COMPARATIVE ANALYSIS OF ROAD 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 first part of the study represents 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.
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.

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.

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

This chapter compares accident rates occurring in the studied tunnels with unidirectional and bi-directional traffic on motorways and expressways. The length of a tunnel has a very substantial influence on relative accident rates. Particularly tunnels of less than one kilometre length have very high accident rates. As the share of short tunnels varies greatly, a comparison of safety is not possible. 71% of all tunnels with unidirectional traffic (78) and 10% of all tunnels with bi-directional traffic (2) are shorter than one kilometre. The question of whether tunnels with bi-directional traffic or tunnels with unidirectional traffic are safer arisen, only with regard to longer tunnels, as short tunnels are usually built as twin tube tunnels. For these and for statistical reasons it seems meaningful to compare only tunnels of a length of one kilometre and more.

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

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Table 1: Number, length and traffic intensity of tunnels of more than one kilometre length with bi-directional and unidirectional traffic (status 2003)

<table>
<thead>
<tr>
<th></th>
<th>Tunnels with bi-directional traffic</th>
<th>Tunnels with unidirectional traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of tunnels studied</td>
<td>18</td>
<td>32</td>
</tr>
<tr>
<td>Total length [km]</td>
<td>86,214</td>
<td>64,307</td>
</tr>
<tr>
<td>Average length [km]</td>
<td>4,790</td>
<td>2,010</td>
</tr>
<tr>
<td>Traffic intensity [ADT]</td>
<td>14,569</td>
<td>12,154</td>
</tr>
</tbody>
</table>

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.

In the analysis below, 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. The calculations below comprise accident rates, accident cost rates, casualty rates and fatality rates for accidents in tunnels with bi-directional and unidirectional traffic.

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 higher 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. 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.

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4. SPECIAL ANALYSIS OF SAFETY IN TUNNELS

In this chapter 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 are analysed in the Chapter before. On the basis of the new results, measures aimed at raising safety in road tunnels are formulated in the following chapter.

4.1. Accident rate and point of origin of the accident

![Bar chart showing accident rates in different tunnel sections]

**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)

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

![Chart showing accident types and origins]

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

In tunnels with bi-directional traffic the most frequent accident type in all areas, excepting the portal area, is rear-end collisions. 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. 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, while in the portal area the main cause is speeding.

![Chart showing accident types and origins]

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

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 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.

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.

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

![Graph showing causes of accidents in tunnels with bi-directional and uni-directional traffic.](image)

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

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.

4.4. Relationship between cause and fault

![Graph showing cause of accidents in tunnels by fault and type of vehicle.](image)

Figure 8: Cause of accidents in tunnels by fault (100%) and type of vehicle, multiple mentions are possible, absolute (1999-2003)
Lacking vigilance is the most frequent cause of both accidents with passenger cars at fault and accidents with Lorries at fault. On the following places are wrong driving behaviour and misinterpretation. What is striking is that the proportion of accidents caused by speeding is especially high in accidents involving passenger cars.

5. **RECOMMENDATIONS**

The analysis of tunnel accidents by type of accidents show that the main problem is not the tunnel as a construction but the generally lacking traffic morality regarding observation of speed limits and maintaining a safe distance to the vehicle in front. Every second accident is due to the failure to maintain a safe distance to the vehicle in front and many accidents are caused by speeding. In order to reduce the accidents in tunnels, it is recommended to install distance measuring devices, radar devices and section control devices.

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.

As the portal area shows 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. 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.

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. Particularly in longer tunnels, lacking vigilance may have serious consequences and lead to partly severe accidents with personal injury and, as a consequence, also to fires.

Driving lessons have already been intensified and, additionally to that, a focus should be laid on measures aimed at making people aware of the importance of a correct driving behaviour in case of accidents, breakdowns and fires in tunnels, as in most of the cases it is the behaviour of the individual driver deciding between life and death.

6. **SUMMARY**

The probability of an accident occurring in a tunnel or of being injured or killed in a tunnel is lower than on the open stretches of motorways, expressways and federal roads. However, if an accident does happen in a tunnel, the severity of injuries is significantly higher than on the open stretches of motorways. As a consequence, the accident cost rate is 52% higher than on the open stretches of motorways. In tunnels the risk of being killed in an accident is twice as high as on the open stretches of motorways

Looking at all accidents in the 130 motorway and expressway tunnels studied, it is not possible to draw any clear conclusions about the safety of tunnels with bi-directional traffic versus those with uni-directional traffic as one major factor influencing accidents is tunnel length. In order to prevent an excessive impact of tunnel length on relative accident rates,
tunnels of a length of more than one kilometre with bi-directional traffic and uni-directional traffic were analysed separately. The accident rates of bi-directional and uni-directional tunnels with a length of over one kilometre are approximately at the same level. However, traffic safety is significantly higher in tunnels with uni-directional traffic than in tunnels with bi-directional traffic. The probability of being killed in an accident is 19% higher in tunnels with bi-directional traffic than in tunnels with uni-directional traffic. In tunnels with bi-directional traffic the accident cost rate and the fatality rate are respectively twice and 2.3 times as high as the corresponding rates in tunnels with uni-directional traffic.

Both in tunnels with bi-directional traffic and in tunnels with uni-directional traffic most accidents occur in the portal area. It is significant that in both types of tunnels the accident rate is higher in the area before the entrance and after the exit than in the interior zone of the tunnel.

In tunnels with bi-directional traffic rear-end collisions are the most frequent accident type in all areas excepting the portal area. In the area of the portals single-vehicle accidents are most frequent, whereas in the interior zone of the tunnel, besides rear-end collisions, mainly frontal collisions occur. In tunnels with uni-directional traffic most part of the accidents occurring in the area before the entrance and after the exit as well as in the area of the portal are single-vehicle accidents, whereas in the area of the entrance and in the interior zone of the tunnel, the main cause of accidents is rear-end collisions.

Generally, the most frequent cause of accidents in tunnels is lacking vigilance (over-fatigue, distraction and inattentiveness). On the second place is the failure to maintain a safe distance to the vehicle in front, wrong behaviour while overtaking and the failure to remain within the marked lane as well as misinterpretation of meteorological conditions and other vehicles. Particularly in tunnels with bi-directional traffic, lacking vigilance represents by far the most important problem, whereas in tunnels with uni-directional traffic wrong driving behaviour plays an as important role as lacking vigilance. Moreover, it must be said that in tunnels with uni-directional traffic the number of accidents caused by speeding is significantly high.

Lacking vigilance is a major problem, especially in the interior zone of the tunnel. This is particularly true in longer tunnels, where lacking vigilance resulting from over-fatigue and inattentiveness may have a high impact. Most part of the accidents occurring in the area of the portal is caused by speeding or by misinterpretation.

REFERENCES:
