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Research on the Effective Reduction of Accidents on Operating Vehicles with fsQCA Method—Case Studies

Xue Zhang [1,2,*], Yi Lu [1], Xianwen Huang [3,*] and Aizhao Zhou [2]

1 School of Traffic & Transportation Engineering, Changsha University of Science and Technology, Changsha 410114, China
2 College of Civil Engineering and Architecture, Jiangsu University of Science and Technology, Zhenjiang 212100, China
3 School of Civil Engineering, Suzhou University of Science and Technology, Suzhou 215009, China
* Correspondence: zhangxue2005@163.com (X.Z.); huangxianwen194@163.com (X.H.)

Abstract: Traffic accidents are caused by man mainly, especially improper driving. The effective way to reduce safety accidents caused by improper driving is to find out the cause and path causing the accident, block the accident formation chain, and then reduce safety accidents. Therefore, using data from 337 road transport safety accidents in operating vehicles caused by improper driving behavior as the initial research sample, this paper uses the fuzzy set qualitative comparative analysis method to conduct a group analysis of typical cases and identifies the cause and path of safety accidents. The research results show that there are mainly four types of paths leading to safety accidents. According to the distribution of their core conditions, safety accidents are highly correlated with passenger transport and the degree of individualization of business models on operating vehicles. The following measures can be taken to prevent safety accidents: strengthen the supervision of operating enterprises (especially individual operations and individual-affiliated operations), carry out detailed safety training, and fully use advanced technology such as big data and high-tech means. The research results will help traffic and road transport management departments to prevent road safety accidents more effectively, which is of great significance to promoting the healthy development of road transport.

Keywords: safety accident; road transportation; operating vehicles; improper driving; the latent Dirichlet allocation (LDA); fuzzy set qualitative comparative analysis (fsQCA)

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1. Introduction

With a critical role in transport, road transport has become the top priority in the transport industry because of its flexibility and adaptability. The total amount of road transport accidents will continue to increase with the increase of highway mileage, which will increase with the improvement of the national economic level. Studies show that more than 90% of road traffic accidents are related to human factors, and improper driving is the leading cause of safety accidents (herein, "safety accident" refers to the accident of personal injury or property loss caused by improper driving on the road) [1], which account for 44–84.7% of total accidents [2]. The probability of road traffic accidents is greater, and the consequences are more serious regarding commercial transport due to the following characteristics: (1) mainly large- and medium-sized vehicles; (2) large operation intensity, long operation time, and complex operation environment; (3) and the technical performance of vehicles declines in advance, and the aging phenomenon of parts is more prominent. Therefore, it is of great practical significance to study how to reduce road traffic accidents caused by vehicle-operating drivers, especially those accidents caused by improper driving, and build a solid road transport safety line.

Regarding reducing traffic accidents, finding out the influencing factors or analyzing the generation mechanism of accidents is the general practice, followed by blocking the generation chain of accidents to prevent safety accidents. Currently, the research on the influencing factors of road transport accidents has been explored from various perspectives, mainly focusing on the correlation between safety accidents and single and multiple elements of the human-vehicle-road-environment relationship and their coupling. The specific approach is to calibrate the relationship between factors and accident frequency and severity, describe accident characteristics, and find out the influencing factors of the accident. The analysis methods of statistical regression analysis, simulation, Bayesian network method, and fuzzy Petri net analysis are usually used.

Concerning the factor of humans, Pablo et al. [3] analyzed the influence of age and sex on vehicle collisions. Laapotti et al. [4] examined the differences in fatal loss-of-control accidents between young male and female drivers. Paulius et al. [5] proved the correlation between the frequency of road traffic accidents and driving experience with mathematical simulation. Concerning the factor of the environment, Qiu et al. [6] found that traffic safety was significantly affected by snowy and icy weather and that snowfall leads to a higher accident rate by reviewing the extensive literature on a snowy and icy climate's impact on traffic accidents. Cai et al. [7] showed that rainfall was positively correlated with the probability of traffic accidents. Yina et al. [8] found that the risk of traffic accidents increased in foggy weather. Xu et al. [9] also pointed out that traffic accidents were affected by weather conditions. Concerning the vehicle factor, Yan et al. [10] analyzed that the vehicle type was the most significant cause of road traffic accidents based on the traffic accident data of northwestern cities. As for road factors, Jung et al. [11] found that the geometric conditions of roads have an essential impact on traffic accidents. Dhanoa et al. [12] analyzed the relationship between the frequency of traffic accidents and the geometric characteristics of roads and traffic characteristics using the negative binomial regression model.

More scholars have studied the impact of multiple factors and their coupling on safety accidents. Mohammed et al. [13] found that driving speed was affected by drivers' operation, vehicle categories, and safety management. Zageer et al. [14] analyzed the correlation between road conditions, traffic environment, and safety accidents. Milton et al. [15] investigated the influence of multiple factors, such as driver behavior and road factor, on safety accidents based on models. Jie [16] established a Bayesian hierarchical joint model using three years of accident data. The results showed that the higher the AADT, the more lanes, and the more entrances, the more accidents occurred. In 2018, Das et al. [17] analyzed traffic accident data in Louisiana using the association rule Eclat algorithm, and the results showed that traffic accidents were highly correlated with the factors of male sex, off-peak hours, and the interaction of frontal collisions.

Drivers are the leading cause of road traffic accidents. Analyzing the characteristics of driving behaviors and their correlation with traffic accidents could effectively reduce and help avoid traffic accidents. In terms of driving behavior, the existing research mainly analyzes the following aspects: drivers' characteristics, such as physiological and psychological characteristics, personality types, gender, age, and occupation [18]; the relationship between drivers and cars, roads, environment, and pedestrians; and the influence of different driving behaviors [19] on driving safety and driving risk. In 2008, Vanlaar [20] conducted a public opinion survey with drivers in Ontario, showing that 58.6% had experienced fatigue driving. In 2014, Elena [21] fit the Poisson regression model with the population traffic information of Catalonia, showing that gender and age interact with road traffic accidents. Dae-Hwan et al. [22] explored the influence of driver characteristics and violations on traffic accidents through road traffic accident data in South Korea. Oppenheim et al. [23] analyzed the correlation between drivers' behavioral characteristics of illegal driving and overspeed driving. Shirley et al. [24] found that male and young drivers bring higher mortality in traffic accidents. Noh et al. [25] analyzed the correlation between drivers' gender, age, and occupation and traffic accidents with the help of a virtual simulation environment.

The existing research was mainly based on statistical regression analysis, focused on the accident-causing theory in the research results, and primarily focused on the influence of drivers on safety accidents and its relationship with other factors. However, there are few studies on the factor-combination effect on traffic accidents caused by improper driving behavior. Furthermore, there is a lack of research identifying the combination path and core factors of safety accidents caused by improper driving on road transport (especially operational road transport).

Hence, this research explores the condition-combination paths and their core factors of road transport accidents caused by improper driving with fuzzy set qualitative comparative analysis (fsQCA) based on cases. Theoretical and practical guidance is provided to effectively reduce the safety accidents caused by improper driving of operational vehicles.

2. Materials and Methods

2.1. Selection of Research Method

Qualitative comparative analysis (QCA) is a comparative method between traditional qualitative and quantitative analysis, which can provide overall and systematic configuration analysis by combining the advantages of the case study and variable study [26]. This is suitable for seeking the best explanatory path for different outcome variables in 10–60 samples [27]. Based on set theory and Boolean operation [28], this method provides a new way to analyze causal complexity, such as multiple concurrency and asymmetry among factors [29]. Currently, the QCA method is widely used in enterprise organization and management, news dissemination, entrepreneurial environment, enterprise mergers and acquisitions, public security, etc.

Human factors are the most complex and changeable among all the influencing factors of road transport safety accidents. There is a phenomenon of multi-factor coupling, a typical multi-condition configuration relationship. The small sample analysis of the QCA method is suitable for this study. This method can be divided explicitly into clear set qualitative comparative analysis (csQCA), fuzzy set qualitative comparative analysis (fsQCA), and multi-valued set qualitative comparative analysis (mvQCA). In this paper, fsQCA is selected as the research method for the following reasons: (1) This paper explores the core factors and occurrence paths of road transport safety accidents. The study objects are affected by multiple factors that meet the requirements of the QCA method [30]. (2) FsQCA can explore the configuration relationship between multiple factors and configuration equivalence, and it has more advantages than csQCA and mvQCA [31]. (3) Compared with regression analysis, fsQCA has more advantages in analyzing small- and medium-sized sample cases. The flowchart of the research methodology is shown in Figure 1.

