the questionnaire, different types of semantic questionnaires can be designed when the impossibility is deleted or the number of replies is small. Symbolized as:

$$W_v = \{p_1, p_2, \ldots, p_k\}$$

where W_v represents the semantic form of the v-type, p_k represents the semantic wording used under the form v.

A total of five semantic wordings were used in this study:

(1) very much agree;
(2) agree;
(3) common;
(4) disagree; and
(5) very much disagree.

After deleting the questionnaires that are unlikely to occur or have fewer copies, seven semantic patterns were generated, as shown in Table AII.

Step 2. Establish the membership function of each respondent for each semantic wording.

Type	Type I	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
Very much agree	√						
Agree	√	√	√	√			
Common	√	√	√		√	√	√
Disagree	√	√		√	√		
Very much disagree						√	

Table AII. Table semantic patterns

According to the specific value in the 1-100 of the semantic wording k filled in by the i-th respondent, subjectively determine the numerical range of each semantic wording to generalize the trapezoidal fuzzy number model:

$$\tilde{A}_{ik} = (a_{ik}, b_{ik}, c_{ik}, d_{ik})$$

where i and k represent the semantic wording k filled in by the i-th respondent respectively, and establish a fuzzy function as following:

$$\int_{\tilde{A}} (x) : R \rightarrow [0, 1]$$

$$\int_{\tilde{A}_{ik}} (x) = \begin{cases} \dfrac{x - a_{ik}}{b_{ik} - a_{ik}}, a_{ik} \leq x \leq b_{ik} \\ 1, b_{ik} \leq x \leq c_{ik} \\ \dfrac{x - d_{ik}}{c_{ik} - d_{ik}}, c_{ik} \leq x \leq d_{ik} \\ 0, \text{其它} \end{cases}$$

where $a_{ik} \leq b_{ik} \leq c_{ik} \leq d_{ik}$, a_{ik} and d_{ik} are the upper and lower bounds of $\tilde{A}_i$, respectively.

When $b_{ik} = c_{ik}$, $\int_{\tilde{A}_{ik}}(x)$ is a triangular fuzzy function. In the formula of fuzzy function, $\int_{\tilde{A}_{ik}}(x) = \frac{x - a_{ik}}{b_{ik} - a_{ik}}, a_{ik} \leq b_{ik}$ is the right membership function of the fuzzy number $\tilde{A}_{ik}$.

Step 3. Integrate the various semantic forms of the survey results

First, find the reference value of the left and right values of the triangular fuzzy function based on the median. Assume that the measure (minimum value, optimal value, maximum value) of the semantic wording k filled in by the i-th respondent is defined as a fuzzy evaluation value:

$$P_{ik} = (l_{ik}, \mathrm{m}_{ik}, \mathrm{r}_{ik})_{L-R}, i = 1, 2, \ldots, n.$$

The median evaluation value is as follows: $P_{m_dk} = (l_{m_dk}, m_{m_dk}, r_{m_dk})_{L-R}$, among them, $l_{m_dk} = median(l_{1k}, l_{2k}, \ldots l_{nk})$, $m_{m_dk} = median(m_{1k}, m_{2k}, \ldots, m_{nk})$, $r_{m_dk} = median(r_{1k}, r_{2k}, \ldots, r_{nk})$. l_{m_dk}, m_{m_dk} and r_{m_dk} are the medians of left, middle and right values of all samples, respectively, which are the new benchmarks for the triangular fuzzy function. Then, a benchmark fuzzy function is established to measure whether the opinions of other respondents deviate from those of the majority of respondents.

Then, samples are screened using the identity measure function. The reference triangular fuzzy function established above is compared with the triangular fuzzy function of other samples to measure the degree of identity between each other, and the degree of deviation is used to remove the sample with a large degree of deviation. The degree of deviation function is used to measure the degree of similarity between two membership functions. The formula is:

$$S\left(\tilde{P}_{m_dk}, \tilde{P}_{ik}\right) = \frac{\int_x \left(\min\left\{f_{\tilde{P}_{m_dk}}(x), f_{\tilde{P}_{ik}}(x)\right\}\right) \partial x}{\int_x \left(\max\left\{f_{\tilde{P}_{m_dk}}(x), f_{\tilde{P}_{ik}}(x)\right\}\right) \partial x}$$

wherein the numerator representation intersects the reference membership function $f_{\tilde{P}_{m_dk}}(x)$ with the sample membership function $f_{\tilde{P}_{ik}}(x)$. The denominator represents the union of the reference membership function $f_{\tilde{P}_{m_dk}}(x)$ and the sample membership function $f_{\tilde{P}_{ik}}(x)$.

Finally, the standard fuzzy number of the semantic wording k evaluation value is established. For the semantic wording k, the minimum value of the left boundary l_{ik} of all the respondent's fuzzy numbers is taken as the left bound value l_k of the standard fuzzy number, i.e:

$$l_k = \min(l_{ik}), i = 1, 2, 3, \ldots, m$$

Taking the geometric mean m_k of the median value m_{ik} of all respondents as the intermediate value of the standard fuzzy number, i.e:

$$m_k = \left(\prod_{i=1}^{n} m_{ik} \right)^{1/n}, i = 1, 2, 3, \ldots, m$$

If there is any $m_{ik} = 0$, then m_k is replaced by the arithmetic mean, i.e:

$$m_k = \frac{\sum m_{ik}}{m}, i = 1, 2, 3, \ldots, m$$

Take the maximum value of the right boundary r_{ik} of all the respondent's fuzzy numbers as the right bound value r_k of the standard fuzzy number, i.e:

$$r_k = \max(r_{ik}), i = 1, 2, 3, \ldots, m$$

Step 4. Convert fuzzy values to explicit values

In the last step, the fuzzy number of each semantic wording k is determined. Referring to the study of Chen and Hsieh (1999), the fuzzy number is converted into explicit value by using the membership degree as a weighting function. The formula is as follows:

$$p(\tilde{A}_k) = \frac{l_k + 4m_k + r_k}{6}$$

The results of this study combined with this formula to transform the study data are shown in Table AIII.

Type	Traditional values	Type I	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
Very much agree	5	0.85						
Agree	4	0.72	0.72	0.72	0.73			
Common	3	0.48	0.49	0.49		0.49	0.48	0.49
Disagree	2	0.22	0.24		0.23	0.23		
Very much disagree	1						0.04	

Table AIII. Table explicit values of seven semantic patterns

Corresponding author
Wei Hu can be contacted at: 335021552@qq.com