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Evaluating Tunnel Users' Literacy on Expressway Tunnel Fire Safety: Questionnaire Analysis and Policy Decisions

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Abstract: The number of tunnel fire accidents has increased with the scale of expressway tunnel construction and traffic flow. Due to the severity of tunnel fires, improving tunnel fire safety and reducing fire accident hazards has become a societal concern. It is essential to explore and evaluate tunnel fire safety literacy among the population. In this study, an online and on-site questionnaire survey was conducted in Hunan Province, China. A total of 1990 questionnaires were collected, of which 1573 were valid. Overall statistical analysis, descriptive statistics, and correlation analysis were performed on valid questionnaires. The results show that the overall level score rate of awareness of drivers and passengers regarding tunnel fire safety was only 0.43. In total, 58.42% of people were unaware of the pedestrian cross passages in expressway tunnels, and 68.40% were unable to recognize them. Similarly, 46.47% of people were unable to recognize evacuation signs in expressway tunnels. In addition, 39.29% of people chose the wrong evacuation behavior. The percentage of people who were aware of the correct usage of firefighting facilities in expressway tunnels was below 50.00%. Correlation analysis results show that tunnel users' demographic characteristics significantly affected their cognition of expressway tunnel escape methods. This study shows that tunnel users' emergency escape knowledge regarding tunnels is relatively low. Corresponding countermeasures were proposed to guide policy decisions for enhancing tunnel fire safety.

Keywords: expressway tunnel; fire safety literacy; pedestrian cross passage; questionnaire survey; correlation analysis

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1. Introduction

1.1. Research Motivation

In the contemporary world, expressway tunnel construction is increasing in scale in order to shorten distances, promote transportation development, and minimize potential environmental impacts [1]. The growth of road tunnels occurs principally by the construction of expressway tunnels [2,3]. China has the most significant growth regarding the number of tunnels in the world [3,4], increasing from 7384 to 23,268 road tunnels between 2010 and 2021. In previous studies, it has been shown that the average annual frequency of tunnel fires increases with the scale of expressway tunnels and the number of traffic vehicles [5], and severe accidents are more frequent in road tunnels [6]. The tunnel fires can cause catastrophic consequences, including loss of life, property damage, and prolonged service disruption [7–9]. The gas temperature inside a narrow and semi-enclosed tunnel can quickly reach over 1000 °C, causing rapid spread of fire and smoke that can last a

long time [10,11]. Evacuation and rescue team intervention for tunnel users is not convenient [12,13]. Reducing the number of fatalities and injuries during tunnel fire evacuations is the main aim of fire safety engineering [14,15]. Therefore, self-evacuation behavior involving suitable decisions and proficient actions is of crucial importance [16].

Some typical tunnel fire cases obtained from the literature [5,17–19] are presented in Table 1. Through analyzing the tunnel fire cases, it can be seen that people are often unaware of the correct escape method, resulting in a large number of losses of lives and property. During the tunnel accident, some people closed their windows and waited for rescue, and some drove or abandoned their cars and fled. The fire spread rapidly and released a large amount of toxic smoke, causing multiple vehicles to crash and people to be trapped, and making evacuation impossible without the guidance of fire rescue teams. Many of those people fainted from the smoke.

Table 1. Selected typical tunnel fire cases.

Year	Tunnel	Victims	Vehicle and Damage
1999	Mont Blanc tunnel, Europe	39 dead	37 cars burned; tunnel facilities were severely damaged
1999	Tauern Motorway Tunnel, Austria	12 dead; 49 injured	40 cars burned; tunnel facilities were severely damaged
2007	Burnley tunnel, Australia	3 dead	11 cars burned; tunnel facilities damaged
2008	Dabaoshan tunnel, China	2 dead; 5 injured	2 trucks burned; tunnel facilities were severely damaged
2014	Yanhou tunnel, China	40 dead; 12 injured	42 cars burned; tunnel facilities were severely damaged
2010	Huishan tunnel, China	24 dead; 19 injured	Damage to cars and tunnel facilities
2011	Xinqidaoliang tunnel, China	4 dead; 1 injured	3 cars burned; tunnel facilities damaged
2013	Liushililiang tunnel, China	6 dead; 2 injured	4 cars burned; some tunnel facilities damaged
2019	Maoliling tunnel, China	5 dead; 31 injured	Cars and tunnel facilities were severely damaged
2020	Xuefengshan tunnel, China	2 dead	31 cars burned; tunnel facilities damaged

These cases highlight the incorrect self-evacuation behaviors to which people resort in the event of a tunnel fire. There may be a significant knowledge gap among most people regarding the correct evacuation procedures. However, behavioral characteristics directly affect the safety of evacuation. Thus, it is necessary to explore and evaluate tunnel users' tunnel fire safety literacy and to make relevant recommendations from a policy perspective to enhance tunnel users' literacy in terms of tunnel fire safety.

1.2. Related Work

In recent years, transportation safety and fire safety have aroused wide concern in academic circles [20–22]. Among them, the interest in tunnel fire safety has significantly increased, principally due to the rapidly increasing number of tunnels being built and catastrophic tunnel fire incidents that have occurred [23,24]. Extensive studies [25–30] have been conducted to study tunnel fire safety. Ren et al. [5] considered tunnel fire accidents in China from 2000 to 2016, and the characteristics of the causes, frequency, and regional distribution of road tunnel fire accidents were obtained. Wang et al. [31] analyzed the influence of different fire locations on evacuation time by using numerical simulation, and Xu et al. [32] studied the vertical temperature distribution of two-layer smoke flow in tunnels during construction. Ntzeremes et al. [33] proposed a tunnel fire risk-based method to support tunnel operators in evaluating the criticality of potential fire incidents by using real-time data. The above studies mostly focused on temperature distributions, fire-causing mechanisms, evacuation rules, tunnel fire risk assessments, and other engineering problems. Real-case analyses, experimental studies, and numerical simulations are usually applied to related studies [34].

