

Research on Intelligent Marketing Scheme Based on Fuzzy Mathematics Theory and Vehicular Networking Data

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Abstract: With the rapid development of information technology, the Internet of vehicles has produced massive data, which has brought new opportunities for the intelligent marketing of the automobile industry. However, there is ambiguity and uncertainty in these data, which brings challenges to effective use. This paper introduces the theory of fuzzy mathematics into the processing of car networking data, aiming to construct an innovative intelligent marketing program. Through the collection of Telematics data, analysis and processing based on fuzzy mathematics, it can realize accurate market positioning, personalized marketing strategy formulation and efficient marketing effect evaluation, helping automobile enterprises to enhance market competitiveness and meet the increasingly diversified and personalized needs of consumers.

Keywords: Fuzzy mathematics theory, Vehicle networking data, Intelligent marketing, Market positioning, Personalized marketing.

1. Introduction

Driven by the wave of digitalization, the automotive industry is undergoing an unprecedented intelligent transformation, in which the Internet of vehicles technology as the core driving force is reshaping the industry ecology. Through the construction of intelligent interconnection networks of vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-person (V2P) and vehicle-to-network (V2N), the vehicle-to-network system generates massive multi-dimensional data resources in real time, including core dimensions such as vehicle operating status, driving behavior characteristics, and user interaction preferences. These data assets provide valuable data support for automobile enterprises to gain in-depth insight into user needs, optimize product design, improve service quality and implement precision marketing strategies. However, the data of the Internet of vehicles has typical fuzzy characteristics and uncertain nature. Specifically, users' evaluation of vehicle experience dimensions such as comfort and safety often presents subjective fuzziness; The key features of driving behavior data, such as "frequent acceleration" and "occasional stoppage", also lack clear quantitative standards. Traditional data analysis methods are difficult to effectively analyze such fuzzy information, resulting in the commercial value of connected vehicle data has not been fully released.

In order to solve this industry pain point, this paper introduces the fuzzy mathematics theory founded by the American cybernetics expert L.A. Zadeh in 1965. This theory innovatively puts forward the concept of membership function and provides a rigorous methodology system for mathematical modeling of fuzzy phenomena. There are successful cases [4-6] of fuzzy mathematics theory in all walks of life. For example, in order to solve the problems of incomplete information and inaccurate data in the post-evaluation process of high-standard farmland construction projects, scholar Su Ling [4] studied the post-evaluation of

high-standard farmland construction projects by using fuzzy mathematics methods. The results show that fuzzy mathematics method can improve the accuracy and objectivity of evaluation results, and provide scientific basis for project improvement and decision-making. In order to build a set of evaluation model based on hierarchical analysis and fuzzy mathematics, Liu Pengfei [5] and other scholars used the principle of fuzzy mathematics to comprehensively evaluate the risk level. The model takes into account subjective judgment and objective data, and can better deal with uncertainties in the construction process, providing theoretical basis and technical support for formulating risk management and control strategies. In order to make the online teaching quality evaluation index system reflect practicability and differentiation, Ding Xiaoxing [6] and other scholars introduced fuzzy mathematics decision rules to further upgrade and improve the system, and got the evaluation grade decision algorithm. The feasibility of the algorithm is verified by an example. Compared with the direct score, the conclusion of the algorithm can objectively reflect the actual teaching level and teaching development stage of the teachers, so as to become the basis and starting point for improving the quality of online teaching. Therefore, fuzzy theory processing subjective evaluation data has a good effect on engineering.

To sum up, the organic combination of the theoretical framework of fuzzy mathematics and the big data of the Internet of vehicles to build an intelligent marketing decision model can not only effectively improve the accuracy of marketing strategies, but also create significant business value for the automotive industry in terms of user experience optimization and market competitiveness improvement.

2. Research Methods

The research of this paper is carried out according to the following three steps. The first step is the theoretical basis of fuzzy mathematics, including fuzzy set, membership degree,

fuzzy relation and fuzzy comprehensive evaluation. The second step is to introduce the characteristics of vehicle networking data, including data diversity, data real-time, data fuzziness and data high value. The third step is the construction of intelligent marketing plan based on fuzzy mathematics and vehicle network, including vehicle network

data collection and preprocessing, data fuzzy processing, index weight determination and fuzzy comprehensive evaluation, personalized marketing strategy formulation based on fuzzy reasoning and other contents. The research roadmap of this paper is shown in Figure 1.

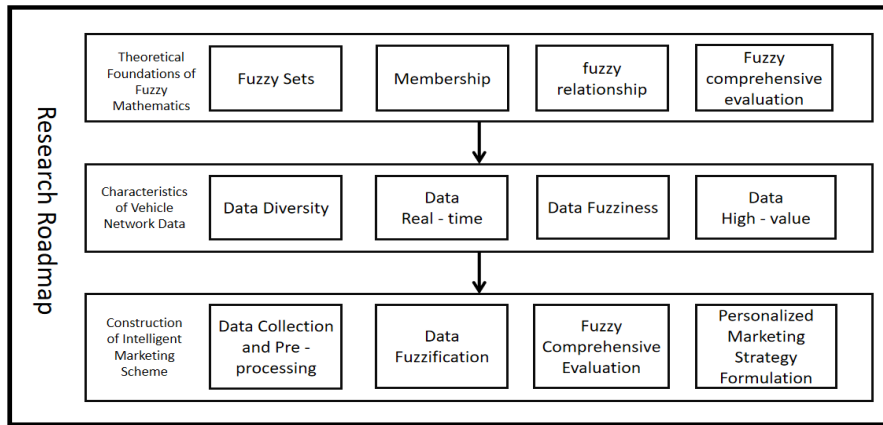


Figure 1. Research roadmap of this paper

2.1. Theoretical Basis of Fuzzy Mathematics

(1) Fuzzy set and membership degree

The core theory breakthrough of fuzzy mathematics is to put forward the concept of fuzzy set, breaking through the limitation of binary membership of traditional classical sets. In classical set theory, the relationship between elements and sets is either one or the other -- either they belong completely (membership 1) or they don't belong at all (membership 0). Fuzzy sets, on the other hand, introduce the concept of continuous membership, which allows elements to belong to a set at any degree between 0 and 1, thus more accurately characterizing ambiguity and uncertainty in the real world.

Take the scene of the Internet of vehicles as an example, if "fast vehicle speed" is defined as a fuzzy set, the membership function can be used to quantify the belonging degree of different vehicle speeds. The specific example is shown in Table 1.

Table 1. Membership function quantifies the degree of belonging of different vehicle speeds

Serial Number	speed	Membership	Conformance
1	120km/h	0.8	Height fit
2	100km/h	0.5	General conformance
3	60km/h	0.2	Partial fit

In practical engineering, it is necessary to optimize the fuzzy mathematical model according to the user's frequent application scenarios and data distribution characteristics to ensure that the fuzzy mathematical model can accurately reflect the complex semantics of the real world.

(2) Fuzzy relation and fuzzy reasoning

Fuzzy relation is an important tool used in fuzzy mathematics to describe the correlation between multi-dimensional fuzzy concepts. In the data analysis of vehicle networking, fuzzy relation matrix can be established to quantify the nonlinear mapping relationship between different vehicle performance indicators (such as power, comfort, economy, etc.) and user satisfaction. This modeling method can effectively capture complex correlation features that are

difficult to be characterized by traditional statistical methods. Fuzzy inference systems build a knowledge base based on fuzzy rules in the form of "if-then", such as: "If the power performance is excellent (membership 0.8) and the fuel economy is good (membership 0.6), the user satisfaction is high (membership 0.7)", the membership of the input variable (performance index) is matched and calculated with the rule base through fuzzy synthesis operation, and the final output has a clear semantic fuzzy conclusion.

(3) Fuzzy clustering and fuzzy comprehensive evaluation

Fuzzy Clustering is an intelligent classification method based on fuzzy set theory, the core of which is to allow data objects to belong to multiple categories in the form of Membership Degree, rather than the Hard Partitioning of traditional clustering algorithms. Compared with K-means and other classical clustering algorithms, fuzzy clustering (such as FCM algorithm) can deal with Fuzziness and Uncertainty in real data more effectively, especially for the user grouping task in the scenario of Internet of vehicles.

In vehicle networking data, users can be divided into several fuzzy clusters with differentiated features by fuzzy clustering algorithm based on multi-dimensional indicators such as driving behavior characteristics (such as cruise duration), vehicle usage patterns (such as average daily mileage), and human-vehicle interaction preferences (such as the utilization rate of intelligent APP). The membership degree of each user in different clusters reflects the mixed characteristics of their behavior patterns, so as to provide a more refined user portrait for enterprises, and support the formulation of personalized marketing strategies such as customized insurance and precise advertising.

2.2. Data Characteristics of Internet of Vehicles

(1) Diversity of data

Vehicle networking data comes from a wide range of sources, with the characteristics of multi-source heterogeneity, mainly from the four dimensions of vehicle sensing system, vehicle electronic system, mobile terminal interaction and environment perception system. The data types cover multiple forms such as numerical type (sensor reading), text type (log recording), and multimedia type (driving image).

(2) Real-time data

Vehicle networking data can reflect the running status of the vehicle and the surrounding environment information in real time. For example, the real-time location, speed, driving direction and other data of vehicles are constantly updated, and the traffic condition information also changes dynamically with time. This real-time and dynamic nature requires the data processing system to have the ability of rapid response and real-time analysis, so as to provide timely decision support for intelligent marketing, such as pushing peripheral relevant service information to the driver according to real-time road conditions.

(3) fuzziness of data

There are a lot of fuzzy and uncertain information in the data of the Internet of vehicles. Users' evaluation of some vehicle functions, such as "beautiful interior" and "comfortable driving experience", has strong subjectivity and fuzziness, and is difficult to be measured with accurate values. There is also ambiguity in the definition of driving behavior data in different scenarios, such as the unclear boundary between "normal driving" and "abnormal driving". In addition, there may be noise and errors in the process of data collection, which further increases the uncertainty of the data.

(4) High value of data

Car networking data contains great value. Through in-depth mining and analysis of these data, we can gain insight into user needs, optimize product design, improve after-sales service quality, and create significant economic benefits for automobile enterprises. At the same time, there is a potential correlation between different types of data in the Internet of vehicles data, such as driving behavior data and vehicle failure data may be related, through the discovery and use of these correlations, we can further enhance the application value of data.

2.3. Construction of Intelligent Marketing Plan

2.3.1. Data collection and pre-processing

(1) Data collection methods

Telematics data is collected through channels such as in-vehicle devices, mobile apps and Telematics platforms. In-vehicle devices such as various sensors collect real-time vehicle status data (such as speed, fuel consumption, engine speed, etc.) and driving behavior data (rapid acceleration, sudden braking times, etc.); Mobile applications can obtain user and vehicle interaction data (such as vehicle information query, reservation maintenance and other operation records) and user preference data (set seat position, music playing style, etc.); The Internet of vehicles platform integrates massive data from different vehicles, and can obtain relevant external data from third-party data sources (such as traffic information providers, weather service platforms, etc.) to enrich the data dimension.

(2) Data cleaning and denoising

Original vehicle networking data often contains noise, error data and duplicate data, which need to be cleaned and denoised to improve data quality. The data smoothing technology (such as moving average method, exponential smoothing method, etc.) is used to process the noisy data caused by the sensor measurement error, so that the data curve is smoother. The exponential smoothing method is shown in formula (1).

$$y'_{t+1} = a * y_t + (1-a) * y'_t \quad (1)$$

In formula (1), y'_{t+1} is the predicted value at t+1, y_t is the actual value at t, y'_t is the predicted value at t, and a is the weighting coefficient.

Duplicate data can be quickly detected and deleted by techniques such as hash algorithm to reduce data redundancy.

(3) Data integration and standardization

The data of the Internet of vehicles comes from many different data sources, and there are differences in data formats, coding methods and data ranges, which need to be integrated and standardized. Adopt data warehouse technology to integrate data from different sources, unify data format and coding, and ensure data consistency.

Data integration: Data from different sources are unified and integrated to eliminate redundancy and contradictions and form a complete data set. The data integration formula is shown in formula (2) below.

$$B = \begin{cases} B \cup b_i & \text{if } b_i \in b \\ B \setminus b_i & \text{if } b_i \notin b \end{cases} \quad (2)$$

For numerical data, the minimum-maximum standardization is used to map the data to a specific interval [7] [0, 1], eliminate the impact of data dimension, and make the data of different indicators comparable to facilitate subsequent data analysis and modeling. max-min standardization is shown in formula (3).

$$x^* = \frac{x - \max}{\max - \min} \quad (3)$$

In formula (3), max is the maximum value of the original data, min is the minimum value of the sample data, max-min is the range, and the deviation standardization retains the relationship existing in the original data.

2.3.2. Data fuzzy processing

(1) Membership function definition

Aiming at the fuzzy concept in the data of vehicle networking, it is necessary to clarify its connotation and construct the corresponding membership function [8-9] first. For example, to calculate the membership function of "radical driving style", the number of rapid acceleration and the number of sudden braking can be selected as the characteristic indicators. The membership function parameters can be determined by the method of expert experience, statistical analysis or the combination of both. The parameter setting adopts the big data statistical method, that is, through the statistical analysis of a large number of driving behavior data, it is found that when the number of rapid acceleration exceeds a/min and the number of sudden braking exceeds b/min, the membership degree is close to 1; When The Times of rapid acceleration are less than c/min and The Times of sudden braking are less than d/min, the membership degree is close to 0.

(2) The fuzzy process is realized

The pre-processed vehicle networking data is substituted into the constructed membership function, and the membership degree of the data in the corresponding fuzzy set is calculated to complete the fuzzy process. For example, for the driving behavior data of a certain vehicle, in a certain period of time, the number of rapid acceleration is 2 times per minute, the number of sudden braking is 1.5 times per minute, and the average driving speed is 70km/h. These data are

substituted into the membership function of "aggressive driving style", and the membership degree in the fuzzy set of "aggressive driving style" is 0.4 through calculation, indicating that the driving style of the vehicle has a certain degree of aggressive tendency during this period of time.

2.3.3. Fuzzy comprehensive evaluation

Comprehensively consider the characteristics of vehicle networking data and automotive marketing needs, The selection includes driving behavior indicators (rapid acceleration frequency, sudden braking frequency, average driving speed, daily mileage, etc.), vehicle usage scenario indicators (urban commuting, long-distance travel, weekend travel, etc.), user preference indicators for vehicle configuration (attention to seat heating, navigation system, sound system, etc.) and related indicators of user consumption power (vehicles Purchase price, insurance cost level, etc.), and can effectively reflect the characteristics and needs of users as evaluation indicators.

The fuzzy C-means clustering (FCM) algorithm is used to cluster the user data [10-11]. By iteratively optimizing the objective function, FCM algorithm makes the similarity of data within the same cluster maximum, and the similarity of data between different clusters minimum. In the process of application, the cluster number K (which can be determined by experiments and domain knowledge, such as the car users are initially divided into economic, comfort, performance and other categories) is first determined, and the cluster center is randomly initialized. Then, the membership degree of each data point in each cluster is calculated according to the distance between the data point and the cluster center, and then the cluster center is updated according to the membership degree, and the objective function is iterated until it converges.

2.3.4. Personalized marketing strategy development

Through on-board devices, mobile phone apps and vehicle networking platforms, vehicle networking data of more than 100,000 vehicles were collected within a year, including vehicle driving data, driving behavior data, user interaction data, etc. The original data were cleaned, de-noised, integrated and standardized, data from different sources were integrated into a unified data warehouse, and numerical data was standardized. Then, the membership function is constructed according to the fuzzy concepts such as driving style and vehicle usage scenario, and the data fuzzy processing is completed.

The above research results allow us to develop and implement personalized marketing strategies for different market segments. For economy users, launch promotion activities for energy-saving models, provide low down payment, long-term loan car purchase programs, and recommend energy-saving auto parts; For comfort users, it emphasizes the upgrade of vehicle comfort configuration, and provides free interior decoration and maintenance services; For performance-oriented users, we organize test-drive events for high-performance models and offer discounts on performance tuning packages; For multi-functional users, diversified space utilization schemes for vehicles will be displayed, and customized services tailored to the needs of outdoor travel will be launched.

3. Conclusion and Prospect

In this paper, the fuzzy mathematical theory is successfully combined with the data of the Internet of vehicles, and an

innovative intelligent marketing scheme is constructed. Through the collection, pre-processing and fuzzy processing of vehicle networking data, fuzzy clustering is used to achieve accurate market segmentation, personalized marketing strategies are formulated based on fuzzy reasoning, and fuzzy comprehensive evaluation is used to evaluate the marketing effect. The scheme can effectively deal with the fuzziness and uncertainty of the data of the Internet of vehicles, improve the accuracy and efficiency of the marketing of automobile enterprises, meet the individual needs of different user groups, and significantly improve the marketing effect and market competitiveness.

Future research can be carried out in the following directions: First, further optimize the fuzzy mathematical model and algorithm to improve the processing ability and analysis accuracy of complex IoV data, such as studying more efficient fuzzy clustering algorithm to adapt to large-scale data processing needs; Second, strengthen the research on the security and privacy protection of the Internet of vehicles data, ensure the security of user data while making full use of the value of data, and can combine blockchain and encryption technology to ensure the safe transmission and storage of data; The third is to expand the application of intelligent marketing solutions in the entire automotive industry chain, including automotive research and development, production, sales, after-sales service and second-hand car trading, so as to realize the intelligent process; Fourth, in-depth research on multi-source data fusion technology, integration of vehicle networking data with social media data, macroeconomic data, etc., to provide more comprehensive decision support for intelligent marketing.

References

- [1] Fan Yanfang, Zhang Zhe, Qin Tianqi, et al. Car networking data sharing based on the block chain review [J/OL]. Computer application research, 1-15 [2025-04-15]. <https://doi.org/10.19734/j.issn.1001-3695.2024.10.0450>.
- [2] REN Shuaifei, Lin Nan, Huang Hongyin, et al. Auto car networking operation data processing method research [J/OL]. Journal of automobile engineering, 1-11 [2025-04-15]. <http://kns.cnki.net/kcms/detail/50.1206.U.20250219.1021.002.html>.
- [3] XU Xianxi, LI Jiongbina, GUO Zhiyuan. Technology Analysis on Security Challenges and Evaluation of Vehicle Networking [J]. Quality and Certification, 2025, (02): 83-86+91. DOI: 10.16691/j.cnki.10-1214/t.2025.02.020.
- [4] Su L. Research on Post-evaluation of high-standard farmland water conservancy project based on fuzzy mathematics method [J]. Water Conservancy Science and Cold Area Engineering, 2025, 8 (03): 75-78.]
- [5] Liu Pengfei, Gao Guanghui. Risk assessment of fault tunnel construction based on Hierarchical Analysis-Fuzzy mathematical evaluation method [J]. Total Corrosion Control, 2025, 39 (03): 105-108. DOI: 10.13726/j.cnki.11-2706/tq.2025.03.105.04.
- [6] DING Xiaoxing, Hou Shuai, FU Xinmeng. Application Research of Online Classroom Teaching Quality Evaluation Index System Based on Fuzzy Mathematics [J]. Journal of Higher Education, 2025, 11 (S1): 95-99. DOI:10.19980/j.CN23-1593/G4.2025.S1.022.
- [7] Zhang Fan, Guo Yaxin, Yang Jing, et al. Research on electric energy prediction based on GBDT+ feature engineering method [J]. Electronic Quality, 2020, (01): 1-4.

- [8] LI T. Optimization method of tea pretreatment process based on AHP-Fuzzy mathematical comprehensive evaluation method [J]. Fujian Tea, 2024, 46 (08): 20-22.
- [9] He Lei. Quality Evaluation of College Ideological and Political Course Distance Teaching System based on Fuzzy Mathematics Comprehensive Evaluation Method [J]. Journal of Microcomputer Applications, 2022, 38 (06): 69-71+78.
- [10] Wu Tiezhou, Zhu Lei, Zhang Min, et al. Research on equilibrium strategy of lithium battery based on density fuzzy C-means clustering algorithm [J]. Journal of Wuhan University of Technology, 2025, 47 (01): 84-90.
- [11] LIANG Bo. Research on data Deep mining in optical Communication network based on improved Fuzzy clustering [J]. Laser journal, 2025, 46 (02): 174-178. The DOI: 10.14016 / j.carol carroll nki JGZZ. 2025.02.174.