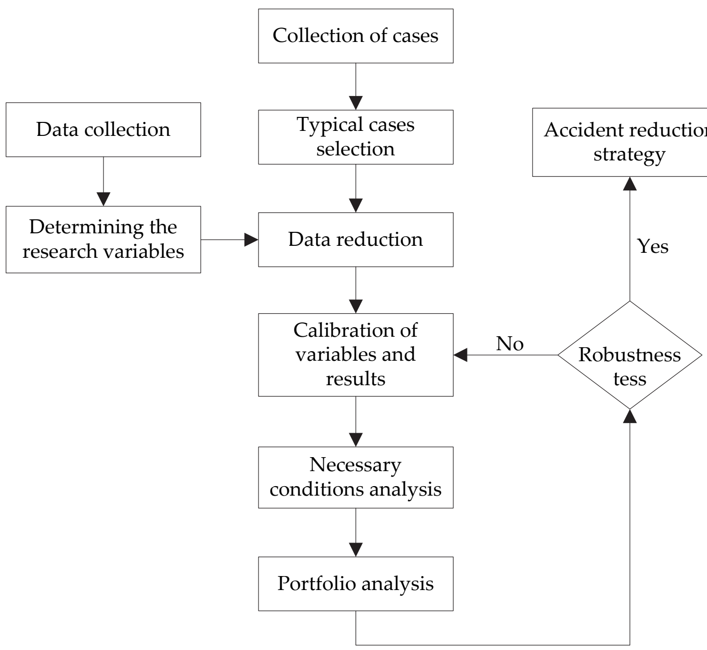

Figure 1. Flowchart of Research Methodology.

2.2. Case Selection for Research

A total of 337 cases of road transport accidents on operating vehicles caused by improper driving behaviors were collected and sorted through the official websites of the National Ministry of Emergency Management, emergency management departments of all provinces, safety management network, and other websites, combined with "Typical Accidents in Transport Safety Production Case Collection" and road transport data of Hunan Province. The initial causes of the accident were: improper operation (26.4%), speeding (20.2%), overcrowding/overloading (19.4%), driving a "sick" vehicle (16.3%), tired driving (7.0%), scrambling for the lane (4.7%), driving on illegal traffic signals (2.3%), driving without a license (1.6%), not giving way according to regulations (1.6%), and drunk driving (0.8%). Four representative accidents were analyzed in the research: improper operation, speeding, overcrowding/overloading, and driving a "sick" vehicle.

Improper operation mainly includes neglecting to observe the road conditions, being careless, not keeping a safe distance from the vehicle in front, bending down to pick up things while driving, and not slowing down when turning. Driving "sick" vehicles mainly means that the vehicle's braking system does not meet the national standards; the vehicle's length, width, and height exceed the prescribed limits; and the vehicle's operation performance is unqualified. Hence, 44 typical cases were selected from the above cases as analysis samples.

The selected typical cases should meet the following conditions:

(1) Integrity. All selected cases have complete accident analysis reports with transparent accident processes, reasons, and complete information;
(2) Representativeness. The accident case has attracted wide attention from society and has been published on the Ministry of Emergency Management website or other media, with significant influence;
(3) Comparability. To ensure the external validity of conclusions, we should select cases that could be comparable; that is, there is heterogeneity among cases [31].

Therefore, among the 44 typical cases selected, 22 belong to major and extremely large-grade road traffic accidents, and 22 belong to relatively large and lower-grade road traffic accidents.

2.3. Variable Selection and Assignment

The causes of road traffic accidents are mainly from four aspects. Namely, people, vehicles, roads and environment, and many influencing factors are involved in each level. To ensure the rationality of the evaluation indicator, we determined the research variables by the latent Dirichlet assignment (LDA) theme model and expert interviews in the research. As a text mining method, the LDA theme model is a three-layer Bayesian machine learning algorithm that can extract topics automatically from large-scale texts without manual processing. It is a corpus-based statistical model to generate potential topics by clustering. It is usually used unsupervised, facilitating researchers to extract potential topics objectively from massive texts. Specifically, LDA is used in this research to identify the topical semantics of 100 highly cited papers from 2000 to 2022. High-frequency words were selected for factor analysis, and Genism and NumPy libraries were used to construct the LDA model [32] after integrating a specialized thesaurus and deactivating undesirable terms.

In this research, the keywords "road traffic accident" and "road traffic safety" were used to search the *China National Knowledge Infrastructure* (CNKI) database, and 100 highly cited papers from 2000 to 2022 were collected. After manual screening and eliminating irrelevant topics such as medical and legal literature, 69 papers were retained as the final analysis text.

The model perplexity of the analyzed texts is illustrated in Figure 2, where it can be seen that the articles had the least confusion when eight topics were selected. However, the best results were obtained using the seven topics extracted in Table 1. Relevant factors were statistically collated after referring to the subject terms, and interviews were conducted with relevant experts. A theoretical research model with seven indicators at four levels was constructed in the research (see Figure 3).

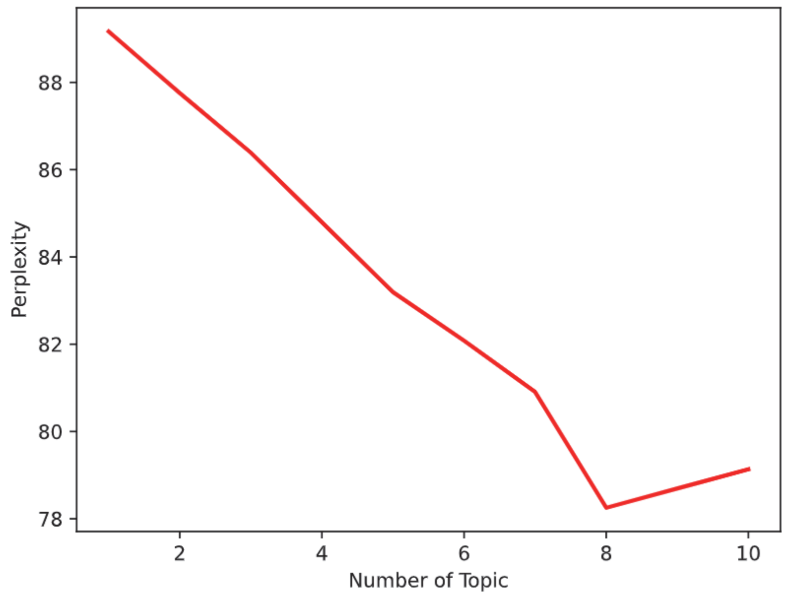

Figure 2. Topic Puzzlement of LDA Model.

Table 1. Extraction Results of Road Traffic Accident Themes.

Topic	Word
0	prediction, model, neural network, network, method, layer, BP, value, error, degree . . .
1	road traffic, traffic, impact, death, number of people, vehicle, driver, accident, environment, lighting, . . .
2	prediction, model, road traffic, accident, impact, death, number of people, traffic, time, highway, . . .
3	accident, vehicle, traffic, driver, damage, system, car, operation, passenger vehicle, speed, . . .
4	accident, driving, death, traffic, driver, number of people, vehicle, road traffic, violation, driving experience, . . .
5	prediction, model, accident, road, desert, number of people, systems, traffic, a section of road, pavement, . . .
6	accident, death, vehicle, emergency response, driving, traffic, data, personnel, background, management, . . .
7	accident, driver, motorcycle, death, system, number of people, prediction, fuzzy, method, loss, . . .

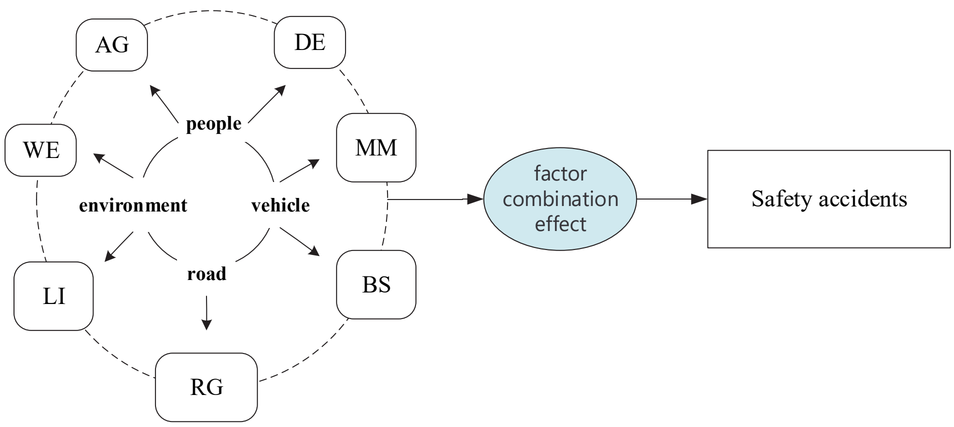

Figure 3. Research Model.

According to the theoretical research, we identified the condition variables: DE (driving experience), AG (age of drivers), MM (management model of operating vehicles), BS (business scope of vehicles), RG (technical grade of roads), WE (weather when driving), and LI (lighting condition when driving). The number of variables meets the requirement of the fsQCA method on the number of variables [33,34]. The dependent variable (outcome variable) is the degree of traffic accidents.

When using the fsQCA method, each condition and outcome are considered a set, and each case has an affiliation score in the set [26]. The tool was calibrated for variable data according to the level of affiliation of cases with the characteristic variables, and all data were assigned values between [0, 1], with larger values indicating higher affiliation (apart from control strength). Direct calibration method and indirect calibration method were used to calibrate each variable in the research. The interpretation and assignment rules of each variable are as follows:

The outcome code, AS, refers to the severity of road transport safety accidents. The more serious the accident, the larger the variable value. According to the classification of safety accident grade following the "Byelaw governing reporting, investigation and handling of production safety accidents" (An order by PRC State Council No 493) (See Table 2), the variable was assigned values according to four-valued fuzzy sets in the fsQCA.

Table 2. Classification of safety accident levels.

Level of Accident	Explanation	Value
Extraordinarily serious accident	Death toll $\geq$ 30, number of seriously injured $\geq$ 100, or direct economic loss $\geq$ CNY 100 million;	1
Serious accident	10 $\leq$ death toll < 30, 50 $\leq$ number of seriously injured < 100, or CNY 50 m $\leq$ direct economic loss < CNY 100 million	0.67
Larger accident	3 $\leq$ death toll < 10, 10 $\leq$ number of seriously injured < 50, or CNY 10 m $\leq$ direct economic loss < CNY 50 m;	0.33
Ordinary accident	Death toll < 3, number of seriously injured < 10, or direct economic loss < CNY 10 m.	0

The condition code, DE, refers to the driving experience. The driving experience was closely related to the road traffic accidents. Drawing on existing research [35,36], driving experience $\leq$ 5 years is considered to be the high-incidence period for traffic accidents, followed by the period of 6–10 years, and the number of traffic accidents and the degree of harm decline slowly and tend to be stable when driving experience > 10 years. However, when the driving experience is more than 20 years, traffic accidents are more likely to occur due to empirical mistakes. Therefore, in this paper, the variable was assigned "1" when driving experience $\leq$ 5 or driving experience > 20, assigned "0.67" when the driving experience was 6–10 years, assigned "0.33" when the driving experience was 16–20 years, and the rest were assigned "0".

The condition code, AG, refers to the age of drivers. Investigation shows that the youngest and oldest drivers have the most severe accident and mortality rates per unit mileage [37]. According to the IIHS report "The Influence of Drivers' Age on Traffic Accidents", 15–19 years old is the age group with the highest rate of traffic accidents. Since then, the accident rate has started to decline with the increase in age, but it has begun to rise significantly after the age of 70. In China, young people aged 20–30 are more likely to lead to traffic accidents, and then, the accident rate falls off with the increase in age [36]. At the same time, the decline in drivers' physical function with growth in age will lead to a rise in the accident rate. Combined with the case samples' age group (26–56), the frequency and severity of traffic accidents were considered to increase with age in this paper. The direct calibration method was used for variable calibration, and 95%, 50%, and 5% were used to set the calibration points with completely affiliated, crossing points, and completely unaffiliated, respectively.

The condition code, MM, refers to the management model of operating vehicles, which has four types: enterprise operation, operation by contract, individual-affiliated operation, and individual operation. The higher the degree of individuation, the greater the security risk. According to the four-valued fuzzy set in fsQCA, the above four modes were assigned values of "0", "0.33", "0.67", and "1", respectively.

The condition code, BS, refers to the business scope of vehicles, which contains line passenger transport, tourist passenger transport, general freight, hazardous chemical transport, and so on. This paper summarizes the above into two categories: passenger transport and freight transport. Referring to the binary system, we assigned "1" when it was a passenger transport, which has larger potential security risks because of the many people involved, and we assigned "0" when it was freight transport.

The condition code, RG, refers to the technical grade of roads. Roads can be divided into expressways, first-class highways, second-class highways, third-class highways, fourth-class highways, and other roads according to the technical grade. According to the safety risk [38], the variable was assigned "1" when the road was expressways and first-class highways, assigned "0.67" when it was second-class highways, assigned "0.33" when it was third-class highways, and the rest were assigned "0".

The condition code, WE, refers to the weather when driving, which includes sunny, cloudy, overcast, rainy, snowy, foggy, windy, and so on. Sunny was good for driving, while adverse weather was dangerous for driving [39]. Referring to the binary system, we assigned "0" when it was sunny and cloudy; otherwise, we assigned "1".

