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Discussion

Characteristics of traffic accidents in Chinese freeway tunnels

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ABSTRACT

The probability of an accident occurring and probability of being injured is lower in tunnels than on open stretches of highways. However, if an accident does happen in a tunnel, especially in a freeway tunnel, the severity of injuries sustained is significantly higher than on open stretches of road. Therefore, a study of traffic accidents based on police-reports from four freeway tunnels for the years 2003 and 2004 has been conducted. Temporal distribution characteristics and space distribution characteristics of traffic accidents are summarized. Based on the results of this analysis various measures aimed at raising traffic safety in tunnels are recommended.

1. Introduction

The strong sustainable economic development in China for the past 10 years has greatly inspired the construction of new highways particularly highway tunnels. Highway tunnels play an important role in developing new highway networks and the number of highway tunnels in China has continually increased rapidly over several years as shown in Fig. 1. This is because of recent development of highway networks through mountain ranges, and also because of the reduction of tunnel construction costs. In addition, with improving construction technology, tunnels have been adopted as an increasingly cost-effective engineering solution to traverse mountain areas with minimum local environment impact. By the end of 2006, China had highway tunnels in 3788 locations, with a total length of 1842 km.

The probability of accident occurring and the probability of being injured is lower in tunnels than on open stretches of highways. However, if an accident occurs in a tunnel, the impact is often much stronger than on stretches of road. The consequences can be extremely destructive and dangerous, especially in the event of a fire, because the enclosed space hinders the dissipation of heat and smoke. In addition, Chinese highway tunnel has just started, and there are many problems in design, construction and management, which make the tunnel section becoming the accident-prone locations. In view of this, it is essential to study the distribution characteristics and causes of traffic accidents in tunnels.

Many scholars have attempted to study traffic accidents in tunnels and obtained some achievements. The Norwegian Public Roads Administration performed a study on traffic accidents based on police-reported accidents with personal injury, and the results showed that the accident rates were higher in the entrance zone than other zones, and the severity of accidents were higher in tunnels than on stretches of road (Amundsen and Ranes, 2000). Haack (2002) introduced some recent fire accidents in tunnels, analyzed the effects of fire and put forward some fire protection measures. Hu and Chen (2003) analyzed the general characteristics of traffic accidents, which happened in Shanghai Yan'andong road tunnel, and suggestions on skid-proof measures for the tunnel are put forward. Ye and Su (2003) discussed properties and potential danger of highway tunnel operation, analyzed the causes for accidents and presented some countermeasures. Zhang and Ma (2006) explore some traffic accidents' characteristics of Shaoguan tunnel group of Jingzhu freeway, and recommend some countermeasures to improve freeway tunnel safety.

The main purpose of this paper is to probe into the main distribution characteristics and laws of freeway tunnel in China. This paper is organized as follows. Section 2 describes the data collection on selected tunnels and classification. Temporal distribution characteristics of traffic accidents can be analyzed through analyzing the monthly and hourly distribution of traffic accidents in Section 3. In Section 4, space distribution characteristics of traffic accident are summarized. Finally, the conclusions are drawn in Section 5 together with recommendations for further study.

2. Data basis

Four freeway tunnels were selected for this study (Table 1). During 2003–2004, a total of 134 accidents occurred including six with fatalities, 32 with injuries, and 96 with property damages

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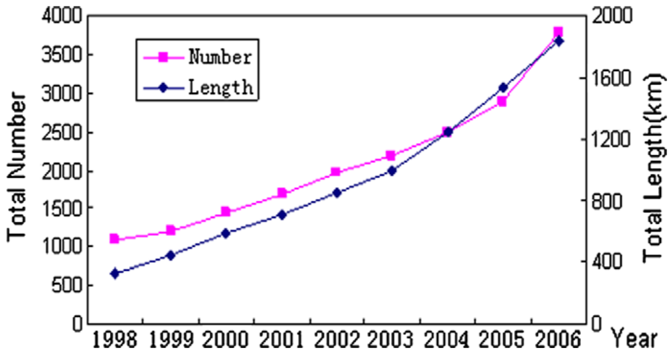

Fig. 1. Increases in total number and length of highway tunnels.

