RESEARCH ON URBAN ROAD TRAFFIC SAFETY RISK IDENTIFICATION METHOD BASED ON ABNORMAL DRIVING BEHAVIOR

Fu Yuan[1]
[1] *Shandong Hi-Speed Qianfang International Technology Co., Ltd.*

Abstract: *To address the issues of ambiguity and subjectivity in current road traffic safety risk identification, this paper proposes a quantitative evaluation method for urban road traffic safety risk based on abnormal driving behavior data. Firstly, abnormal driving behaviors (such as speeding, sudden acceleration, sudden deceleration, sharp lane changes, and sharp turns) are identified on road segments using GPS trajectory data, and an indicator system of abnormal driving behavior rates is constructed. Based on this, the AHP-EW integrated weighting method is employed to determine the weight of each behavior on safety risk. Combined with the fuzzy comprehensive evaluation method, a road traffic safety risk assessment model is established to achieve quantitative risk grading. Validation using actual road segments in a city in Shandong Province demonstrates that this method can effectively identify high-risk road sections, providing traffic management departments with accurate and real-time data support for road network safety risk identification and control.*

Keywords: *Abnormal driving behavior, Road traffic safety risk, AHP-EW integrated weighting method, Fuzzy comprehensive evaluation, Risk identification.*

ISTRAŽIVANJE METODE IDENTIFIKACIJE RIZIKA ZA BEZBEDNOST DRUMSKOG SAOBRAĆAJA U GRADU ZASNOVANE NA ABNORMALNOM PONAŠANJU U VOŽNJI

Fu Yuan[1]
[1] *Shandong Hi-Speed Qianfang International Technology Co., Ltd.*

Rezime: *Da bi se rešili problemi dvosmislenosti i subjektivnosti u trenutnoj identifikaciji rizika po bezbednost drumskog saobraćaja, ovaj rad predlaže kvantitativnu metodu evaluacije rizika po bezbednost drumskog saobraćaja u gradu zasnovanu na podacima o abnormalnom ponašanju u vožnji. Prvo, abnormalna ponašanja u vožnji (kao što su prebrza vožnja, naglo ubrzanje, naglo usporavanje, oštre promene trake i oštra skretanja) se identifikuju na segmentima puta pomoću podataka o GPS putanji i konstruiše se sistem indikatora stopa abnormalnog ponašanja u vožnji. Na osnovu toga, integrisana metoda ponderisanja AHP-EW se koristi za određivanje težine svakog ponašanja na bezbednosni rizik. U kombinaciji sa fuzzy sveobuhvatnom metodom evaluacije, uspostavljen je model procene rizika po bezbednost drumskog saobraćaja kako bi se postiglo kvantitativno ocenjivanje rizika. Validacija korišćenjem stvarnih segmenata puta u gradu u provinciji Šandong pokazuje da ova metoda može efikasno identifikovati deonice puta visokog rizika, pružajući odeljenjima za upravljanje saobraćajem tačnu podršku u realnom vremenu za identifikaciju i kontrolu rizika za bezbednost putne mreže.*

Ključne reči: *Abnormalno ponašanje u vožnji, Rizik po bezbednost drumskog saobraćaja, AHP-EW integrisana metoda ponderisanja, Fuzzy sveobuhvatna evaluacija, Identifikacija rizika.*

1. INTRODUCTION

Urban road traffic safety has become an increasingly critical issue, with traffic accidents representing the traffic problem causing the greatest loss of life and property and the widest social impact [1]. Research has consistently demonstrated that driver-related factors, particularly abnormal driving behaviors, are the primary causes of traffic accidents, accounting for over 94% of all incidents [2, 3].

With the rapid advancement of network communication and data acquisition technologies, vehicles operated by transportation enterprises generate massive amounts of trajectory data, providing new data sources for studying driving behavior recognition and road traffic safety risks [4]. Previous studies have explored driving behavior recognition using various data sources, including onboard sensors, smartphones, and GPS devices

[1] Corresponding author: 1575526391@qq.com

[5-7]. However, current road traffic safety risk identification methods often suffer from ambiguity and subjectivity, with risk levels difficult to quantify. Furthermore, data-driven approaches to road traffic safety risk identification have yet to receive widespread practical application [8].

This study addresses these limitations by mining GPS trajectory data from operating vehicles to identify abnormal driving behaviors on urban road segments. Based on this identification, a road safety risk indicator system is constructed using abnormal driving behavior data. Subsequently, a road safety risk assessment model is established to investigate the relationships among trajectory data, driver abnormal driving behavior, and road safety risks. This paper focuses specifically on the methodology for quantifying road safety risk using abnormal driving behavior data, providing traffic management departments with accurate and real-time data support for road network safety risk identification and control.

2. ABNORMAL DRIVING BEHAVIOR THRESHOLD EXTRACTION AND IDENTIFICATION RESULTS

2.1. Driving Style Classification and Threshold Determination

Based on the driving style classification methodology described in Chapter 4 of the author's thesis, drivers were categorized into three distinct groups using K-means clustering: normal drivers (56.74%), moderate-risk drivers prone to rapid acceleration/deceleration (23.58%), and high-risk drivers prone to aggressive turning/lane changing (19.69%). The 90th percentile values of the relevant metrics from the "high-risk" driver cluster were extracted as the final recognition thresholds, as presented in Table 1.

Table 1. *Abnormal driving behavior recognition threshold extraction results*

Behavior Category	Recognition Threshold
Sudden Acceleration	2.45 m/s²
Sudden Deceleration	-2.73 m/s²
Sharp Lane Change	7.83°/s
Sharp Turn	9.72°/s

These threshold values are consistent with reference thresholds reported in related studies [9, 10], validating the methodological approach. Notably, this data-driven method accounts for the actual geographical characteristics and traffic control variations across different cities, enabling dynamic determination of abnormal driving behavior recognition thresholds.

2.2. Segment-Level Abnormal Driving Behavior Quantification

The identified thresholds were input into the abnormal driving behavior recognition algorithms to obtain behavior counts for each road segment. To account for variations in traffic volume across different segments, the raw behavior counts were normalized by the total traffic volume on each segment, yielding abnormal driving behavior rates as evaluation indicators.

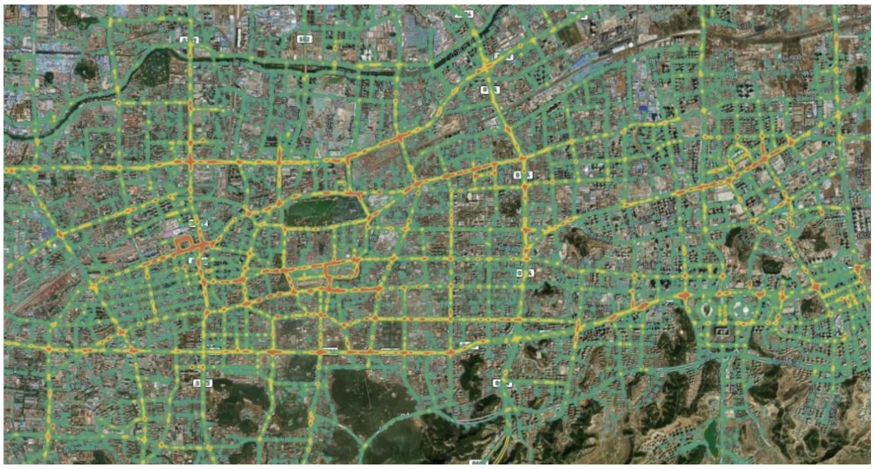

Figure 1. *Thermal map of urban abnormal driving behavior rate distribution*

Figure 1 clearly presents the abnormal driving behavior rate distribution across different urban road network segments, enabling preliminary safety risk assessment. For instance, segment 14900778 exhibits relatively high rates across multiple behavior categories and appears as red shading on the thermal map, indicating elevated safety risk.

3. CONSTRUCTION OF ROAD TRAFFIC SAFETY RISK EVALUATION MODEL

3.1. Establishment of model index system

In the relevant research on the road traffic safety risk evaluation model, the primary work is the selection of model evaluation indicators. The existing research has problems such as difficult index quantification, incomplete index coverage, and low real-time performance of index data.

The abnormal driving behavior data adopted in this paper is a collection of all the above evaluation indicators in the driver's behavior to a certain extent, which is the data embodiment of the driver's behavior habits and the potential safety risks of the road. Such natural driving data has the characteristics of wide coverage, strong real-time performance and low acquisition difficulty. Taking the behavior rate of five abnormal driving behaviors (speeding, sudden acceleration, sudden deceleration, sharp lane change, sharp turn) on each road section as the evaluation index of road risk, the index system of the road traffic safety risk evaluation model is constructed.

3.2. Model construction idea and process

Abnormal driving behavior is the result of the driver's physical and psychological activities, and also reflects the road traffic safety status. In the road sections with road traffic safety risk problems, similar abnormal driving behaviors often occur. For example, sudden deceleration and sharp turn behaviors are prone to occur in sharp curve sections of the city; sudden deceleration and speeding behaviors are prone to occur in long steep slope sections; sudden acceleration, sudden deceleration, speeding and sharp turn driving behaviors are prone to occur in abnormal non-signal intersection sections.

Based on the influence of road dangerous factors on the occurrence of abnormal driving behavior, the road traffic safety risk evaluation model is constructed with the AHP-EW integrated weighting method and the fuzzy comprehensive evaluation method. The model construction process is as follows:

1. Determine the evaluation index system based on the abnormal driving behavior rate;
2. Use the AHP-EW integrated weighting method to solve the weight of each evaluation index, combining subjective weight and objective weight;
3. Aiming at the fuzziness in the evaluation process, the fuzzy comprehensive evaluation method is used to evaluate the road traffic safety risk degree, and the evaluation results are quantified.

4. DETERMINATION OF INDEX WEIGHT BASED ON AHP-EW INTEGRATED WEIGHTING METHOD

The degree of influence of each index in the abnormal driving behavior data on the road traffic safety risk is different, so it is the basic work to establish the road traffic safety risk identification model to calculate the index weight by using a scientific and reasonable weight determination method. The AHP-EW integrated weighting method organically combines the Analytic Hierarchy Process (AHP) and the improved Entropy Weight Method (EW), calculates the subjective weight by the AHP, the objective weight by the improved EW, and integrates the subjective weight and the objective weight by the integrated weighting method to obtain the comprehensive weight of each index.

4.1. AHP subjective weight assignment

The AHP decomposes all research factors related to the decision-making problem into a hierarchical structure of indicators, criteria and schemes, and determines the weight of each level qualitatively and quantitatively on this basis. The target layer is set as "road traffic safety risk evaluation", the criterion layer is divided into three secondary indicators: "accident-prone behavior", "instantaneous abnormal behavior" and "sustained abnormal behavior" according to the behavioral characteristics and damage degree of each abnormal driving behavior, and the abnormal driving behavior rate is taken as the indicator layer.

According to the hierarchical structure model, the importance judgment matrix is constructed according to the importance degree of each factor, and the consistency test is carried out. The random consistency ratio CR is less than 0.1, which passes the consistency test. The hierarchical total sorting is carried out, and the subjective weight assignment of the road traffic safety risk evaluation model based on the AHP is obtained by multiplying the weight of the criterion layer with the weight of the indicator layer. The subjective weight results of each abnormal driving behavior index are shown in Table 2.

Table 2. *Subjective weight assignment results of abnormal driving behavior indicators*

Criteria Layer	Accident-prone (0.5396)	Transient (0.1634)	Continuous (0.2970)	Subjective Weight
Speeding Rate	0.5396	0	0.6251	0.4768
Sudden Acceleration Rate	0	0.3333	0	0.0545
Sudden Deceleration Rate	0.2970	0.6667	0	0.2692
Sharp Lane Change Rate	0.1634	0	0.2384	0.1590
Sharp Turn Rate	0	0	0.1365	0.0405

It can be seen from the subjective weight assignment results that the speeding rate has the largest weight among the abnormal driving behavior indicators, and the sharp turn rate has the smallest weight, which is in line with the general cognition of the traffic industry.

4.2.Improved EW objective weight assignment

The EW is an objective weighting method that calculates the weight of each index through the actual information of the data, and determines the weight of each index mainly through the variation degree of the index. Aiming at the problem that the traditional EW cannot accurately calculate the entropy value when there is zero-value sample data in the data set, this paper proposes a method of adding a small index increment to the zero-value data column to eliminate the adverse effects caused by zero-value data.

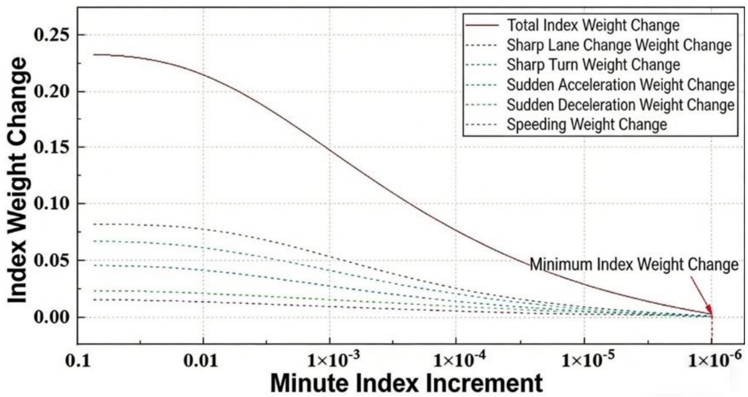

Figure 2. *Correspondence between index increment and weight change*

Taking the extraction results of the road section abnormal driving behavior rate as the data source for the EW calculation, the index system indicators are all negative indicators, and the index matrix is established. The python program is used to standardize the data and add a small increment of 1×10^{-6} to the zero-value data column. The objective weight of the abnormal driving behavior rate index calculated by the improved EW is: w_EW=(0.3852, 0.1025, 0.2863, 0.1587, 0.0673).

4.3. Comprehensive weight determination of AHP-EW integrated weighting method

The subjective weight calculated by AHP and the objective weight calculated by EW are substituted into the weight distribution coefficient solution formula, and the distribution coefficients a=0.62 and b=0.38 are solved. The final comprehensive weight determined by the AHP-EW integrated weighting method is:

$\boldsymbol{w}$=(0.4436, 0.0712, 0.2756, 0.1589, 0.0507)

It can be seen from the comprehensive weight results that speeding and sudden deceleration behaviors have a relatively large weight on road traffic safety risks, which are the key factors affecting road traffic safety.

5. ROAD TRAFFIC SAFETY RISK EVALUATION BASED ON FUZZY COMPREHENSIVE EVALUATION METHOD

Based on the weight assignment results of abnormal driving behavior indicators determined by the AHP-EW integrated weighting method, the road traffic safety risk evaluation model is established based on the Fuzzy Comprehensive Evaluation (FCE) method to realize the road traffic safety risk grade identification. The FCE method quantifies the evaluation factors that are not easy to be quantified according to the membership degree theory in fuzzy mathematics, and evaluates the grade status of the object restricted by multiple factors.

5.1. Determination of FCE three sets

1. Factor set U: U={Speeding rate, Sudden acceleration rate, Sudden deceleration rate, Sharp lane change rate, Sharp turn rate};

2. Comment set V: Combined with the industry road traffic safety classification standard, the comment set is divided into four grades: safe, good, general and dangerous, and the corresponding scores are set as 90, 70, 50 and 30 respectively;

3. Weight set W: The comprehensive weight determined by the AHP-EW integrated weighting method is adopted, that is, $\boldsymbol{W}$=(0.4436, 0.0712, 0.2756, 0.1589, 0.0507).

5.2. Construction of membership matrix and fuzzy comprehensive evaluation

The trapezoidal distribution function with the widest universality is selected as the membership function to construct the membership matrix R. According to the trapezoidal membership function of each evaluation grade and the reference value of the membership degree of the abnormal driving behavior index to each grade, the membership degree of each abnormal driving behavior index to the evaluation grade V is calculated.
Taking the road section No.14900778 as an example, its membership matrix is constructed, and the fuzzy operation of the membership matrix is carried out by using the weighted average fuzzy operator:
$\boldsymbol{S}=\boldsymbol{W}\odot\boldsymbol{R}$=(0.1254, 0.2863, 0.4521, 0.1362)

Based on the maximum membership degree principle, the final risk grade of the road section No.14900778 is classified as general, and the comprehensive score of traffic safety risk of this road section is calculated as 53.24 points according to the risk grade score setting.

6. MODEL VERIFICATION AND ROAD TRAFFIC SAFETY RISK IDENTIFICATION RESULTS

6.1. Example verification of the evaluation model

Taking the road section No.14900778 as an example to verify the validity of the model, the section is the east entrance of a large local railway station with a large road width and traffic flow. The dangerous points of the section are a combination of steep slopes and an oversized abnormal intersection. Drivers are prone to sudden deceleration and speeding driving behaviors when driving downhill; due to the reason that passengers rush to enter the station, drivers are prone to radical driving behaviors such as speeding, sudden acceleration and sharp turn at the abnormal intersection, and the section is relatively dangerous, which verifies that the established road traffic safety risk evaluation model has practical reference significance. The actual situation and abnormal driving behavior distribution of the road section are shown in Figure 3.

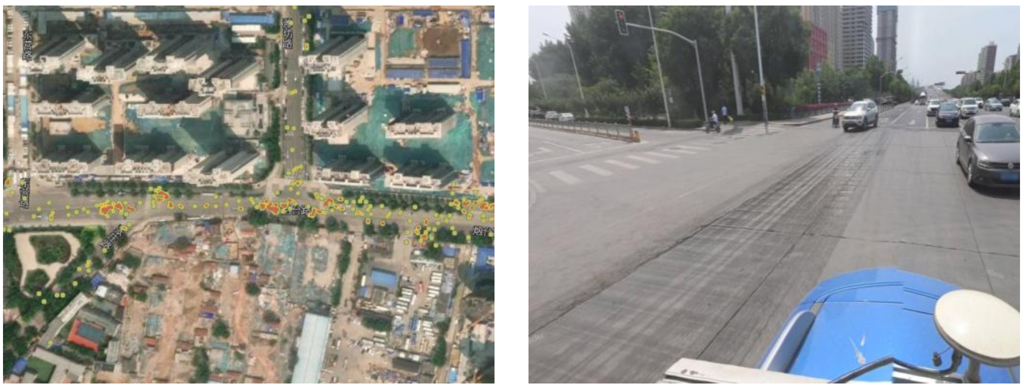

Figure 3. *Road section No.14900778*

(a) Abnormal driving behavior distribution (b) Actual situation of the road section

6.2. Road traffic safety risk identification results

Based on the solution method of the established road traffic safety risk evaluation model, the SPSSAU auxiliary tool is used to calculate the safety risk score of all road sections of a city in Shandong Province. The statistics of the road sections with the worst scores in the city are shown in Table 3, and the visualization of the 20 road sections with the lowest scores is shown in Figure 4.

Table 3. *Results of urban road traffic safety risk evaluation in a city in Shandong*

Road section number	Road name	Start point	End point	Safety risk evaluation score	Safety risk evaluation grade
12000568	Beiyuan Elevated Road	Jiluo Road	Kuangshan Interchange	31.21	Dangerous
13301297	Weiyi Road	Jingsi Road	Jingyi Road	32.10	Dangerous
11000322	Chonghua Road	Huayuan East Road	Gongye South Road	32.26	Dangerous
12000567	Beiyuan Elevated Road	Kuangshan Interchange	Jiluo Road	32.51	Dangerous
12200110	Kanghong Road	Aoti Middle Road	Kaituo Road	32.89	Dangerous

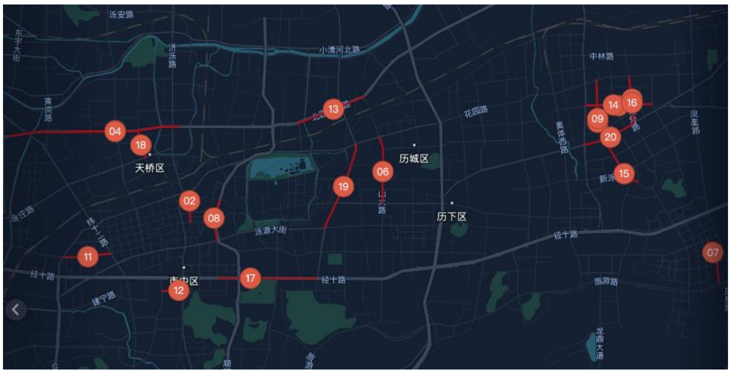

Figure 4. *The urban road sections with the lowest traffic safety risk score in a city in Shandong Province*

7. CONCLUSIONS

Based on the abnormal driving behavior data on road sections, a quantitative method of road traffic safety risk degree based on AHP-EW integrated weighting method and fuzzy comprehensive evaluation method is proposed, and a road traffic safety risk evaluation model is established to realize the safety risk identification of urban road network. The main research conclusions are as follows:

1. The recognition thresholds of abnormal driving behaviors are extracted from the high-risk driver group, and the abnormal driving behavior data on different road sections are quantified by the threshold-based identification model. The abnormal driving behavior rate is used as the evaluation index, which eliminates the influence of traffic flow difference and can objectively reflect the safety risk status of road sections.

2. The AHP-EW integrated weighting method is used to determine the weight of each abnormal driving behavior index on traffic safety risk. The results show that speeding and sudden deceleration behaviors have a relatively large weight, which are the key factors affecting road traffic safety, and it is necessary to focus on the supervision of road sections with frequent occurrence of these abnormal driving behaviors.

3. The road traffic safety risk evaluation model constructed by the fuzzy comprehensive evaluation method can effectively identify the high-risk road sections in the urban road network. The example verification and statistical analysis results show that the model has high practical reference value, can realize the real-time identification of road sections with potential safety hazards in the urban road network, and

provide accurate and real-time data support for traffic management departments to carry out road network safety risk identification and control.

In the follow-up research, multi-source data fusion can be carried out by adding road basic attributes, road linear slope, weather conditions and other factors to enrich the road traffic safety risk evaluation index system, and the actual road section accident data can be added to verify the model results in reverse, so as to further improve the accuracy and reliability of the model.

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