The condition code, LI, refers to the lighting condition when driving, which contains three situations: daytime, nighttime with street lighting, and nighttime without street lighting. Respectively, the variable was assigned "0", "0.5", and "1" for the above situations, respectively, because the better the lighting conditions are, the lower the driving safety risk [39].

All variables of cases were assigned values between [0, 1] according to the above variable assignment rules and calibration methods. Then, a truth table excerpt was compiled as shown in Table 3.

Table 3. Truth table of safety accidents (excerpt).

Number	DE	AG	MM	BS	RG	WE	LI	AS
1	0	0	1	0	1	1	0	1
2	0	0	1	1	1	0	1	1
3	1	0	1	0	1	1	1	1
4	0	1	1	1	0	0	0	1
5	1	0	1	0	1	0	0	0
6	0	1	1	1	0	0	0	1
7	1	1	1	0	1	0	0	1
8	0	0	0	1	1	0	0	1
9	1	1	1	1	0	1	0	1
10	1	1	0	1	0	0	0	0
				……				

3. Results

3.1. Necessary Conditions Analysis

Before analyzing the relevant groupings, it is necessary to determine whether there were necessary conditions that affected the outcome variable. Consistency is an important criterion to measure the necessary conditions. Generally, one condition is considered necessary if the consistency is greater than 0.9. In this paper, necessity was analyzed by fsQCA, and the results are shown in Table 4, revealing that the consistency of all conditions is less than 0.9, indicating that no condition led to the safety accident necessarily, and the data can be further analyzed.

Table 4. Necessity detection of condition.

Antecedent Condition	Outcome Variable	
	Consistency	Coverage
DE	0.689594	0.579259
~DE	0.543210	0.724706
AG	0.635802	0.658748
~AG	0.690917	0.708729
MM	0.778660	0.744519
~MM	0.585097	0.654339
BS	0.589065	0.607273
~BS	0.410935	0.423636
RG	0.896825	0.580645
~RG	0.292328	0.739130
WE	0.470899	0.508571
~WE	0.529101	0.521739
LI	0.411199	0.564836
~LI	0.719753	0.593837

Note: ~, absence.

3.2. Portfolio Analysis of Influencing Factors

Unlike necessity analysis, configuration analysis aims to find the configurations composed of conditions leading to the results. Based on existing research [31,40–42], “0.8” and “1” were set as the raw consistency and case thresholds, and PRI consistency was set to “0.75”. The results were analyzed by outputting complex, parsimonious, and intermediate solutions. In this paper, intermediate solutions [26,28], with both representativeness and parsimony, were selected for analysis, supplemented by parsimonious solutions. The conditions jointly contained in the parsimonious and intermediate solutions are called “core conditions”, and those contained only in the parsimonious solution are called “auxiliary conditions”. The antecedent condition configurations leading to safety accidents are shown in Table 5.

From Table 5, we found that the total consistency was 0.96141, which meets the requirement; the total coverage was 0.571208, indicating that the cases explain 57.12% of the reasons for safety accidents. Eleven paths that may lead to safety accidents were obtained, with consistency greater than 0.8. That is, all of them were sufficient conditions leading to safety accidents. Each path contains more than three antecedent conditions, indicating that multiple factors caused the safety accident. From a lateral perspective in the table, BS as the core condition was contained in most configurations, indicating its importance for the safety accident. In addition, safety accidents were influenced by all antecedent conditions, which appear in all configurations, and from a longitudinal perspective, the eleven paths can be summarized into four types according to the distribution of core conditions.

Type 1 contains paths S1–S3, which can be simplified to: AG*~LI*(DE*MM*~BS*RG*WE + ~DE*MM*BS*~RG*~WE + DE*MM*BS*~RG*WE). AG and ~LI were the core conditions common to this type, which shows that older drivers are more likely to cause accidents during the day. This is related to the higher transport turnover during the day and greater safety risk with higher turnover.

Type 2 contains paths S4–S5, which can be simplified to: MM*WE*(DE*~BS*RG*LI + ~AG*BS*RG*~LI). MM and WE were the core conditions common to this type, which shows that in bad weather conditions, the higher the degree of individualization of the management model, the more likely the safety accident.

Table 5. Conditional configuration analysis of road transportation safety accident.