Table 1
Data on selected tunnels

Tunnel	Direction	Lane number	Length (m)
Baolinshan	Left	3	975
	Right	3	1014
Dabaoshan	Left	3	1585
	Right	3	1565
Kaoyishan	Left	3	2981
	Right	3	2949
Wulongling	Left	3	200
	Right	3	200

only. Six fatal accidents resulted in nine persons killed, and 32 injured accidents resulted in 59 persons injured. In comparison with a Norway study (Amundsen and Ranes, 2000), no matter from the number of tunnels or the number of accidents, the sample size is relative small, which is the limitation for this study. Relevant tunnel data such as traffic volume, lengths, widths, number of tubes and other information were taken form the tunnel management center of Jingzhu freeway at the Shaoguan section.

Data on accidents and locations were retrieved from police-reported tunnel database for the years 2003–2004 and were grouped into the following four categories (Fig. 2):

- *Zone* 1: the first 100 m in front of the tunnel openings.
- *Zone* 2: the first 100 m inside the tunnel.
- *Zone* 3: the next 300 m inside the tunnel.
- *Zone* 4: the mid-zone, i.e., the remainder of the tunnel.

Tunnels shorter than 200 m have only zones 1 and 2; tunnels shorter than 800 m do not have a mid-zone (zone 4).

Amundsen and Ranes (2000) define the length of zones 1, 2 and 3 are 50 m, 50 m and 100 m, respectively, which are much shorter than those of above mentioned in this paper. About 520 national road tunnels, which include one-way tunnel and two-way tunnel, were selected in Amundsen's study. There is great difference between tunnels in terms of tunnel length and lane width.

Although the length of tunnels selected in this study is different, the width of tunnels is just the same. Four freeway tunnels selected for this study are one-way tunnels, and lane number of each tube are three, respectively. Furthermore, design speed inside tunnel section and outside tunnel section are 80 km/h and 100 km/h, respectively. If total reaction time is 4 s, the braking distances are 88.9 m and 111.1 m, respectively. For the sake of analysis, zones 1 and 2 round a number to the integer. Therefore, zones 1 and 2 are identified as the length of 100 m, respectively, in this paper. According to specification for design of ventilation and lighting of highway tunnel (JTJ 026.1-1999) in China, the length of lighting transition section is approximately 300 m, so the length of zone 3 is 300 m in this paper.

3. Temporal distributions of traffic accidents

Temporal distribution characteristics of traffic accidents can be analyzed through analyzing the monthly and hourly distribution of traffic accidents.

3.1. Monthly distribution characteristics of traffic accidents

The monthly distribution of traffic accidents in tunnels is shown in Fig. 3. One can observe that the number of traffic accidents in January is much higher than others, and the least number is in September. The results may be related to traffic exposure and human factor. A rang of commentators (Fridstrom et al., 1995; Massie et al., 1997) have argued that traffic exposure, measured by vehicle flow, is the most important contributor to crash counts in an area. From Fig. 3, MADT is only slightly higher in January than others, but the number of accidents in January is 3.5 times as high as median of all other months. For that reason above any other, traffic exposure has nothing to do with the accident happened. In fact, daily traffic volume fluctuates greatly in January, which is inexistence in other months. The main cause is that the most important traditional festival in China, that is Spring Festival, which is on February 1, 2003 and January 22, 2004, respectively. According to the system of vacation in China, the most people will enjoy seven days holiday, so those who live away from their hometown will go home and have a holiday with their family on this gathering time. Four freeway tunnels selected is the part of Guangdong section of Jingzhu freeway, which is a main traffic artery connecting Guangdong province and its northern provinces. Before the Spring Festival, traffic volume is very heavy, and maximum traffic volume reaches 46576 PCU per day.

The characteristic of spring festival transportation is concentration before festival and ease after festival. Although the tunnel management center pays more attention to traffic safety during the spring festival, some drivers are deaf to all these requirements in order to return home on time which results in the behavior of speeding and illegal passing constantly occurring. However, almost all departments and units in China are not strict request on duty for their staff after spring festival because the lantern festival marks the end of the celebrations of the Chinese New Year, which cause people return work in no hurry. So traffic volume is relative ease after spring festival by comparison with before spring festival.

