COMPARATIVE ANALYSIS OF SAFETY IN TUNNELS

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ABSTRACT

The probability of an accident occurring and the probability of being injured is lower in tunnels than on open stretches of roads. However, if an accident does happen in a tunnel, the severity of injuries sustained is significantly higher than on open stretches of motorways. In a tunnel the risk of being killed in a traffic accident is twice as high as on open stretches of motorways. Traffic safety is significantly higher in tunnels with uni-directional traffic than in tunnels with bi-directional traffic. In tunnels with bi-directional traffic the probability of being killed in a traffic accident is 2.3 times as high as in tunnels with uni-directional traffic. Both in tunnels with bi-directional traffic and in tunnels with uni-directional traffic the highest accident rates occur in the portal area. Based on the results of this analysis various measures aimed at raising traffic safety in tunnels are recommended.

Key words: tunnels, road safety, uni-directional, bi-directional

1. INTRODUCTION

In recent years, a number of spectacular traffic accidents occurred in tunnels, which triggered debates about the safety of road tunnels. Every year, an average of 88 accidents in motorway and expressway tunnels occurs in Austria which causes an average of 13 fatalities, 37 severe injuries and 108 minor injuries. The macroeconomic costs amount to a total of EUR 13 million. The study “Comparative Analysis of Safety in Tunnels” of the Austrian Road Safety Board by order of the Federal Ministry of Transport, Innovation and Technology (Robatsch K., Nussbaumer C., 2005) explores the traffic safety of road tunnels on motorways and expressways compared with safety on other types of roads and also compares traffic safety in tunnels carrying bi-directional traffic with safety in tunnels with unidirectional traffic.

The main research questions in the following paper are how safe are tunnels compared with open sections of roads and how safe are tunnels with bi-directional traffic compared with uni-directional traffic. The methodical approach of the paper is an in-depth analysis of police database to gain accident data in tunnels and a comparison of relative accident rates.

The first part of this paper presents a continuation of the study „Tunnels with bi-directional and uni-directional traffic” (Robatsch, Nussbaumer, 2004). This study dealing with accidents occurring in Austrian tunnels between the years 1999 and 2001 is now completed by the present study dealing with accidents occurring in 2002 and 2003. In the second part accidents in tunnels are evaluated by point of origin, cause and fault. Based on the results of this study, recommendations are made on measures aimed at raising safety in road tunnels.

2. SAFETY IN TUNNELS VERSUS SAFETY ON OTHER TYPES OF ROADS

A variety of relative accident rates and the distance travelled in all of the tunnels studied are compared with the corresponding figures for motorways, expressways and federal roads on open sections.

In tunnels, the accident rate and the casualty rate are significantly lower than on motorways, expressways, and federal roads. A comparison of accident cost rates shows tunnels ahead of motorways, but behind expressways and federal roads (see Figure 1).

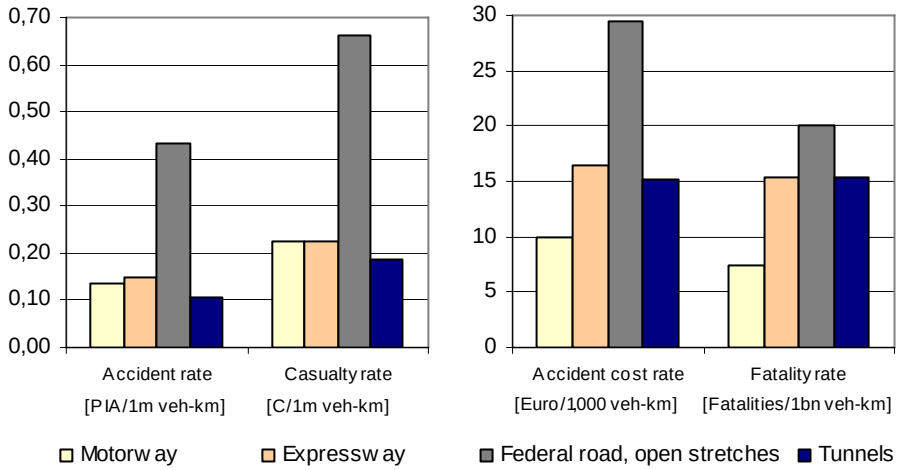

Figure 1: Relative accident rates and costs for tunnels and other types of roads (1999-2003); source: Accident data base KfV, Statistics Austria

The probability of an accident occurring and the probability of being injured or killed is lower in tunnels than on motorways and expressways. However, the risk of being killed in a traffic accident is twice as high in tunnels as on motorways.

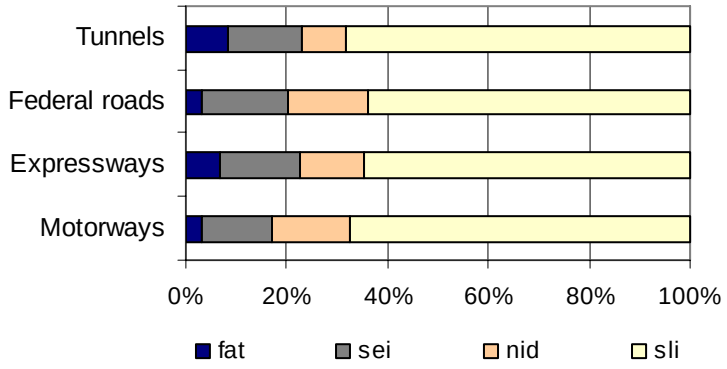

Figure 2: Severity[1] of casualties in tunnels versus other types of roads (1999-2003); source: Accident data base KfV, Statistics Austria

Figure 2 shows that in tunnels, the severity of casualties is significantly higher than on motorways, expressways and federal roads. While 3.3% of those injured on motorways die, the fatality rate in tunnels is substantially higher at 8.2%. The number of persons killed relative to all casualties is by far the highest in tunnels.

[1] Fat = fatalities, sei = severely injured, nid = severity of injury not identifiable, sli = slightly injured.

3. SAFETY IN TUNNELS WITH UNI- AND BI-DIRECTIONAL TRAFFIC

This section compares accident rates occurring in the studied tunnels with unidirectional and bi-directional traffic on motorways and expressways.

As a result of the paper „Tunnels with bi-directional and uni-directional traffic" (Robatsch, Nussbaumer, 2004) the length of a tunnel has a very substantial influence on relative accident rates and particularly tunnels of less than one kilometre length have very high accident rates. For statistical reasons it is not acceptable to compare 78 tunnels with unidirectional traffic with only 2 tunnels with bi-directional traffic within the category of tunnels of less than one kilometre. The research question of whether tunnels with bi-directional traffic or tunnels with unidirectional traffic are safer has arisen only with regard to longer tunnels, as tunnels of less than one kilometre length are usually built as twin tube tunnels.

Table 1: Number, length and traffic intensity of tunnels of more than one kilometre length with bi-directional and unidirectional traffic (status 2003); data source: Asfinag and Nadler, F.

	Tunnels with bi-directional traffic	Tunnels with unidirectional traffic
Number of tunnels studied	18	32
Total length [km]	86,214	64,307
Average length [km]	4,790	2,010
Traffic intensity [ADT]	14.569	12.154

In the calculations below, 18 tunnels with bi-directional traffic are compared with 32 tunnels carrying unidirectional traffic. On average, tunnels with bi-directional traffic that are longer than one kilometre are 2.4 times as long as tunnels with unidirectional traffic. At 14,569 vehicles per day, the average traffic intensity in tunnels with bi-directional traffic is slightly higher than in tunnels with uni-directional traffic, which carry 12,154 vehicles per day (see Table 1).

A variety of relative accident rates have been calculated and compared for tunnels with bi-directional traffic and unidirectional traffic. In addition to the absolute accident figures and the relative accident rates it is helpful to also include the severity of casualties. Therefore accident rates, accident cost rates, casualty rates and fatality rates were calculated for accidents in tunnels with bi-directional and unidirectional traffic (see Figure 3).

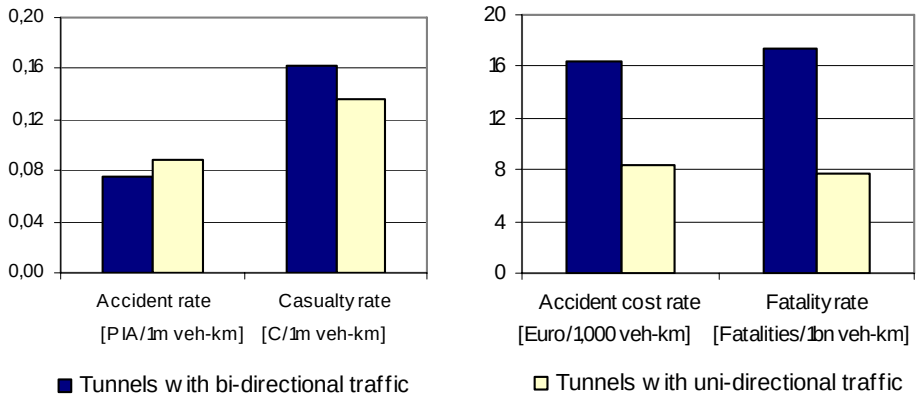

Figure 3: Relative accident rate for tunnels of over 1 kilometre length with bi-directional traffic and tunnels with unidirectional traffic (1999-2003)

In tunnels with bi-directional traffic, the accident rate - at 0.076 accidents per one million vehicle-kilometres - is slightly lower than in tunnels with uni-directional traffic, where the corresponding rate is 0.088 accidents per one million vehicle-kilometres.

The probability of being injured or killed in an accident is 19% higher in tunnels with bi-directional traffic than in tunnels with uni-directional traffic. As figure 3 shows, while the casualty rate in tunnels with bi-directional traffic is 0.163 casualties per 1 million vehicle-kilometres, the corresponding rate in tunnels with uni-directional traffic is 0.137 casualties per 1 million vehicle-kilometres. In tunnels with bi-directional traffic, the accident cost rate and the fatality rate are respectively twice and 2.3 times as high as in tunnels with uni-directional traffic. While in tunnels with bi-directional traffic, 17.3 traffic fatalities occur per one billion vehicle-kilometres, the corresponding figure for tunnels with uni-directional traffic is 7.6 persons killed per one billion vehicle-kilometres. The accident cost rate in tunnels with bi-directional traffic is EUR 16.4 per 1,000 vehicle-kilometres and in tunnels with uni-directional traffic EUR 8.4 per 1,000 vehicle-kilometres.

4. SPECIAL ANALYSIS OF SAFETY IN TUNNELS

In this section accidents with personal injury in tunnels are analysed by the parameters point of origin, fault and cause.

As several aspects regarding the occurrence of accidents, e.g. causes and faults, are not considered in the accident statistics released by the authorities, evaluations performed by the police were included in the accident statistics 1999-2003. The tabulation below is meant as a supplement to the accident statistics of the authorities, which were analysed in the previous section. On the basis of the new results, measures aimed at raising safety in road tunnels are formulated in the following section.

4.1. Accident rate and point of origin of the accident

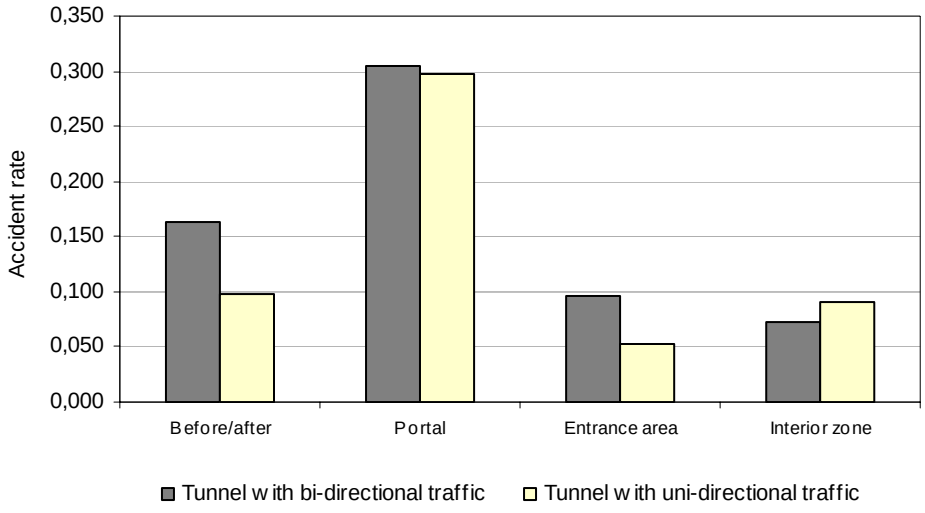

Figure 4: Personal injury accident rate [PIA/1 million vehicle-kilometres] in tunnels with bi-directional traffic and uni-directional traffic by point of origin of the accident (1999-2003); source: police database

As figure 4 shows, in tunnels with bi-directional traffic and uni-directional traffic the highest accident rates are reported in the portal area. What is striking is that in both types of tunnels

the accident rate is higher in the areas before the entrance and after the exit than in the interior zone of the tunnel. The by far highest accident rate in tunnels with uni-directional traffic is found in the portal area. The lowest rate of accidents occurring in the interior zone of the tunnel is reported in tunnels with bi-directional traffic, but at the same time the rate of accidents occurring before the entrance and after the exit is very high due to the transition from uni-directional traffic to bi-directional traffic. The by far highest rate of accidents occurring in the portal area is found in tunnels with uni-directional traffic.

4.2. Accident type and point of origin of the accident

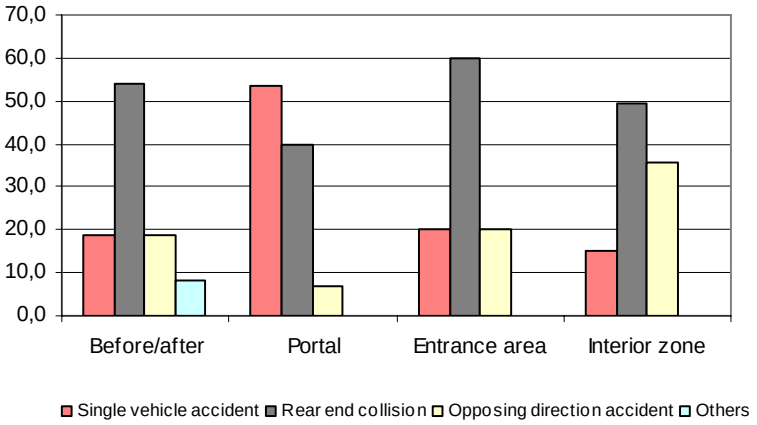

Figure 5: Types of accidents in tunnels with bi-directional traffic by point of origin of the accident, in percent (1999-2003); source: police database

In tunnels with bi-directional traffic the most frequent accident type in all areas, except the portal area, is rear-end collisions (see Figure 5). The highest proportion of rear-end collisions is reported in the entrance area (60%), which is mainly due to jams and to drivers not being attentive to the tunnel traffic lights installed in this area. The most frequent accident type in the portal area is single-vehicle accidents, whereas in the interior zone of the tunnel, besides rear-end collisions, mainly frontal collisions occur. The in-depth analysis of the police database showed that in tunnels with bi-directional traffic most part of the accidents are due to the failure to maintain a safe distance to the vehicle in front (rear end collisions), while in the portal area the main cause is speeding (single vehicle accidents).

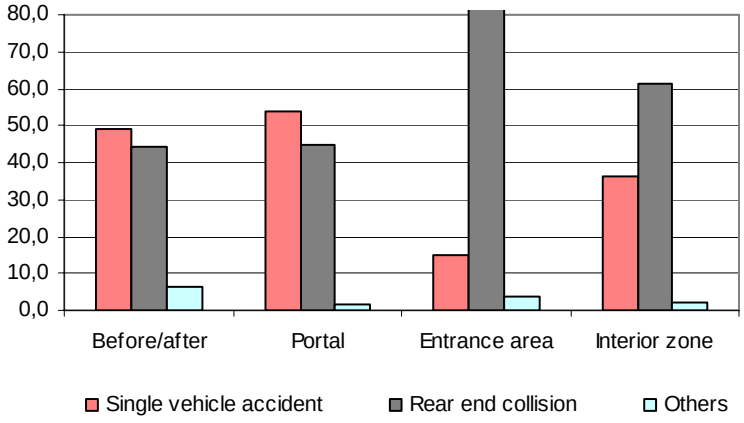

Figure 6: Types of accidents in tunnels with uni-directional traffic by point of origin of the accident, in percent (1999-2003); source: police database

In tunnels with uni-directional traffic two major trends are identifiable: In the areas before the entrance and after the exit as well as in the portal area, most part of the accidents occurring is single-vehicle accidents, whereas in the entrance area and in the interior zone of the tunnel mainly rear-end collisions occur. In total, rear-end collisions are the most frequent cause of accidents in uni-directional tunnels which is according to the in-depth analysis of the police database mainly due to the failure to maintain a safe distance to the vehicle in front. In the areas before the entrance and after the exit most of the accidents occurring are due to speeding (single vehicle accidents).

Summing up, in tunnels the proportion of rear-end collisions is significantly high. In the area of the portal mainly single-vehicle accidents occur, whereas in tunnels with bi-directional traffic the high number of opposing direction accidents occurring in the interior zone of the tunnel represents an additional problem.

4.3. Relationship between cause of accidents and traffic directionality of tunnels

In course of the in-depth analysis police records were analysed by researchers and they made an estimation about the relevant accident causes (multiple mentions were possible).

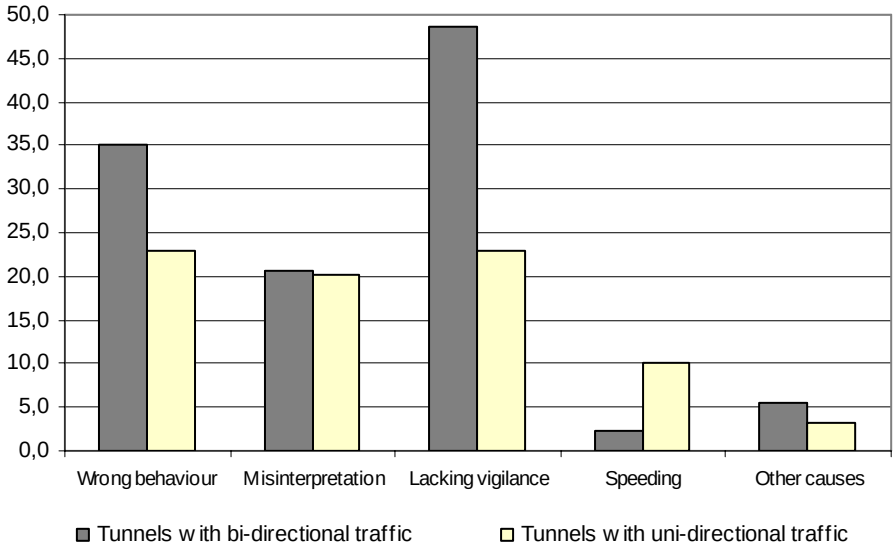

Figure 7: Causes of accidents in tunnels with bi-directional and tunnels with uni-directional traffic, in percent (1999-2003); source: police database

Generally, the most frequent cause of accidents in tunnels is lacking vigilance (over-fatigue, distraction, inattentiveness). On the second place are wrong driving behaviour such as the failure to maintain a safe distance to the vehicle in front, wrong overtaking and the failure to remain within the marked lane. The third most frequent cause is misinterpretation of road design and layout, meteorological conditions and other vehicles.

Lacking vigilance is by far the most important problem, particularly in tunnels with bi-directional traffic, whereas in tunnels with uni-directional traffic wrong driving behaviour plays an as important role as lacking vigilance. Moreover, the rate of accidents caused by speeding is particularly high in tunnels with uni-directional traffic. Other causes of accidents, such as unpredictable events and technical defects (motor, tyres and brakes) were negligible.

5. DISCUSSION AND CONCLUSIONS

In recent years, a number of spectacular traffic accidents and fires (e.g. Tauern tunnel) occurred in tunnels, which triggered debates about the safety of road tunnels and especially safety in tunnels with bi-directional traffic (single-tube tunnels). Single accidents with serious consequences dominated the media but the probability of an accident occurring and the probability of being injured is lower in tunnels than on open stretches of roads. However, if an accident does happen in a tunnel, the severity of injuries sustained is significantly higher than on open stretches of motorways.

According to a Swiss study on safety in road tunnels (2004) the risk of an accident occurring in a tunnel or of a person being injured or killed in an accident per unit of length is lower in longer tunnels than in shorter tunnels. The risk of a collision in a tunnel and the risk of being injured or killed in an accident rise with increasing traffic intensity and decreasing distances between vehicles. These results are supported by the Austrian study on tunnels with uni- and bi-directional traffic (2004).

The Swiss study came to the conclusion that the risk of an accident occurring or of being injured or killed in an accident is higher in single-tube tunnels (with bi-directional traffic) as in twin-tube tunnels (with uni-directional traffic). The Austria study on safety in tunnels (2005) can only support the conclusion that the risk of being injured or killed in an accident is significantly higher in tunnels with bi-directional traffic. The accident rates in the analysed tunnel types are nearly equal in Austria.

When comparing a Norwegian study on accidents and fires in tunnels (1997) and the Austrian study (2005), one can see that about a quarter of all personal injury accidents are occurring in the portal area. As the portal area show the by far highest accident rates, a focus should be laid on the design of the portal. With this regard the installation of so called “impact dampers” should also be considered. The effectiveness of these dampers, however, should first be examined in a separate study. Another problem regarding the portal area consists in the fact that many drivers are not attentive to the red tunnel traffic light. If a driver stop at the red light the following drivers often cause a rear-end collision. To solve this problem, measures aimed at making people aware of this problem should be taken and the placement of the traffic lights at the tunnel portal should be re-considered.

Based on the results of the comparison of accident rates in tunnels by point of origin of the accident, it is recommended that the measures aimed at raising tunnel safety should concern the area before the tunnel portal. For this reason the installation of a section control device and similar measures are recommended for the area before the portal, beginning at least at 250 m before the portal, in order to raise tunnel safety in an optimal way.

The analysis of tunnel accidents records shows that most of the problems are not special for the tunnel as a construction. The general problems on Austrian roads are speeding and the failure to maintain a safe distance to the vehicle in front. Nearly every second accident in tunnels is a rear-end collision which is usually due to the failure to maintain a safe distance to the vehicle in front and many accidents are caused by speeding before and in the entrance area of a tunnel. In order to reduce the accidents in tunnels, it is recommended to install distance measuring devices, radar devices and section control devices.

As the most frequent cause of accidents in tunnels is lacking vigilance, the observation of the driving and resting times prescribed for lorry drivers and the driving ability of passenger car drivers should be checked more frequently. At the same time, appropriate traffic education programmes and public relation campaigns should make people aware of the possible consequences of over-fatigue, distraction and alcohol.

The estimation of point of origin and accident causes by evaluating police records is critical. Especially the quality and length of descriptions of accident records varies greatly and it needs experienced traffic researchers to estimate accident causes. Moreover tunnel accidents in the portal area with high speed are under the suspect to be suicides. The accident causes speed, alcohol, drugs and over-fatigue are traditionally underreported in police records.

Since tunnel accidents are quite seldom and the reasons for their occurrence are not exclusively due to the specific point of origin in a tunnel, problems with statistical significance are possible. The standard deviation of the sample for tunnels with uni-directional traffic is 0.101, with a 95% probability that the mean value is within +/- 0.03. Especially Tunnels with bi-directional traffic show a value which is +/- 0.04 of its mean within the 95% confidence interval.

The study on safety in tunnels was one of the first attempts to collect data about tunnel accidents in Austria because tunnel accidents are not exactly identifiable in the official accident data base. The indication of kilometers of tunnel accidents (location in road network) is often inaccurate and the parameter “accident location tunnel” in accident sheets is not continuously used by policemen. Therefore it was necessary to check the area 1 kilometer before and after tunnels in Austria and compare “suspect” accidents with the corresponding accident records at the police stations. Moreover several aspects regarding the occurrence of accidents, e.g. causes and point of origin, are not considered in the accident statistics released by the authorities in Austria, so the analysis of police records was used for an in-depth analysis to complete the official accident statistics 1999-2003.

For the reason that a lot of data problems occurred within the tunnel study the Austrian Ministry of Transport decided to install a database for tunnel accidents in Austria. This data base is filled since January 2006 by operators which are monitoring tunnels and contains not only personal injury accidents but also property damage accidents, breakdowns and fires. The data in the new tunnel database are supplemented by data of the official accident data base and will allow extended research in tunnel accidents.

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