Variables		**T1**			**T2**		**T3**		**T4**		
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**
DE	*	×	*	●		*	*	×	×	×	*
AG	●	●	●		⊗	*	*	⊗	⊗	⊗	×
MM	*	●	●	●	●	*	*	×	*		*
BS	⊗	●	●	⊗	×	●	●	●	●	●	
RG	*	⊗	⊗	●	*	*	*	*	*	*	*
WE	⊗	×	*	●	●	⊗	⊗	*	×	×	*
LI	⊗	⊗	⊗	●	⊗	●	●	*		×	*
consistency	1	1	1	1	0.992496	1	1	1	0.914141	0.859155	1
Raw coverage	0.0458554	0.0440917	0.0348324	0.0662698	0.174956	0.0507055	0.058642	0.0586861	0.159612	0.13179	0.0821429
Unique coverage	0.0458553	0.0185185	0.0282187	0.00886244	0.117725	0.0149912	0.0295414	0.0441358	0.0282628	0.0180776	0.0101852
Solution consistency						0.96141					
Solution coverage						0.571208					

Note: ● (presence) and ⊗ (absence) represent core condition; * (presence) and × (absence) represent peripheral condition; blank represents no impact.

Type 3 contains paths S6–S7, which can be simplified to: BS*~WE*LI*(~DE*AG*~MM*RG + DE*AG*MM*RG). BS, ~WE, and LI were the core conditions common to this type, which shows that in sunny and cloudy weather, passenger transport at night is more likely to lead to safety accidents.

Type 4 contains paths S8–S10, simplified to: ~AG*BS*(~DE*~MM*RG*WE*LI + ~DE*MM*RG*~WE + ~DE*RG*~WE*~LI). ~AG and BS were the core conditions common to this type, which shows that younger drivers are more likely to lead to safety accidents. It reflects that young drivers, although full of energy, were more likely to lead to safety accidents due to lacking calm responses when encountering an emergency.

3.3. Robustness Test

Adjusting for the level of consistency is a common method of determining QCA robustness (Greckhamer et al., 2018). According to Greckhamer et al. [43], the robustness of a method refers to its capacity to remain unaffected by small variations in the methodological parameters. Hence, it can be ascribed to "reliability".

In this research, the consistency level threshold was increased to 0.8 from 0.75, and group analysis was performed again using the same frequencies. The results show that there were no substantial changes in the number of condition configurations, overall consistency, and coverage. Hence, the model is robust and reliable.

4. Discussion

Based on the eleven paths ascertained from the analysis, the following three major suggestions are offered to resolve the problem:

1. Strengthen supervision over the self-employed.

In the results, the variable "MM" is the core condition of type 2, indicating that safety accidents are more likely brought on by individual operation. Meanwhile, from the perspective of a single-antecedent condition (horizontal), the variable "MM" also appears more frequently in all configurations, indicating the importance of this variable for safety accidents, to which we should be paid attention. The higher the degree of individualization of the management model, the higher the probability of leading to safety accidents, especially in the individual and affiliated operations. The key to blocking such accidents is strengthening operating enterprises' supervision, especially the individual and affiliated operations. First, we need to improve the safety management system, consolidate the safety responsibilities of all parties, truly implement the capacity assessment of safety in production on the legal body of enterprise and safety management personnel, and ensure safety and orderly production by improving the safety management ability of the person in charge of enterprise and safety management personnel effectively. For example, the evaluation of system construction and the application of measures of "zero hidden danger" in safety production could be carried out in the transportation industry. All large- and medium-sized vehicles operated by individuals shall be checked in each jurisdiction where they are registered and managed by classification according to the business scope of vehicles and state of operation. We need to ensure that all vehicles are well-supervised, with no illegal operation. Second, we need to deepen safety training. The training model and assessment mechanism with scientific, efficient, and practical factors should be established. The form of on-site centralized training (offline training) and network training (online training) can both be adopted to enhance drivers' driving skills and crisis management ability. For example, training on business knowledge update for safe driving, "illegal driver training" on operating vehicles, and safety production education activities could be conducted.

2. Attaching importance to passenger transport safety.

"BS" is the core condition both in type 3 and type 4, which can be considered an important variable leading to safety accidents. On the other hand, "BS" appears in most configurations from the perspective of a single-antecedent condition (horizontal), indicating the importance of this variable for safety accidents. More attention should be paid to passenger transport. As a special transport carrier, passenger vehicles (especially medium buses) bring great safety risk because of their characteristics of more person loading and their high frequency of starts and stops. Generally, the following three major suggestions are offered to block the path of such passenger traffic accidents: Firstly, we should strengthen safety management and supervision on passenger vehicles, especially those operated by individuals or individual-affiliated, and enhance the sense of responsibility and consciousness of safety supervision by investigating and handling accidents strictly, holding departments and personnel accountable for the non-performance of their duties. For example, safety assessment could be carried out on the persons in charge of enterprises and the persons engaging in safety management in urban passenger transport enterprises. The following points can be thoroughly checked: qualification of passenger vehicles and the drivers, the safety condition and GPS installation and usage on the passenger vehicle, and implementation of a safety management system in passenger transport enterprises. Secondly, standardized and comprehensive safety education and training could be carried out to ensure that everyone in safety production is involved. Thirdly, management and monitoring of all staff (vehicle), the whole process, and during the full 24 h could be implemented on drivers and vehicles based on an intelligent supervision platform, which can prevent conditions from becoming out of control, such as preventing drivers without qualification certificates from driving on the road and preventing fatigue driving. For example, a vehicle intelligent supervision platform can be used for two types of vehicles: chartered buses for a tour and buses running on a line. By monitoring online in real time, 17 unsafe driving behaviors (such as smoking, talking on the phone while driving, speeding, etc.) can be accurately managed. Safety management and production could be strengthened from the system, method, and psychological level to reduce/block the such safety accidents.

3. Be aware of negligence and carelessness.

It is worth noting that "~LI" and "~AG" are core conditions in type 1 and type 4, indicating that safety accidents caused by drivers' negligence should be indicated even under good driving conditions. The frequency and harmful degree of safety accidents that occur during the day are more serious although there is a considerable safety risk when driving at night. Meanwhile, safety accidents also emerge among experienced drivers. All of the above indicates that negligence and carelessness should be alerted. The key to preventing such accidents are as follows: Firstly, mobilization and deployment should be done better to enhance safety responsibility. The job should be implemented from the supervision department to enterprises and then to personnel, layer by layer, which ensures the awareness of safety responsibility is improved effectively. Secondly, we should pay attention to publicity and education and improve traffic safety awareness. Thirdly, we must strengthen road control and investigate and punish illegal vehicles. The concrete solutions are as follows: Registration and inspection strictly on the road can be carried out on passenger vehicles, precise inspection on passenger vehicles can be conducted in accordance with the rules and characteristics of major road traffic accidents involving passenger vehicles under the jurisdiction, and personnel involved in production safety (the leading persons in charge of the enterprises, the persons in charge of safety and operation, the persons in charge of the departments, etc.) shall be punished for passenger transport enterprises with more than two illegal driving instances within two years. We should strengthen patrol and control on the accident-prone section of roads, strictly inspect the passing transport vehicles, remove the latent danger in road transportation in real time to keep people away from negligence and carelessness, and always pay attention to safety.

5. Conclusions

This paper aims to analyze how to effectively reduce traffic accidents caused by improper driving of operational vehicles, focusing on the analysis of the causes and conditions combination path of traffic accidents caused by improper driving. The main contribution of this paper is to provide a new perspective for the study of safety accidents, reflected in the following aspects: considering the impact of road transport operation characteristics on safety accidents, using LDA thematic model in constructing indicators, and conducting a group analysis based on cases.

From the results of the single-factor analysis, there are no necessary conditions for safety accidents. From the results of portfolio analysis with multiple factors, it was found that several paths leading to safety accidents and improvements depend on choosing different methods for different situations. Through the analysis of the horizontal and vertical dimensions of the eleven paths, it can be found that the accidents caused by improper driving in operating vehicles mainly involve passenger vehicles, and the management model on operating vehicles has an important impact on the formation of safety accidents. Measures such as strengthening the supervision of operating enterprises (especially the individual operations and the individual-affiliated operations), conducting detailed safety training, and making full use of advanced technologies such as big data and high-tech means are suggested to prevent safety accidents.

Many factors affect road transport safety in the complex system composed of person-vehicle-road-environment factors. Only seven variables (DE, AG, MM, BS, RG, WE, LI) are analyzed in this paper. The conditional combination paths of other variables could be analyzed in the future, whose results can be referenced for preventing road transport accidents. In addition, owing to the limited access to data, the sample of this paper only included 44 typical cases, which is small. Thus, the statistical results may show unstable or limited results despite the model's robustness. Therefore, the comprehensiveness of the control measures proposed in this paper deserves further study. In future research, multiple testing methods and results analyses should be used to offer better cross-check validity.

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