3.2. Hourly distribution characteristics of traffic accidents

The hourly distribution of traffic accidents in tunnels is shown in Fig. 4. From Fig. 4, we can see that there are obviously three peak periods, namely 5:00–7:00, 9:00–10:00 and 15:00–17:00. The number of traffic accidents occurring in the three periods accounts for 41% of the total traffic accidents. In general, the most tired stage of the drivers is at dawn. At the moment, indistinct sight lines make the driver's sight drop and lead to the decline of the driver's

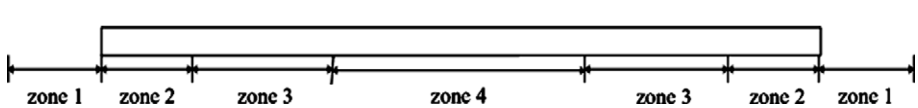

Fig. 2. Freeway tunnel zones.

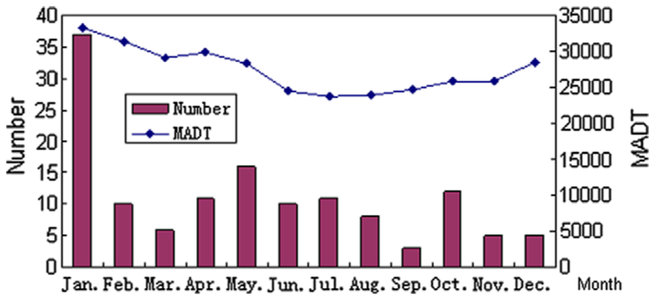

Fig. 3. Monthly distribution of traffic accidents in tunnels.

attention on driving. At the same time, owing to the lack of sleep and gradual accumulation during the dawn time period, the fatigue of this time is cumulative fatigue which is more dangerous than universal fatigue. In addition, traffic composition defined as the percentage of heavy vehicle with respect to the total number of vehicle (Joel et al., 2004), is also related to crash counts. The traffic composition has changed drastically between 9:00–10:00 and 15:00–17:00. The share of cars has drastically increased from 19.5% in 9:00 to 35.3% in 10:00, while the share of cars has drastically reduced from 37.2% in 15:00 to 26.2% in 17:00.

4. Space distributions of traffic accidents

4.1. Accident severity

During 2003–2004, a total of 134 accidents occurred including six with fatalities, 32 with injuries, and 96 with property damages only for this study. The frequency of four freeway tunnels crashes in the various tunnel zones is showed in Table 2. In tunnels, fatal accidents accounts for 4.5% of the total accidents, while the corresponding proportion in all zones is 4.3%. Furthermore, almost half of the accidents that took place inside the tunnel occurred within 300 m from the opening equally split between zones 2 and 3.

A total of 59 persons injured and nine killed in the 134 accidents included in this paper. The severity of the injuries in the various tunnel zones is shown in Table 3. In tunnels, 12.1% of the injured are killed, while the corresponding proportion in all zones is 13.2%. The proportion of killed in tunnel accidents in Norway is just 3.6% (Amundsen and Ranes, 2000), which is much lower than in China. Therefore, it is very necessary to reduce the severity of traffic accidents in Chinese freeway tunnels. Table 3 also shows that the severity of casualties in zone 4 is significantly higher than other zones.

Owing to data problems, the item of injured accident in the tunnel database in China did not divide into seriously injured accident and slightly injured accident in this study, which cannot accurate measure accident severity. Therefore, the standard and normalization of accident data call for more attention in the future.

4.2. Accident rates

The accident rates shown in Table 4 are estimated by dividing the number of accidents per year with the number of vehicle kilometers driven. The vehicle kilometer values used are based on the sums for each tunnel zone lengths.

Table 4 shows that the accident rate in zone 3 (100–400 m inside the tunnel) is higher than others, while the accident rate in

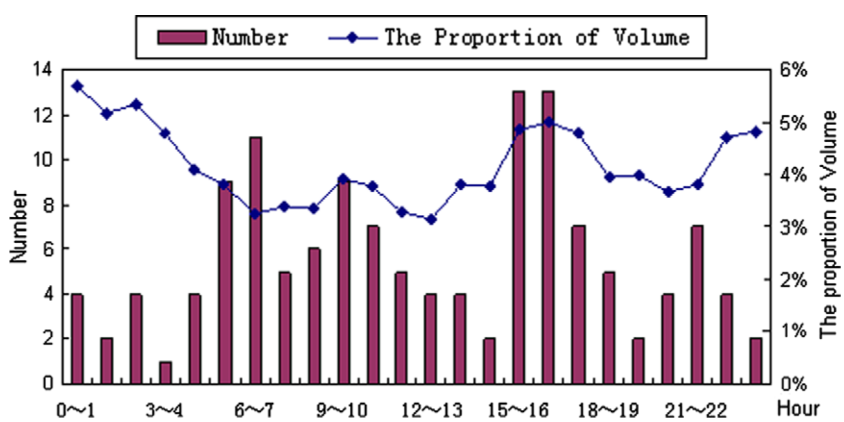

Fig. 4. Hourly distribution of traffic accidents in tunnels.

Table 2
Frequency of four freeway tunnels crashes

Frequency	Zone 1	Zone 2	Zone 3	Zone 4	Total	Inside tunnel
Fatalities	1	0	3	2	6 (4.5%)	5 (4.3%)
Injuries	2	5	10	15	32 (23.9%)	30 (25.9%)
Property damages only	15	12	29	40	96 (71.6%)	81 (69.8%)
Total	18	17	42	57	134	116

Table 3
Number injured by severity and tunnel zone

Severity	Zone 1	Zone 2	Zone 3	Zone 4	Total	Inside tunnel
Killed	2	0	4	3	9 (13.2%)	7 (12.1%)
Injured	8	7	18	26	59 (86.8%)	51 (87.9%)
No killed or injured	10	7	22	29	68	58

Table 4
Accident rates in the various tunnel zones

Tunnel zone	Length (km)	AADT	The number of accidents	Accident rates (acc/mill. veh. km)
Zone 1	1.6	27,609	18	0.56
Zone 2	1.6	27,609	17	0.53
Zone 3	3.6	27,394	42	0.58
Zone 4	6.27	27,394	57	0.45
All zones	13.07	27,609	134	0.51
Entire tunnel (excl. zone 1)	11.47	27,609	116	0.5
Transition zone (zones 1 and 2)	3.2	27,609	35	0.54
Entrance zone (zones 2 and 3)	5.2	27,609	59	0.56

zone 4 (the mid-zone) is the lowest. When sorting the various tunnel zones in sequential order, there is clear decline in the accident rate at first when proceeding into the tunnels, and then rise between zones 2 and 3, then decline again between zones 3 and 4, as indicated in Table 4.

The definition of accident rate in the Norway study (Amundsen and Ranes, 2000) is the ratio of sum person injury accidents to million vehicle kilometers driven, which is different from in China. The major difference is the numerator of the formula of accident rate. The numerator is the total number of accidents which include fatal accidents, injured accidents and property damages only accidents in this study, but it is the number of accidents of injuries and deaths in the Norway study.

In order to do a comparative analysis with the Norway study, 38 person injury accidents were used to calculate the casualty rate in the following section. Table 5 shows the casualty rate of four freeway tunnels. The results of zones 1 and 2 in China are much lower than in Norway, but the results of zones 3 and 4 are opposite. The distribution of casualty rates in tunnel zones in China is significant different from those of in Norway, which shows a clear decline in the accident rate when proceeding into the tunnels. This is an indication that improved lighting and entrance zone design have contributed positively to a significant reduction in tunnel entrance zone accidents.

4.3. Accident types

All accidents are classified by accident type. The distribution of freeway tunnel accidents by accident type is shown in Table 6. Understandably, there are no pedestrian accidents and vehicle turning accidents, because freeway tunnel do not allow pedestrian traffic and the four tunnels are one-way traffic in two tubes.

As indicated in Table 6, the proportion of rear-end collision is the highest, which accounts for 57.5%. Especially inside tunnel, rear-end collision accidents increases with the distance from the tunnel entrance. Both collision with fixtures and rollover accidents occur most frequently in zone 1. Sideswipe collision accidents increases with the distance from the tunnel entrance. The share of accidents between fire accidents is roughly the same in the various tunnel zones except for zone 2, which has slightly fewer accidents. It should be emphasized that fire accident is one of accident type in China, and it induced by human factors or vehicle factors in the course of driving. For other accidents the opposite is the case, with a somewhat higher share of accidents in zone 2.

In total, rear-end collisions are the most frequent accident type in freeway tunnels which is according to the in-depth analysis of the police-reported tunnel database mainly due to the failure to maintain a safe distance to the vehicle in front. This conclusion in China is consistent with that of an Austrian study (Nussbaumer, 2007).

4.4. Multi vehicles accident

As Fig. 5 shows that the probability of multi-vehicle accident occurred is higher than that of single-vehicle accident except for zone 1. Especially in zone 3, the number of multi-vehicle accidents is approximate three times higher than that of single-vehicle accidents. For tunnels with uni-direction in Austrian, most part of the accidents occurring is single-vehicle in zones 1 and 2 (Nussbaumer, 2007).

4.5. Accidents versus weather

A study was also made to ascertain the weather under which accidents occurred. Understandably, the share of accidents occurred in rainy days as much as 46.7% of the total number of accidents. Of accidents occurring within 100 m of a tunnel opening (zones 1 and 2), 29.4% took place in rainy days, while the proportion was 63.6% and 42.9% in zones 3 and 4, respectively.

How can rain influence accidents inside a tunnel? If the entrance of the tunnel or the end of the tunnel is downgrade, the rainwater will go into the tunnel on rainy days. In addition, the wheels will lead rainwater into a tunnel on rainy days, when vehicles enter the tunnel. The particulate emission of fuel vehicles in tunnel form a layer of material similar to oil that does not dissolve the water and reduces the friction coefficient of pavement. When tunnel road surface is wet, the friction coefficient of pavement reduces rapidly, which very easily causes traffic accidents.

However, accidents often happen in fogy and snowy days and the pavement may be still wet after rain. Therefore, it is insufficient to study the relationship between accidents and weather, and it is reasonable to study the relationship between accidents and road condition. But it is very regrettable that the item of weather in

Table 5
Casualty rares in the various tunnel zones

Tunnel zone	Length (km)	AADT	The number of casualty accidents	Casualty rates (acc/mill. veh.km)
Zone l	1.6	27,609	3	0.09
Zone 2	1.6	27,609	5	0.16
Zone 3	3.6	27,394	13	0.18
Zone 4	6.27	27,394	17	0.14
All zones	13.07	27,609	38	0.14
Entire tunnel (excl. zone 1)	11.47	27,609	35	0.15
Transition zone (zones 1 and 2)	3.2	27,609	8	0.12
Entrance zone (zones 2 and 3)	5.2	27,609	18	0.17

Table 6
Accidents in freeway tunnels by accident type

Accident type	Zone 1	Zone 2	Zone 3	Zone 4	Total	Inside tunnel
Rear-end collision	38.9%	58.8%	69%	54.4%	57.5%	60.3%
Collision with fixtures	27.8%	5.9%	9.5%	15.8%	14.2%	12.1%
Sideswipe collision	0%	0%	2.4%	3.5%	2.2%	2.6%
Rollover	16.7%	11.8%	4.8%	8.8%	9%	7.8%
Fire	5.6%	0%	2.4%	5.3%	3.7%	3.4%
Others	11.1%	23.5%	11.9%	12.3%	13.4%	13.8%
Sum of accidents	18	17	42	57	134	116

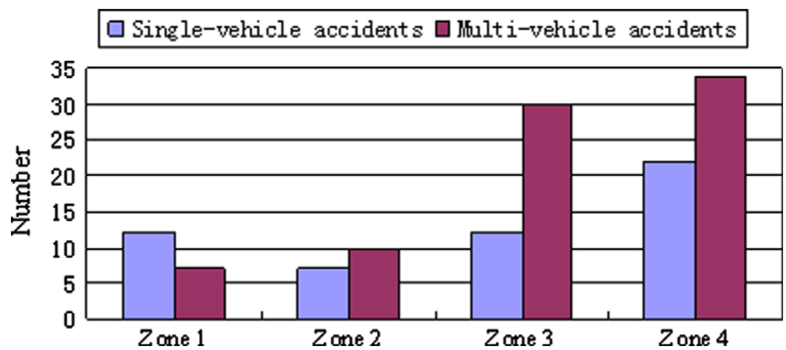

Fig. 5. Accident involved the number of vehicles in the various tunnel zones.

the tunnel accident database only record the rainy days and non-rainy days.

5. Discussion and conclusions

In recent years, a number of spectacular traffic accidents and fires occurred in freeway tunnels, which triggered debates about the safety of freeway tunnels. If an accident does happen in a freeway tunnel, the severity of injuries sustained is usually higher than on open stretches of freeway.

This study has been conducted using data based on police-reports from four freeway tunnels for the years 2003 and 2004. For the two study years, a total of 134 accidents including six with fatalities, 32 with injuries, and 96 with property damages only have been reported. The limitation for this study is that the sample size is relative small.

The monthly distribution of traffic accidents in tunnels shows that the number of traffic accidents in January is the most. The causes include traffic exposures and human factors. It is recommended to pay much attention to traffic management and enforcement in the peak transport before Spring Festival.

The hourly distribution of traffic accidents in tunnels shows that there are three peak periods, namely 5:00–7:00, 9:00–10:00 and 15:00–17:00, which accounts for 41% of the total traffic accidents. The results show that traffic accidents occurring coincide with traffic volume and traffic composition.

Accident severity is somewhat higher in freeway tunnels than in freeway in general. This is especially the case for zones 3 and 4. When comparing a Norwegian study on traffic accidents in road tunnels (2000), one can see that the severity in China is significant higher than that of Norway. One of possible reasons is that the speed is probably higher in Chinese freeway tunnels than in Norwegian two-lane tunnels.

The definition of accident rate in this study is different from in a Norway study. In order to do a comparative analysis with the Norway study, the casualty rates of four freeway tunnels are calculated. The distribution of casualty rates in tunnel zones in China is significant different from those of in Norway, which shows a clear decline in the accident rate when proceeding into the tunnels. It is recommended that the measures aimed at raising tunnel safety should concern the area of entrance zone (zones 2 and 3). Improving tunnel entrance design and illumination may be very effect measures to reduce the accident rate.

The analysis of freeway tunnel accidents records shows that most of problems are not special for the tunnel as such. The general problems in freeway tunnels are speeding and the failure to maintain a safe distance to the vehicle in front. Of accidents occurring, 57.7% is a rear-end collision which is usually due to the failure to maintain a safe distance to the vehicle in front. In order to reduce the accidents in tunnels, it is recommended to install distance measuring devices, radar devices and section control devices.

The number of multi-vehicle accidents is higher than that of single-vehicle accidents. This is especially the case for zones 3 and 4. This might be the result of the higher accident rate of the more severe collision accidents. The results are supported by the Austrian study on tunnels.

The share of accidents occurred in rainy day as much as 46.7% of the total number of accidents. Understandably, by far most accidents took place in non-rainy days within 100 m of a tunnel opening (zones 1 and 2). In fact, the non-rainy day doesn't mean that the friction coefficient of pavement is high, for example, the rain stops in a short while. Therefore, it is insufficient to study the relationship between accidents and weather, and it is reasonable to study the relationship between accidents and road condition. But it is very regrettable that the item of weather in the tunnel accident database only record the rainy days and non-rainy days.

The study on safety in four freeway tunnels was one of the first attempts to collect data about tunnel accidents in China. In China, the availability of reliable accident records presents one of the biggest challenges in highway safety studies. The most obvious is the institutional barriers, which cannot make data sharing, especially the detailed accident data. For that reason, this article is based on a relatively small number of accidents and tunnels.

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References

Amundsen, F.H., Ranes, G., 2000. Studies on traffic accidents in Norwegian road tunnels. Tunnelling and Underground Space Technology 15 (1), 3–11.
Fridstrom, L., Ifver, J., Ingebrightsen, S., Kulmala, R., Krogsgard Thomsen, L., 1995. Measuring the contribution of randomness, exposure, weather, and daylight to the variation in road accident counts. Accident Analysis and Prevention 27 (1), 1–20.
Haack, A., 2002. Current safety issues in traffic tunnels. Tunnelling and Underground Space Technology 17 (2), 117–127.
Hu, X.L., Chen, L.D., 2003. Analysis on traffic accidents in urban roads tunnel. China Municipal Engineering 12 (6), 5–7.
Joel, M.A.F., Arcanjo, L., Paulo, H.T.Z., 2004. Effects of traffic composition on road noise: a case study. Transportation Research Part D: Transport and Environment 9 (1), 75–80.
Massie, D.L., Green, P.E., Campbell, K.L., 1997. Crash involvement rates by gender and the role of average annual mileage. Accident Analysis and Prevention 29 (5), 675–685.
Nussbaumer, C., 2007. Comparative analysis of safety in tunnels. In: Young Researchers Seminar 2007, May 28, Brno.
Ye, F., Su, C.H., 2003. Safety analysis and countermeasures for highway tunnel operation. Modern Tunnelling Technology 40 (1), 31–33.
Zhang, S.R., Ma, Z.L., 2006. Traffic accident characteristics in freeway tunnels, In: Proceedings of 5th International Conference on Traffic and Transportation Studies, pp. 771–779.