In addition to the study on engineering and technology problems, there is also increasing attention on tunnel fire safety from the "people" perspective, including psychological

behavior, path choice, and facility cognition during evacuations. The related studies mostly used computer simulations and experimental studies. Some numerical simulations of several fire accidents scenarios in a real urban tunnel were conducted. The outcomes of the simulations indicated that the number of threatened people may be very high, even under common circumstances. In the worst case, over half of the people trapped inside may come into contact [35]. By performing evacuation experiments in a tunnel, Porzycki et al. [36] discovered that movement speed in smoky environments is influenced by tunnel visibility, evacuee attitude, tunnel familiarity, and evacuation procedures. By carrying out on-site tunnel evacuation experiments by means of video recording, questionnaire surveys, and interviews, Zhang et al. [37] found that information signs played an important guiding role in tunnel users' escape route choices. Ronchi et al. [38] conducted an evacuation experiment in a road tunnel. It was found that the addition of information signs, way-finding signs, and loudspeakers at the tunnel emergency exit may improve the likelihood of people finding and using tunnel emergency exits.

In order to investigate tunnel users' psychological behavior during evacuations and tunnel fire safety knowledge, the questionnaire method was adopted. Zhou et al. [39] conducted a questionnaire survey to study the characteristics of tunnel users' psychological behavior during an evacuation of a road tunnel due to a fire. The study found that most people had poor psychological quality. The age, gender, education level, and fire safety education were significant factors associated with psychological evacuation in road tunnels. Lee et al. [40] discovered gaps in drivers' knowledge of tunnel safety and equipment through a questionnaire. Drivers often adopt inappropriate habits and behaviors while driving through tunnels. Kirytopoulos et al. [41] conducted a survey of drivers in Greece and found that, in the event of a tunnel fire, quite a few people chose to stop the car, close the windows, and wait in the car for rescue, which proved to be highly undesirable during the Mont Blanc fire. There are few studies that have specifically targeted tunnel users' fire safety literacy in expressway tunnels.

Most previous studies have focused on engineering and technology problems, as well as tunnel users' psychological behavior during evacuation. However, fire safety literacy in expressway tunnels from the perspective of "people" has rarely been investigated in existing studies. Actually, the improvement of tunnel fire safety should be based on the analysis of tunnel user's current fire safety knowledge. Therefore, investigating tunnel users' fire safety literacy in expressway tunnels holds significant importance for tunnel fire safety protection.

1.3. Aim of the Paper

As mentioned above, tunnel users' literacy regarding expressway tunnel fire safety has rarely been studied at present. In an expressway tunnel, a pedestrian crossing passage connects the main tunnel to a safe place and provides a safe route for the evacuation of tunnel users from a tunnel fire [42]. At the same time, firefighters and rescuers can enter the fire tunnel quickly from safety tunnels via the crossing passages so as to fight the fire. In addition, expressway tunnels are installed with evacuation signs and firefighting facilities. However, according to existing tunnel fire cases, people are unaware of the correct method of escape from tunnel fires. The effectiveness of pedestrian cross passages and firefighting facilities in expressway tunnels has not been significant. To address this issue, further study is needed to explore and evaluate tunnel users' fire safety literacy.

In this study, a questionnaire survey was carried out to investigate tunnel users' cognition regarding escape methods and firefighting facilities in expressway tunnels. Thus, it is beneficial to understand tunnel users' fire safety literacy and to propose measures from a policy perspective to improve it. Hunan Province of China, which has many tunnels, was selected as the study area. On the basis of the investigation results, recommendations were put forward to enhance tunnel fire safety. The outcomes of this study can serve as a foundation for developing evacuation and emergency plans from a policy perspective.

Valuable insights and supporting data for improving expressway tunnel safety are offered by this study.

2. Materials and Methods

2.1. Survey Outline

To survey tunnel users' cognitive understanding of the escape methods and firefighting facilities in expressway tunnels, a questionnaire survey was conducted in this study. The relevant literature was extensively reviewed to ensure that the content of the questionnaire was rational, logical, easily understood, and purposeful. The questionnaire consisted of 18 questions, including tunnel users' basic information and their understanding of escape methods and firefighting facilities in expressway tunnels. The basic information included gender, age, education level, frequency of use of expressway tunnels, types of vehicles used, and participation in fire safety training or drills. The understanding of escape methods in expressway tunnels includes awareness of pedestrian cross passages in expressway tunnels, recognition of pedestrian cross passages, recognition of evacuation signs in expressway tunnels, and choice of the correct evacuation route in the middle section of an extra-long tunnel. The investigation focused on the cognition of escape methods in expressway tunnels. The understanding of firefighting facilities in expressway tunnels includes the recognition of fire extinguishers, fire hydrants, manual alarm buttons, and emergency telephones, as well as awareness of the correct usage of these firefighting facilities.

2.2. Survey Implementation

The target population of this questionnaire survey included drivers and passengers, because passengers are also potential users of tunnels. The survey was conducted using on-site surveys as the main method and online questionnaires as the auxiliary method. The online questionnaire was principally distributed through the Wenjuanxing (https://www.wjx.cn/ (accessed on 1 July 2022)) platform, which provides services for collecting appropriate questionnaires [43]. The collection methods were principally self-filling questionnaires, with face-to-face interviews used for some people. Hunan Province, China, was selected as the study area, and the data collection was principally concentrated in Changsha City, Hunan Province. There were 900 road tunnels in Hunan Province in 2021, including 37 extra-long tunnels. The long expressway tunnels were principally located in Changsha, Huaihua, Yongzhou, Jishou, Zhuzhou, Zhangjiajie and other regions of Hunan Province. The average daily traffic flow on expressways where the Hunan extra-long tunnel is located is high, increasing the risk of tunnel fires. Therefore, the survey focused on cities like Changsha, Huaihua, Chenzhou, and Zhuzhou. Among them, Changsha City was the principal survey area. In order to make the data more authentic and targeted, part of the survey area included rest service areas near expressway tunnels in Changsha, such as Dongyang Service Area and Changshaxi Service Area. In addition, questionnaire surveys were carried out in shopping malls, residential areas, street fronts, and elsewhere. This not only ensured diversity of the samples, but also ensured the data's reliability. The survey lasted eight months, from July 2022 to February 2023.

A pilot study was conducted before the formal start of the investigation, providing significant inputs for the modification and improvement of the questionnaire design [44]. Through an online questionnaire, a small survey of drivers and passengers was conducted. According to the answers and questions raised by the respondents, the questionnaire content was improved to ensure that it was scientific, rational, and effective. Finally, according to the final version of the questionnaire, we started a formal large-scale investigation. In general, the survey was carried out in two stages. In the first stage, the main content of the questionnaire included the tunnel user's basic information and their cognition of expressway tunnel escape methods, for a total of nine questions. In the second stage, an additional section on cognition of firefighting facilities in expressway tunnels was added to the questionnaire, for a total of 18 questions. During the survey, respondents were informed

that the data would only be used for academic research, and anonymity was maintained. All respondents were requested to provide truthful responses on a voluntary basis.

2.3. Participants' Profiles

A total of 1990 questionnaires were collected in the survey. However, some respondents did not answer all questions on the paper, or gave too-short or inconsistent answers. These questionnaires were excluded from the final sample. In general, only a total of 1573 effective questionnaires were obtained, with an effectiveness rate of 79.05%. In the first stage, 792 effective questionnaires were collected, including two parts. In the second stage, 781 effective questionnaires were obtained, including three parts. Thus, the number of questionnaires including both the tunnel user's basic information and their cognition of expressway tunnel escape methods was 1573. All of these numbers exceeded the minimum sample size requirement of 400 at a 95% confidence level and a sampling error of 0.05, meeting the needs of the study. Under a 95% confidence level (t = 1.96), the sample size required for different sampling errors was calculated using Equation (1) [45].

$$n = \frac{t^2}{4e^2} \tag{1}$$

where t is the critical value corresponding to the confidence level and e is the allowable sampling error.

In the questionnaire data, the male proportion was 56.52%, while the female proportion was 43.48%. The age group was principally concentrated in the 18–55 age group, for which it is easy to carry out a questionnaire survey, as this population tends to have strong reaction abilities. The education levels were principally a high school or technical school degree or a bachelor or college degree. Among them, the bachelor or college degree population was the highest. The highly educated people more easily filled out the questionnaire and showed a higher degree of cooperation. The less educated people had more difficulty filling in the questionnaire and often had a lower degree of cooperation. With regard to the number of times people passed through expressway tunnels in a year, more than 77.00% of them passed through approximately 50 times or less in a year. A total of 69.27% of the respondents had participated in fire safety training or a drill. The vehicles that most people drove or took through expressway tunnels were private cars, minibuses or buses, and service cars (taxis, e-hailing, etc.). The number of people driving or riding small and medium-sized trucks, large trucks and trailers, and hazardous chemical transport vehicles was relatively small. Descriptive statistics of the characteristics are shown in Table 2.

2.4. Statistical Analysis

2.4.1. Overall Statistical Analysis

The purpose of the overall statistical analysis was to quantitatively evaluate the overall level of awareness of drivers and passengers regarding tunnel fire safety. The overall score for the awareness of drivers and passengers regarding tunnel fire safety can be expressed as F. The questions in the questionnaire that show the level of awareness of drivers and passengers can be expressed as i, and the number of questionnaires can be expressed as n. A total of 12 questions were related to the awareness of drivers and passengers regarding tunnel fire safety (i = 12). The questions were all single-choice: those were aware or able to recognize were given scores of 1, and those who were unaware or unable to recognize were given scores of 0. The score of each question on a single questionnaire can be expressed as p_j ($1 \leq j \leq i$). The score of each question was summed up. The ratio of the actual score of each question to the optimal score was the value of the evaluation index P_j ($1 \leq j \leq i$) for each question. The calculation processes for P_j and F are shown in Equations (2) and (3), respectively.

$$P_j = \frac{\sum_{1}^{n} p_j}{n} \quad (2)$$

$$F = \frac{\sum_{1}^{i} P_j}{i} \quad (3)$$

where F represents the overall level of awareness of drivers and passengers regarding tunnel fire safety. The higher the value of F, the higher the overall level of awareness of drivers and passengers, and vice versa.

Table 2. Descriptive statistics of the characteristics.

Variable	Categories	Frequency	Proportion (%)
Gender	Man	889	56.52%
	Woman	684	43.48%
Age	Under 18 years old	40	2.54%
	18–35 years old	938	59.63%
	36–55 years old	522	33.18%
	Over 55 years old	73	4.64%
Education level	Junior high school degree or below	292	18.56%
	High school or technical school degree	494	31.40%
	Bachelor or college degree	712	45.26%
	Master's degree or above	75	4.77%
Frequency of use of expressway tunnels	Less than or equal to 10 times a year	699	44.44%
	10–50 times (including 50 times) a year	527	33.50%
	50–200 times (including 200 times) a year	245	15.58%
	More than 200 times a year	102	6.48%
Participation in fire safety training or drills	Have participated in	541	69.27%
	Have not participated in	240	30.73%
Types of vehicles used	Private car	1161	73.81%
	Service car	476	30.26%
	Minibus or bus	485	30.83%
	Small and medium truck	64	4.07%
	Large truck and trailer	51	3.24%
	Hazardous chemical transport vehicle	4	0.25%
	Other	52	3.31%

2.4.2. Descriptive Statistical and Correlation Analysis

Quantitative processing and data entry were carried out for the collected valid questionnaires. Through descriptive statistics, the distribution characteristics of the answers and the relevant information in the questionnaire were obtained. Thus, the tunnel users' literacy regarding expressway tunnel fire safety were collected.

The goal of this questionnaire survey was to investigate tunnel users' understanding of expressway tunnel escape methods. For further analysis, the study intends to investigate gender, age, education level, number of times a year one passes through expressway tunnels, whether one has participated in fire safety training or drills, and types of vehicles used, as well as the impact of these variables on the cognition of expressway tunnel escape methods. The collected data were statistically analyzed using SPSS 27.0, and correlation analyses

were performed using the χ^2 test. The χ^2 test was applied to the correlation analysis of two categorical variables. The significantly correlated factors were then analyzed in the form of graphs. The calculation process of χ^2 is shown in Equations (4) and (5) [45].

$$\chi^2 = \sum \frac{(f_o - f_e)^2}{f_e} \tag{4}$$

$$f_e = \frac{n_r \times n_c}{N} \tag{5}$$

where f_o is the observed (actual) frequency of each cell in the interaction classification table, f_e is the expected frequency corresponding to f_o in the interaction classification table, n_r denotes the total number of rows in which each f_o is located, n_c denotes the total number of columns in which each f_o is located, and N denotes the total number of cases.

The degrees of freedom can be calculated by Equation (6).

$$df = (r - 1) \cdot (c - 1) \tag{6}$$

where r and c are the number of rows and the number of columns in the interaction classification table, respectively.

After calculating the χ^2 values and degrees of freedom, the p-value could be calculated by checking the χ^2 distribution table. The significance level was set at 0.05. If p was greater than 0.05, there was no effect between the row and column variables. If p was less than 0.05, the row and column variables were significantly correlated.

3. Results and Discussion

3.1. Overall Level of Tunnel Users' Awareness

According to the principle of overall statistical analysis and the results of the questionnaires, the overall level score rate of awareness of drivers and passengers on tunnel fire safety was found to be $F = 0.43$. The result indicates that the overall level of awareness of drivers and passengers on tunnel fire safety does not reach the 50% level. The level of fire safety literacy among tunnel users has not improved in the past decade [39]. There is much room for improvement in the overall level of awareness.

3.2. Cognition of Escape Methods in Expressway Tunnels

In this study, an analysis of 1573 valid questionnaires was used to determine tunnel users' understanding of expressway tunnel escape methods. There are pedestrian cross passages between adjacent tunnels designed for evacuation. Expressway tunnels of more than 500 m have pedestrian cross passages at intervals of no less than 250 m. As shown in Figure 1, only 41.58% of people were aware of the pedestrian cross passages in expressway tunnels, and 58.42% lacked this awareness. Furthermore, only 31.60% of people were able to recognize the pedestrian cross passages in expressway tunnels, and 68.40% of them were unable. The results show that only a small proportion of people have knowledge of the escape facilities in expressway tunnels, and even fewer can use them correctly. Some of the respondents were aware of pedestrian cross passages, but unable to recognize them. They may have acquired knowledge of pedestrian cross passages through fire prevention lectures, news reports, and similar sources, but lacked a clear understanding of their locations, function, and use.

On both sides of a tunnel's walls, pedestrian cross passages at the entrances and exits should be installed with appropriate evacuation signs to guide the direction of escape in case of fire. The analysis results of the survey data (see Figure 1) revealed that only 53.53% of people were able to recognize evacuation signs in expressway tunnels, leaving 46.47% unable to do so. Clearly, almost half of the respondents are not familiar with crucial evacuation signs, which would impact their evacuation route selection and efficiency in

tunnel fires. Promoting awareness of proper escape methods and improving fire safety literacy among people is crucial.

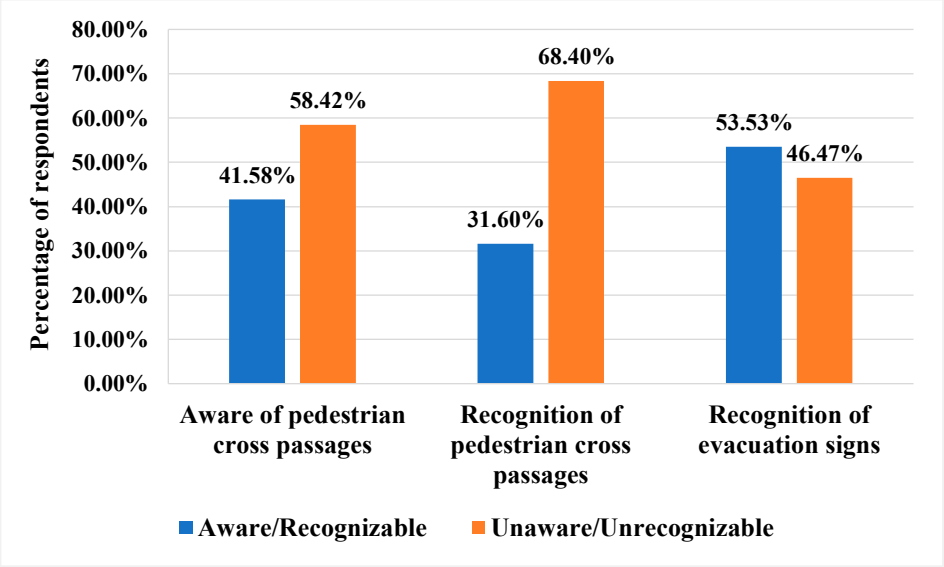

Figure 1. Tunnel users' cognition of pedestrian cross passages and evacuation signs.

Through analyzing previous tunnel fire cases, tunnel users have tended to escape in a panic, leading to inappropriate choices of escape routes. This study explores the ability of people to choose the correct evacuation route in the middle section of an extra-long tunnel fire. As shown in Figure 2, 12.27% of people believe that the correct evacuation route involves collective action and escape where there are many people. Additionally, 7.63% would choose to stay in the car and wait for help, while 19.39% would choose to quickly escape towards the entrances or exits of the tunnel and exit the tunnel as soon as possible. Moreover, 60.71% of people would choose to follow the evacuation signs inside the tunnel to find pedestrian cross passages and then escape. It can be seen that 39.29% of people chose the wrong evacuation route, indicating a serious lack of knowledge regarding tunnel escape routes. However, when faced with an actual tunnel fire scenario, the percentage of people who can evacuate in the correct evacuation route will be even lower.

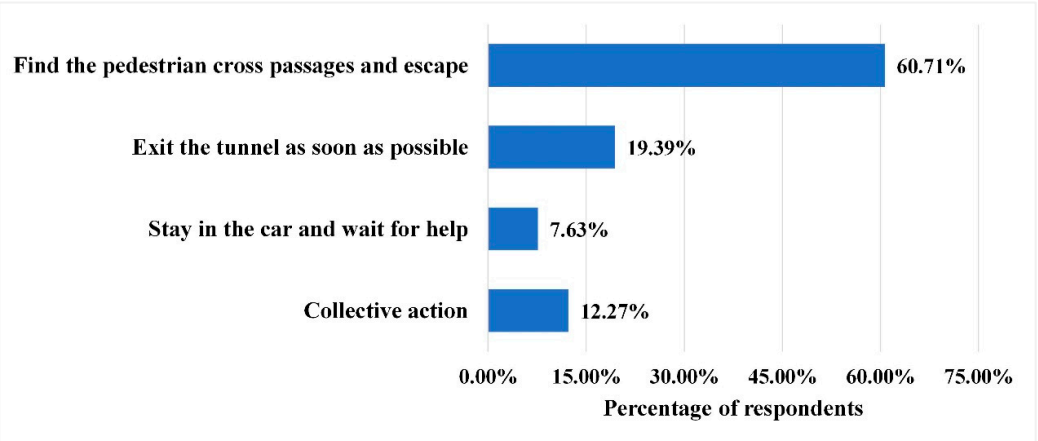

Figure 2. Tunnel users' choice of correct evacuation route.

3.3. Cognition of Firefighting Facilities in Expressway Tunnels

In the second round of the questionnaire survey conducted in this study, an additional section was added to investigate the knowledge of the participants regarding firefighting

facilities in expressway tunnels. A total of 781 people filled out this section, and the results are displayed in Figures 3 and 4. As can be seen from Figure 3, the participants showed the highest recognition rate for fire extinguishers (56.21%), followed by fire hydrants, manual alarm buttons, and emergency telephones, whose recognition rates were all under 50%. The manual alarm button had the lowest recognition rate at only 38.92%. According to Figure 4, less than half of the participants were aware of the correct usage of firefighting facilities. Alarmingly, 73.24% were unaware of the correct usage of fire hydrants. The results indicate that tunnel users' knowledge of firefighting facilities' correct usage is extremely low. Thus, it is crucial to intensify their training on the practical usage of firefighting facilities.

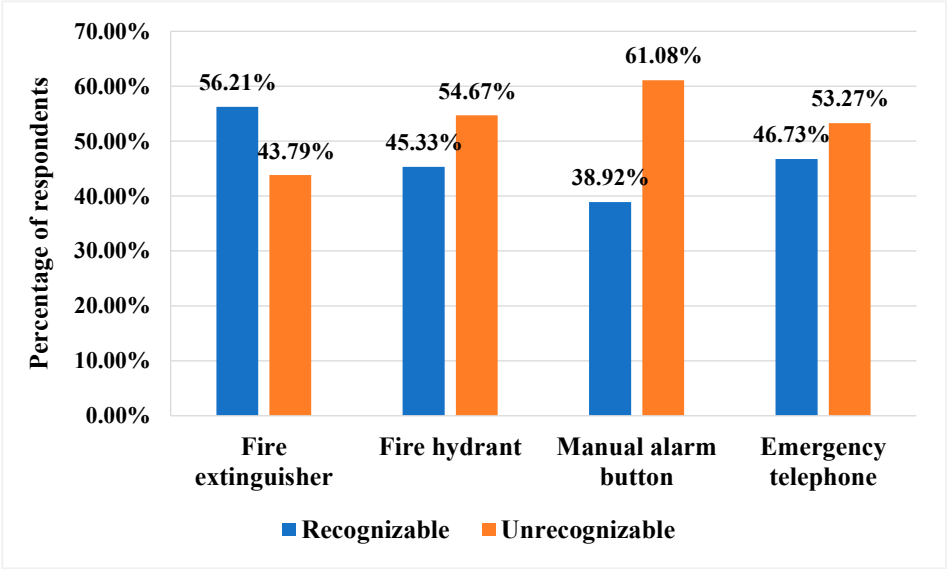

Figure 3. Recognition of firefighting facilities in expressway tunnels.

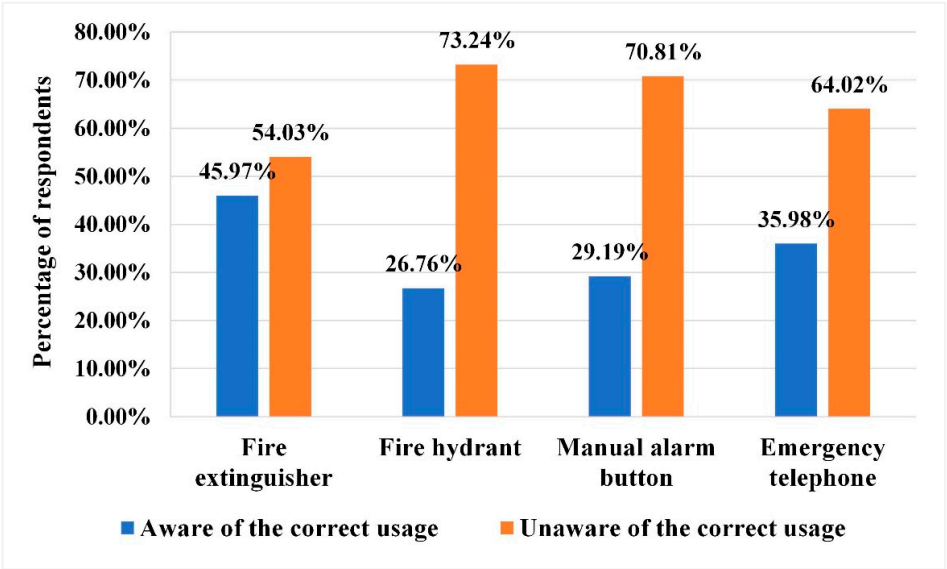

Figure 4. Awareness of the correct usage of firefighting facilities.

3.4. Differences in Tunnel Users' Fire Safety Literacy

The *p*-values according to the χ^2 test are shown in Table 3.

The results of the χ^2 test indicate that tunnel users' awareness and recognition of the pedestrian cross passages are significantly correlated with five factors: gender, age, frequency of use of expressway tunnels, participation in fire safety training or drills, and

types of vehicles used. However, the education level did not show correlation, highlighting the need for widespread dissemination of knowledge regarding tunnel escape methods to people of all educational levels. The ability to recognize evacuation signs was significantly correlated with all six of these factors. The choice of the correct evacuation route from a tunnel fire was not correlated with gender, but was significantly correlated with the remaining five factors. The study analyzes the differences between these six factors and the participants' cognition of expressway tunnel escape methods.

Table 4 shows the differential statistics of gender and cognition of expressway tunnel escape methods. As shown in Table 4, a higher percentage of women were found to be unaware of escape facilities in expressway tunnels compared to men. The percentage of men and women who were unaware of pedestrian cross passages and those who were unable to recognize them both exceeded 50%. Remarkably, among females, the percentage of those who were unable to recognize pedestrian cross passages reached as high as 74.85%. Therefore, it is evident that women have a lower level of knowledge about tunnel escape methods and require more attention during emergency evacuation from tunnels. The government and relevant departments should improve fire safety training and knowledge transfer to female tunnel users.

Table 3. *p*-values for the χ^2 test.

Cognition of Expressway Tunnel Escape Methods	Gender	Age	Education Level	Frequency of Use of Expressway Tunnels	Participation in Fire Safety Training or Drill	Types of Vehicles Used
Awareness of pedestrian cross passages	0.000	0.000	0.081	0.000	0.000	0.000
Recognition of pedestrian cross passages	0.000	0.000	0.114	0.000	0.000	0.000
Recognition of evacuation signs	0.000	0.000	0.000	0.000	0.000	0.000
Choice of the correct evacuation route	0.368	0.025	0.000	0.000	0.000	0.000

Table 4. Differential statistics of gender and tunnel users' cognition levels.

Cognition of Expressway Tunnel Escape Methods		Gender	
		Man	Woman
Awareness of pedestrian cross passages	Aware	46.46%	35.23%
	Unaware	53.54%	64.77%
Recognition of pedestrian cross passages	Able to recognize	36.56%	25.15%
	Unable to recognize	63.44%	74.85%
Recognition of evacuation signs	Able to recognize	59.62%	45.61%
	Unable to recognize	40.38%	54.39%

Table 5 shows the differential statistics of age and cognition of expressway tunnel escape methods. As shown in Table 5, people under 18 and over 55 years old had the highest proportion of unawareness and inability to recognize pedestrian cross passages in expressway tunnels. Specifically, the proportion of people over 55 years old who were unaware reached as high as 82.19%, and the proportion of those who were unable to recognize the escape routes was as high as 87.67%. People over 55 years old may be weaker in terms of reaction ability and observation ability. The proportion of people of all ages who were aware of pedestrian cross passages was less than 50%. Regarding evacuation signs in expressway tunnels, the proportion of people over 55 years old who were unable

to recognize them was the highest (73.97%). The proportion of people over 55 years old who chose the correct evacuation route was the lowest, at only 45.21%. These results show that people under 18 and over 55 years old have a lower cognition of escape routes, but particularly the latter. Organizing the relevant departments of schools and communities to carry out tunnel fire safety publicity, education, and training is paramount.

Table 5. Differential statistics of age and tunnel users' cognition levels.

Cognition of Expressway Tunnel Escape Methods		Age			
		Under 18 Years Old	**18–35 Years Old**	**36–55 Years Old**	**Over 55 Years Old**
Awareness of pedestrian cross passages	Aware	30.00%	40.62%	47.51%	17.81%
	Unaware	70.00%	59.38%	52.49%	82.19%
Recognition of pedestrian cross passages	Able to recognize	20.00%	30.60%	36.97%	12.33%
	Unable to recognize	80.00%	69.40%	63.03%	87.67%
Recognition of evacuation signs	Able to recognize	55.00%	54.69%	55.17%	26.03%
	Unable to recognize	45.00%	45.31%	44.83%	73.97%
Choice of the correct evacuation route	Collective action	7.50%	11.73%	11.69%	26.03%
	Stay in the car and wait for help	2.50%	7.68%	7.66%	9.59%
	Exit the tunnel as soon as possible	15.00%	19.83%	18.97%	19.18%
	Find the pedestrian cross passages and escape	75.00%	60.77%	61.69%	45.21%

Table 6 presents the differential statistics of education level and cognition of expressway tunnel escape methods. As can be seen from Table 6, the proportion of people who were able to recognize evacuation signs and choose the correct evacuation route in expressway tunnels increases with the level of education. The results indicate that the proportion of people with higher levels of education who were able to recognize evacuation signs and choose the correct evacuation route was higher. However, there was no correlation between education level and awareness or recognition of pedestrian cross passages in expressway tunnels. Thus, it is recommended that the dissemination of tunnel escape knowledge to people with various education levels be enhanced. Tunnel fire safety knowledge should be incorporated into the general education curricula of schools.

Table 6. Differential statistics of age and tunnel users' cognition levels.

Cognition of Expressway Tunnel Escape Methods		Education Level			
		Junior High School Degree or Below	**High School or Technical School Degree**	**Bachelor or College Degree**	**Master's Degree or Above**
Recognition of evacuation signs	Able to recognize	42.47%	53.64%	57.72%	56.00%
	Unable to recognize	57.53%	46.36%	42.28%	44.00%
Choice of the correct evacuation route	Collective action	16.78%	15.18%	9.13%	5.33%
	Stay in the car and wait for help	8.22%	11.13%	5.34%	4.00%
	Exit the tunnel as soon as possible	23.29%	17.41%	19.66%	14.67%
	Find the pedestrian cross passages and escape	51.71%	56.28%	65.87%	76.00%

Table 7 shows the differential statistics of frequency of use of expressway tunnels and cognition of expressway tunnel escape methods. As can be seen from Table 7, the proportion of people who were able to recognize the escape facilities in expressway tunnels increased with the frequency of use of expressway tunnels. This may be because people passing through the tunnels more frequently have a higher tendency to observe escape facilities. Interestingly, the lowest percentage of correct evacuation route choices was for those who pass through the expressway tunnels 50–200 times a year (including 200 times). This result suggests that a higher frequency of passing through the tunnels may not necessarily lead to a higher proportion of people choosing the correct evacuation route. We suggest that tunnel operators should strengthen tunnel management and enhance tunnel users' training. Regular emergency drills in tunnels should be organized with the participation of public security traffic polices, expressway management, fire rescues, tunnel operators, and medical services [34]. During the tunnel renovation phase, visitors should be invited to view tunnel escape facilities, and animation videos about tunnel fire safety knowledge should be played for the community. Tunnel operators may also regularly recruit volunteers in expressway service areas to distribute tunnel fire safety pamphlets. Moreover, adopting intelligent evacuation guide signs and optimizing evacuation signs to improve evacuation efficiency will be essential [46].

Table 8 shows the differential statistics of previous participation in fire safety training or drills and cognition of expressway tunnel escape methods. As shown in Table 8, people who have participated in fire safety training or drills have higher levels of knowledge regarding how to escape from expressway tunnels than those who have not. However, the cognition levels of both groups were still not high. The results indicate that previous fire safety training or drills may not have fully covered road tunnel fire evacuation, and there may be a lack of knowledge regarding the specific nature of escape from a road tunnel fire. We suggest that self-rescue knowledge should be included in the publicity and training programs of local governments and their relevant departments. Government departments have added facilities for tunnel fire safety education in technology museums and fire experience halls. Multi-channel dissemination of tunnel safety knowledge through online and offline training should be carried out [47].

Table 7. Differential statistics of frequency of use of expressway tunnels and tunnel users' cognition levels.

Cognition of Expressway Tunnel Escape Methods		Frequency of Use of Expressway Tunnels			
		Less than or Equal to 10 Times a Year	**10–50 Times (Including 50 Times) a Year**	**50–200 Times (Including 200 Times) a Year**	**More than 200 Times a Year**
Awareness of pedestrian cross passages	Aware	30.76%	43.07%	58.37%	67.65%
	Unaware	69.24%	56.93%	41.63%	32.35%
Recognition of pedestrian cross passages	Able to recognize	20.17%	32.45%	50.20%	60.78%
	Unable to recognize	79.83%	67.55%	49.80%	39.22%
Recognition of evacuation signs	Able to recognize	44.49%	55.98%	64.49%	76.47%
	Unable to recognize	55.51%	44.02%	35.51%	23.53%
Choice of the correct evacuation route	Collective action	12.73%	11.20%	14.69%	8.82%
	Stay in the car and wait for help	6.58%	7.02%	15.10%	0.00%
	Exit the tunnel as soon as possible	21.75%	19.73%	14.69%	12.75%
	Find the pedestrian cross passages and escape	58.94%	62.05%	55.51%	78.43%

Table 8. Differential statistics of fire education and tunnel users' cognition levels.

Cognition of Expressway Tunnel Escape Methods		Participation in Fire Safety Training or Drill	
		Have Participated in	Have Not Participated in
Awareness of pedestrian cross passages	Aware	39.26%	17.47%
	Unaware	60.74%	82.53%
Recognition of pedestrian cross passages	Able to recognize	25.77%	10.62%
	Unable to recognize	74.23%	89.38%
Recognition of evacuation signs	Able to recognize	52.15%	33.90%
	Unable to recognize	47.85%	66.10%
Choice of the correct evacuation route	Collective action	13.70%	28.77%
	Stay in the car and wait for help	9.20%	21.23%
	Exit the tunnel as soon as possible	27.61%	24.66%
	Find the pedestrian cross passages and escape	49.49%	25.34%

Table 9 shows the differential statistics of the types of vehicles used and cognition of expressway tunnel escape methods. As shown in Table 9, people driving small and medium trucks, large trucks and trailers, and hazardous chemical transport vehicles had higher levels of awareness and recognition of pedestrian cross passages in expressway tunnels. This may be due to passing through the tunnel at a higher frequency and their stronger safety awareness, which leads to in-depth knowledge of tunnel safety. On the other hand, people driving minibuses or buses and service cars (taxis, e-hailing, etc.) had lower levels of cognition of pedestrian cross passages. Additionally, the recognition of evacuation signs in expressway tunnels was poor for people driving hazardous chemical transport vehicles, minibuses or buses, and service cars. The percentage of people of hazardous chemical transport vehicles, small and medium trucks, and minibuses or buses, and their choice of the correct evacuation route was also poor. These results suggest that management and control should be strengthened for minibuses or buses, hazardous chemical transport vehicles, and service cars, with a particular focus on improving the tunnel safety knowledge of people with these vehicle types. Regarding the control of tunnel vehicles, tunnel administration can adopt a smarter style of management by transforming the traditional management method into an innovative, intelligent, and integrated monitoring system. The establishment of an intelligent tunnel patrol inspection system, intelligent evacuation guidance measures, and intelligent tunnel fire rescue systems can be included. In addition, the topics of emergency treatment and safe escape in expressway tunnels fire should be increased during driver's certificate tests [48].

3.5. Limitations and Future Research Directions

This study has some limitations. The survey focused on Hunan Province in China; thus, using these data to represent the entire population may have some flaws. In future research, if there are more sufficient resources, the investigation can be expanded nationwide to increase the representativeness of the survey sample for the overall population. In addition, the majority of questionnaire data were collected from highly educated people, leading to a significant difference between the education levels of the survey population and those of the actual population. In further studies, questionnaires should consider the representativeness of the sample for the population. The proportion of education levels in the sample should be closer to the actual proportion, or the survey proportion should be adjusted using a mathematical method.

Table 9. Differential statistics of types of vehicles used and tunnel users' cognition levels.

Cognition Of Expressway Tunnel Escape Methods		Types of Vehicles Used						
		Private Car	Service Car	Minibus or Bus	Small and Medium Truck	Large Truck and Trailer	Hazardous Chemical Transport Vehicle	Other
Awareness of pedestrian cross passages	Aware	46.17%	37.82%	31.13%	51.56%	66.67%	50.00%	23.08%
	Unaware	53.83%	62.18%	68.87%	48.44%	33.33%	50.00%	76.92%
Recognition of pedestrian cross passages	Able to recognize	35.57%	26.26%	21.86%	39.06%	60.78%	50.00%	19.23%
	Unable to recognize	64.43%	73.74%	78.14%	60.94%	39.22%	50.00%	80.77
Recognition of evacuation signs	Able to recognize	57.54%	52.31%	47.63%	56.25%	64.71%	25.00%	28.85%
	Unable to recognize	42.46%	47.69%	52.37%	43.75%	35.29%	75.00%	71.15%
Choice of the correct evacuation route	Collective action	8.70%	13.45%	10.93%	12.50%	1.96%	0.00%	21.15%
	Stay in the car and wait for help	5.77%	9.66%	7.22%	9.38%	5.88%	75.00%	15.38%
	Exit the tunnel as soon as possible	16.80%	19.96%	25.98%	29.69%	9.80%	25.00%	13.46%
	Find the pedestrian cross passages and escape	68.73%	56.93%	55.88%	48.44%	82.35%	0.00%	50.00%

4. Conclusions

The purpose of the study was to evaluate and enhance the cognition of Chinese drivers and passengers with regard to escape methods in expressway tunnels, which we evaluated based on the questionnaire results. To accomplish this purpose, we conducted a questionnaire survey in Hunan Province, China, collecting a total of 1573 effective questionnaires through both online and on-site surveys. Through overall statistical, descriptive statistical, and correlation analysis of the data, tunnel users' cognition of escape methods and firefighting facilities in expressway tunnels was determined. From the policy insights, some recommendations according to investigation results are proposed.

The results show that the overall score rate of awareness of drivers and passengers regarding tunnel fire safety is only 0.43, meaning that 58.42% of people are unaware of pedestrian cross passages in expressway tunnels, while 68.40% are unable to recognize them. Furthermore, 46.47% of people are unable to recognize the evacuation signs in expressway tunnels. In terms of choosing the correct evacuation route during a tunnel fire, 39.29% of people choose the incorrect way. Moreover, recognition of firefighting facilities in expressway tunnels is below 50.00%. With less than 50.00% of people aware of the correct usage of firefighting facilities, among them, 73.24% are unaware of the correct usage of fire hydrants. In order to study the relationship between tunnel users' demographic characteristics and their cognition of expressway tunnel escape methods, the χ^2 test was conducted. The results of the χ^2 test showed that gender, age, education level, frequency of use of expressway tunnels, participation in fire safety training or drills, and types of vehicles used positively affect tunnel users' cognition of expressway tunnel escape methods.

Overall, this study shows that the general level of people's tunnel escape knowledge is low, and their basic knowledge of emergency escape is limited. Therefore, it is urgent to take measures to raise awareness among people about safe escape from expressway tunnels. The study proposes countermeasures from a policy perspective. Tunnel fire safety publicity, tunnel emergency drills, tunnel safety management, and other measures should be considered by the relevant departments. Despite these contributions, additional research is required in a number of areas. Future research can be focused on nationwide tunnel users' literacy on expressway tunnel fire safety. In addition, to make the survey results more scientific and feasible, proportion control of the sample should be considered. The study results can provide basis for making evacuation and emergency plans, and can provide related workers with a basis for prioritizing their implementation and ultimately decreasing tunnel fire accidents.

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