SAFETY IN TUNNELS ON MOTOR- AND EXPRESSWAYS

Nussbaumer C., Nitsche P.
Department of Transport and Mobility
Austrian Road Safety Board

ABSTRACT

Both the probability of accidents 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 risk of being killed is significantly higher than on open stretches of motorways. In a tunnel the risk of being killed in a traffic accident is 1.5 times the risk of open stretches on motorways. In tunnels with bi-directional traffic the probability of being killed in a traffic accident is 1.4 times as high as in tunnels with unidirectional traffic. Both in tunnels with bi-directional traffic and in tunnels with unidirectional 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, unidirectional, bi-directional

1. INTRODUCTION

The safety of road tunnels is still an important topic in road safety although the Austrian Tunnel Commission and the implementation of the EU directive “Minimum safety requirements for tunnels” already achieved improvements in the area of tunnel safety. Accidents and fires in tunnels must not be neglected because of the high potential of those catastrophes.

Every year, 93 accidents in motorway and expressway tunnels occur in Austria on the average. These accidents result in 9 fatalities, 24 severe injuries and 118 minor injuries. The macroeconomic costs amount to a total of 19.8 million Euros per year. The study “Safety in Road Tunnels” of the Austrian Road Safety Board commissioned by the Federal Ministry of Transport, Innovation and Technology (Nussbaumer C., Nitsche P. 2008) explores the traffic safety of road tunnels compared with safety on motorways and expressways and also compares traffic safety in tunnels carrying bi-directional traffic and unidirectional traffic.

The first part of the study represents a continuation of the study „Comparative Analysis of Safety in Tunnels” (Robatsch, Nussbaumer, 2005). This study dealing with accidents occurring in Austrian tunnels between the years 1999 and 2003 is now completed by the present study dealing with accidents occurring between 2004 and 2007. In the second part accidents in tunnels are evaluated by point of origin and cause. Based on the results of this study, recommendations are made on measures aimed at raising safety in road tunnels.

Relevant data for accidents in tunnels between 2004 and 2005 has been collected in an in-depth analysis carried out by using police and court files. For the period 2006 to 2007 data of the new developed tunnel database have to be corrected with official accident statistics. This evaluation is not yet fully completed (accident data for 2007 are not available for the last quarter and a reform of the court system delayed the accident record collection). For this reasons the results of this study may differ slightly when all accidents have been evaluated for the national report.
2. DEVELOPMENT OF THE TUNNEL INCIDENT DATABASE

The analysis of tunnel accidents in the accident statistics released by the authorities is difficult and a tunnel accident is not always clearly identifiable. Tunnels can be found by kilometer in the network and tunnel accidents are identified by code 30 in the category “identification of the scene of an accident”. The problem is the inaccurate indication of kilometers and the code 30 is not used continuously for tunnel accidents. Mainly in the portal area it is uncertain if an accident happened before or in the tunnel. For the study „Comparative Analysis of Safety in Tunnels“ (Robatsch, Nussbaumer, 2005) tunnel accidents of the official accident statistic have been checked and supplemented by collection of police records.

2004 the European Union has implemented reporting duties for incidents in tunnels but the collection of police records is time consuming and costly. Therefore the Federal Ministry of Transport, Innovation and Technology commissioned the Austrian Road Safety Board to develop a tunnel incident database. The Asfinag provided the company server for the database and personal for the data input in the tunnel control centers. The tunnel incident database contains data about tunnels on motor- and expressways as well as data about incidents in tunnels. The data are recorded since 1.1.2006 in the tunnel control centers according to the requirements of the EU directive and future research.

3. SAFETY IN TUNNELS VERSUS MOTOR- AND EXPRESSWAYS

Presently, 137 tunnels exist on motorways and expressways in Austria. According to the annual report of the Asfinag 2006 the road network of the Asfinag is 2.062 km long and thereof 193 km are tunnels. A variety of accident rates and the distance travelled in all of the tunnels studied are compared with the corresponding figures for motorways and expressways on open sections.

![Figure 1: Relative accident rates for tunnels versus motor- and expressways (1999-2007)](image)

In tunnels, the accident rate and the casualty rate are significantly lower than on motorways and expressways. A comparison of accident cost rates shows that the difference between tunnels and motorways is very small. By far the highest accident cost rate occurs on expressways. The probability of an accident occurring in tunnels is lower than on motorways and expressways. However, the risk of being killed in a traffic accident in tunnels is 1.5 times the risk on motorways but lower than on expressways.
4. SAFETY IN TUNNELS WITH UNI- AND BI-DIRECTIONAL TRAFFIC

This chapter compares accident rates occurring in the tunnels being surveyed with unidirectional and bi-directional traffic on motorways and expressways. In the present study, all Austrian tunnels with a length of at least 200 meters that have been opened before 1.1.2007 have been analysed. In the calculations below, 21 tunnels with bi-directional traffic are compared with 179 tunnel tubes carrying unidirectional traffic.

Table 1: Number, length and traffic intensity of tunnels with bi-directional and unidirectional traffic (status 2007)

<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>21</td>
<td>179</td>
</tr>
<tr>
<td>Total length [km]</td>
<td>87,959</td>
<td>206,346</td>
</tr>
<tr>
<td>Average length [km]</td>
<td>4,188</td>
<td>1,146</td>
</tr>
<tr>
<td>Traffic intensity [ADT]</td>
<td>13.628</td>
<td>12.678</td>
</tr>
</tbody>
</table>

On average, tunnels with bi-directional traffic are 3.7 times as long as tunnels with unidirectional traffic. At 13.628 vehicles per day, the average traffic intensity in tunnels with bi-directional traffic is slightly higher than in tunnels with unidirectional traffic, which carry 12.678 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. 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 2: Relative accident rate for tunnels with bi-directional traffic and unidirectional traffic (1999-2007)
In tunnels with bi-directional traffic, the accident rate of 0.043 accidents per one million vehicle-kilometres is significantly lower than in tunnels with unidirectional traffic, where the corresponding rate is 0.109 accidents per one million vehicle-kilometres.

While the casualty rate in tunnels with bi-directional traffic is 0.099 casualties per 1 million vehicle-kilometres, the corresponding rate in tunnels with unidirectional traffic is 0.185 casualties per 1 million vehicle-kilometres. In tunnels with bi-directional traffic, the accident cost rate is slightly lower than in tunnels with unidirectional traffic. The accident cost rate in tunnels with bi-directional traffic is EUR 17.6 per 1,000 vehicle-kilometres and in tunnels with unidirectional traffic EUR 18.3 per 1,000 vehicle-kilometres.

It is worth mentioning that the fatality rate in tunnels with bi-directional traffic is 1.4 times the risk in tunnels with unidirectional traffic. While in tunnels with bi-directional traffic, 10.3 traffic fatalities occur per one billion vehicle-kilometres, the corresponding figure for tunnels with unidirectional traffic is 7.3 persons killed per one billion vehicle-kilometres.

5. **IN-DEPTH ANALYSIS OF SAFETY IN TUNNELS**

In this chapter, accidents with personal injury in tunnels are analysed by the parameters point of origin, accident type and cause. On the basis of the results, measures aimed at raising safety in road tunnels are formulated.

5.1. **Accident rate and point of origin of the accident**

![Graph](image)

*Figure 3: Personal injury accident rate [PIA/1 million vehicle-kilometres] in tunnels with bi-directional traffic and unidirectional traffic by point of origin of the accident (1999-2007)*

In tunnels with bi-directional traffic and unidirectional traffic, the highest accident rates are reported in the portal area. In tunnels with bi-directional traffic, the accident rate in the areas before the entrance is higher than in the interior zone of the tunnel. 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 is very high due to the transition from unidirectional traffic to bi-directional traffic.
5.2. Accident type and point of origin of the accident

![Figure 4: Types of accidents in tunnels with bi-directional traffic by point of origin of the accident, in percent (1999-2007)](image)

In tunnels with bi-directional traffic, the most frequent accident type in all areas, except the portal area, is type 1, accidents in the same direction. These accidents include rear-end collisions sharing 47% of all accidents in tunnels with bi-directional and unidirectional traffic. They also include accidents due to overtaking and lane changing. As shown in Figure 4, the highest proportion of accidents in the same direction is reported in the entrance area (70%), 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 (62.5%).

Opposing direction accidents have an overall proportion of 30% in tunnels with bi-directional traffic. Most of those accidents occur in the interior zone of the tunnel. Aside from touching collisions, mainly frontal collisions occur in opposing direction accidents. 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 causes are overfatigue and speeding.

![Figure 5: Types of accidents in tunnels with unidirectional traffic by point of origin of the accident, in percent (1999-2007)](image)
In tunnels with unidirectional traffic single vehicle accidents mainly occur in the portal area (61.9%). In all other tunnel areas the accidents in the same direction (including rear-end collisions among others) have the highest proportion. Especially in the entrance area, most accidents occur in the same direction (80.2%). In total, rear-end collisions are the most frequent type of accidents in unidirectional 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 wrong driver behaviour like the failure to maintain a safe distance to the vehicle in front, wrong overtaking and the failure to remain within the marked lane.

Summing up, in tunnels the proportion of rear-end collisions is significantly high. In the portal area 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.

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

![Figure 6: Causes of accidents in tunnels with bi-directional and tunnels with unidirectional traffic, in percent (1999-2005)](image)

Generally, the most frequent cause of accidents in tunnels is wrong driving behaviour, followed by lack of vigilance such as overfatigue, distraction or inattentiveness. 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 has a proportion of 44.1% in tunnels with bi-directional traffic. This value is slightly higher than in tunnels with unidirectional traffic (38.4%). The third most frequent cause (6.89%) is misinterpretation of road design and layout, meteorological conditions and other vehicles. Speeding has an almost similar proportion with 6.0%. Other causes of accidents, such as unpredictable events and technical defects (motor, tyres and brakes) were negligible.

The accident causes speed, alcohol, drugs and over-fatigue are traditionally underreported in police records.
6. ANALYSIS OF INCIDENTS IN TUNNELS

Aside from accidents with personal injury other incidents also occur, which have a high impact on road safety. The development of incidents over time can only be analysed when data of the following years are available. It is possible that data in the first year of the new developed tunnel incident database are not reported completely.

Table 2: Accidents and fires in tunnels, absolute (2006-2007)

<table>
<thead>
<tr>
<th></th>
<th>Accident with personal injury</th>
<th>Accident with damage to property</th>
<th>Fire</th>
<th>Incidents total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>57</td>
<td>88</td>
<td>8</td>
<td>152</td>
</tr>
<tr>
<td>2007</td>
<td>73</td>
<td>246</td>
<td>8</td>
<td>327</td>
</tr>
<tr>
<td>Total</td>
<td>130</td>
<td>334</td>
<td>16</td>
<td>479</td>
</tr>
<tr>
<td>Share of all incidents (%)</td>
<td>27,1</td>
<td>69,7</td>
<td>3,3</td>
<td>-</td>
</tr>
</tbody>
</table>

Within two years, a total of 130 accidents with personal injury, 334 accidents with damage to property and 16 fires happened in tunnels on motor- and expressways. The highest share of all incidents in tunnels is accidents with damage to property (69.7%), followed by 27.1% accidents with personal injury. Fires are comparatively seldom in tunnels.

7. RECOMMENDATIONS

7.1. Enforcement

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 morality regarding maintaining a safe distance to the vehicle in front and/or observation of speed limits. Every 2nd accident in a tunnel is a rear-end collision (failure to maintain a safe distance to the vehicle in front) and many accidents are single accidents (mainly caused by over-fatigue, wrong driving behaviour and 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 also recommended for the area before the tunnel tube, beginning at least at 250 m before the portal, in order to raise tunnel safety in an optimal way.

As one of 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.

7.2. Traffic education

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.
7.3. Infrastructure

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. To solve this problem the placement of the traffic lights at the tunnel portal should be re-considered.

8. SUMMARY

The probability of an accident occurring or being injured in a tunnel is lower than on the open stretches of motorways and expressways. However, if an accident does happen in a tunnel, the risk of being killed is significantly higher than on the open stretches of motorways. In tunnels, the risk of being killed in an accident is 1.5 times as high as on the open stretches of motorways.

In the present study, 21 tunnels with bi-directional traffic and 179 tunnel tubes with unidirectional traffic have been examined. The accident rate (accidents per 1 million vehicle-km) in tunnels with unidirectional traffic is 2.5 times as high as in tunnels with bi-directional traffic. Despite, in tunnels with bi-directional traffic the probability of being killed in an accident is higher than in tunnels with unidirectional traffic. This is due to the high severity in opposing direction accidents.

Both in tunnels with bi-directional traffic and in tunnels with unidirectional traffic most accidents relative to the distance travelled occur in the portal area. The accident rate before the entrance of tunnels with bi-directional traffic is higher than in the interior zone. The transition from unidirectional to bi-directional traffic may be the reason for those results.

In all tunnels, rear-end collisions are the most frequent accident type in all areas excepting the portal area. In the areas of the portals single-vehicle accidents are most frequent. Opposing direction accidents share 30% of all accidents in tunnels with bi-directional traffic. Most of those accidents occur in the interior zone of the tunnels.

Generally, the most frequent cause of accidents in tunnels is wrong driving behaviour. Every fifth accident in tunnels is due to the failure to maintain a safe distance to the vehicle in front. Approximately 28% of all tunnel accidents are caused by lacking vigilance consisting of over-fatigue, distraction and inattentiveness among others. Speeding and misinterpretation of road design and layout, meteorological conditions and other vehicles have almost similar proportions.

9. REFERENCES:
