A COMPARATIVE RISK ANALYSIS FOR SELECTED AUSTRIAN TUNNELS

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ABSTRACT

Public opinion about tunnel safety is often based on irrational assumptions. This is especially the case in the aftermath of severe tunnel accidents. The public calls for the implementation of costly measures like the installation of sprinkler systems in all tunnels. To rationalise decisions concerning tunnel safety a Quantitative Risk Assessment (QRA) software was developed in a joint OECD, PIARC and EU project. This software makes it possible to calculate the societal risk in the form of F/N curves. F/N curves show the relationship between accident frequency and accident severity.

In the year 2001 the Federal Ministry of Transport, Innovation and Technology initiated an Austrian tunnel safety board. The issue of tolerable risk was discussed in this committee. The members of the safety board agreed on threshold values for tolerable and non tolerable risk. Between this two there is an area of conditional tolerable risk which is called ALARP-region (As Low as Rational Possible). The QRA software in combination with this definition makes it possible to assess the risk for existing and planned tunnels. If the F/N curve of a tunnel is in the range of tolerable risk, no action is required. If the F/N curve touches the area of non tolerable risk, immediate action is required independent from costs. If the F/N curve is situated in the ALARP region, mitigation measures are necessary, but issues of cost effectiveness can be taken into account.

In a project funded by the Federal Ministry of Transport, Innovation and Technology the Institute for Transport Planning and Traffic Engineering carried out a QRA study for 13 selected Austrian tunnels. The tunnel length ranged from about one to ten kilometres. The selection covered uni- and bi-directional tunnels as well as a broad range of different ventilation systems. None of the analysed tunnels reaches the area of non tolerable risk. All F/N curves are situated more or less within the ALARP region. None is lying exclusively in the area of tolerable risk. Suggestions for risk mitigating measures were made.

Key words: tunnels, quantitative risk assessment, heavy goods vehicles, dangerous goods

1. INTRODUCTION

Public opinion about tunnel safety is often based on irrational assumptions. This is especially the case in the aftermath of severe tunnel accidents like the Tauerntunnel accident in 1999 or the Gleinalmtunnel accident in 2001. The public calls for the implementation of costly measures like the installation of sprinkler systems etc. in all tunnels. A tunnel safety board was installed by the Austrian Federal Ministry of Transport, Innovation and Technology after the fatal accident in the Gleinalmtunnel. To rationalise decisions concerning tunnel safety the use of Quantitative Risk Assessment (QRA) was suggested in this committee. A QRA software suitable for this purpose was developed in a joint OECD, PIARC and EU project (Knoflacher, 2001; Knoflacher and Pfaffenbichler, 2001; OECD, 2001). This software makes it possible to calculate the societal risk in the form of F/N curves. F/N curves show the relationship between accident frequency and accident severity. A more detailed description about risk and F/N curves is given in (Knoflacher and Pfaffenbichler, 2001). The application of the QRA software to the case study Tauerntunnel was shown in (Knoflacher et al., 2002).

The question of tolerable risk was extensively discussed in the Austrian tunnel safety board. The members of this committee agreed on threshold values for tolerable and non tolerable risk (Figure 1). The basis for the threshold of non tolerable risk is that the risk in tunnels must not exceed that on open road. The threshold for tolerable risk is about the same magnitude as getting killed by a lightning or a similar natural disaster. Between these two thresholds there is an area of conditional tolerable risk. This is given the name ALARP-region (As Low as Rational Possible). Another principle is that each fatality is valued equally, i.e. the tolerated frequency for an incident causing ten fatalities is one tenth of that of an incident causing one fatality. This assumption defines the slope of the tolerance curves. The software in combination with this definition makes it possible to assess the risk in existing tunnels. If the F/N curve of a tunnel is completely in the range of tolerable risk, no action is required. If the F/N curve touches the area of non tolerable risk, immediate action is required no matter what it costs. If the F/N curve is situated in the ALARP region, mitigation measures are necessary, but issues of cost effectiveness can be taken into account.

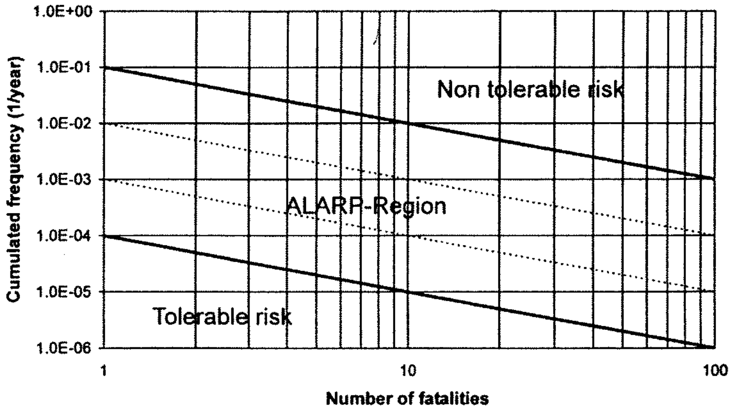

Figure 1: Tolerable risk as suggested by the Austrian Commission for Tunnel Safety for a 1 km road tunnel

2. TEST TUNNELS

In a project funded by the Federal Ministry of Transport, Innovation and Technology the Institute for Transport Planning and Traffic Engineering, Vienna University of Technology carried out a QRA study in 13 selected Austrian tunnels (see Figure 1 and Table 1). The tunnel length ranged from about one to ten kilometres. The selection covered uni- and bi-directional tunnels as well as a broad range of different ventilation systems (see Table 1).

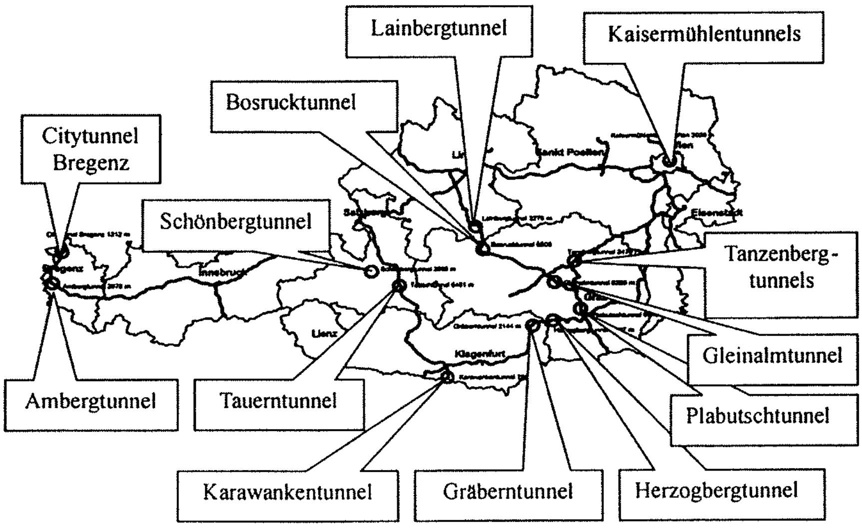

Figure 2: Location of the QRA case study tunnels

Table 1: Basic characteristics of the QRA case study tunnels

Name	Length (km)	Bores	Ventilation	Emergency exits[1)]	AADT (Veh./d)	HGV share
Ambergtunnel	2.978	one	ST	-	22,721	8.6 %
Bosrucktunnel	5.500	one	T	366 m	7,365	38.5 %
Citytunnel Bregenz	1.311	one	L plus extraction	656 m	12,911	3.7 %
Gleinalmtunnel	8.320	one	T	-	14,068	10.7 %
Gräberntunnel	2.144	one	ST	-	16,505	18.9 %
Herzogbergtunnel	2.007	one	ST	-	16,118	19.8 %
Kaisermühlentunnel	2.020	two	L	100 m	84,644	10.6 %
Karawankentunnel	7.864	one	L and T	393 m	5,106	10.4 %
Lainbergtunnel	2.278	one	L	760 m	9,435	20.2 %
Plabutschtunnel	9.919	two/one	T	3,036 m	20,681	15.4 %
Schönbergtunnel	2.988	one	L	998 m	8,448	12.9 %
Tanzenbergtunnel	2.384 / 2.476	two	ST/L	408 m	21,479	11.2 %
Tauerntunnel	6.397	one	T	-	13,200	21.0 %

Abbreviations: L...Longitudinal ventilation, ST...Semi-transverse ventilation, T...Transverse ventilation

1) "-" no emergency exits; distance as used in the QRA software

3. QRA RESULTS

This section presents the societal risk[1] as calculated in the 13 case studies in the form of F/N-curves (Knoflacher et al., 2003). Section 3.1 shows a compilation of all results. The sections 3.2 to 3.5 give a more detailed presentation of the results for five selected tunnels. These results include the societal risk of a base case and the effects of several tunnel specific mitigation measures and scenarios.

3.1. Summary

Figure 3 shows a compilation of the F/N-curves of all 13 tunnels tested. The highest societal risk was calculated for the Viennese Kaisermühlentunnel. As the Kaisermühlentunnel has by far the highest traffic volumes (nearly four times that of the next highest, the Ambergtunnel) this result was expected. The highest number of potential fatalities was calculated for the Plabutschtunnel. Again the result is plausible. The Plabutschtunnel is the longest tunnel in the case study. The two tunnels with the lowest risk levels are the Citytunnel Bregenz and the Schönbergtunnel. The Citytunnel is relatively short and has a very low share of heavy goods vehicle (HGV) traffic. The Schönbergtunnel is rather new and has a low traffic volume.

Five tunnels were selected for a more detailed presentation of their QRA results. The Kaisermühlentunnel was chosen for the high level of societal risk. On the other end of the spectrum the Schönbergtunnel was chosen because of the low risk level. The highest share of HGV traffic of the tested tunnels was the reason for the selection of the Bosrucktunnel. The Gleinalmtunnel is seen as representative for the average longer one bore tunnels. The Tanzenbergtunnel was chosen because besides the Kaisermühlentunnel this is the only two bore tunnel in the case study.

[1] Note: The QRA software calculates the societal risk caused by incidents with HGV involvement. The risk of incidents involving only passenger cars is not included.

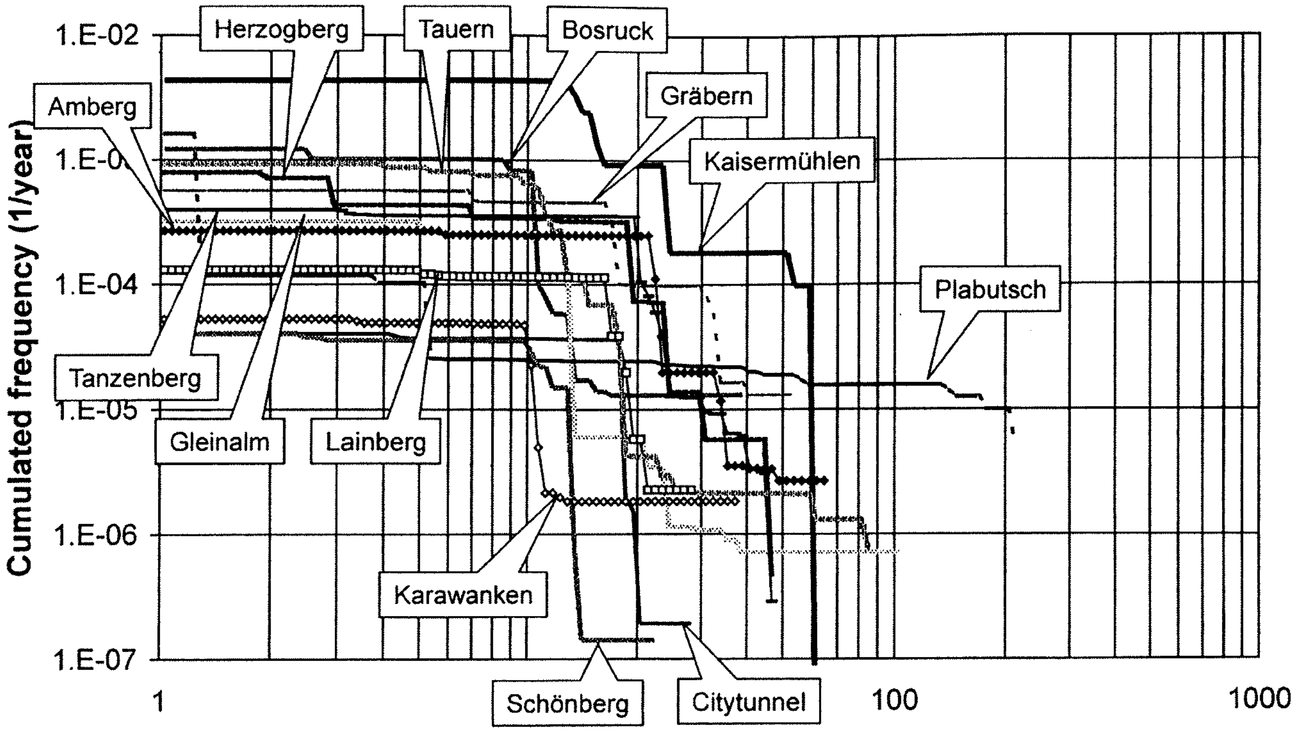

Figure 3: Comparison of the F/N curves of the 13 case study tunnels

3.2. Kaisermühlentunnel

The Kaisermühlentunnel is an urban tunnel and is part of the highway A22 "Donauuferautobahn". The traffic volumes are very high. There are entrance and exit ramps within the tunnel. Due to a nearby tank farm the share of HGVs carrying flammable liquids (motor spirit, diesel oil,...) is high. The societal risk calculated for the Kaisermühlentunnel was the highest of all tested tunnels (Figure 4). Nevertheless it still stays clear from the threshold for intolerable risk. The F/N-curve of the base case is situated within the ALARP region. I.e. mitigation measures taking cost effectiveness into account should be implemented. In Figure 4 the effects of two potential mitigation measures are shown. The first is banning heavy goods vehicles transporting dangerous goods (DG-HGV) from the Kaisermühlentunnel. The grey triangles in Figure 4 show the F/N-curve of this scenario. The potential to mitigate the risk is rather low. The major effect is for incidents with more than eleven fatalities. Additionally it would be necessary to reroute the DG-HGVs over two bridges and a road with heavy traffic and intersections. The total risk of the DG-HGV ban would be higher than in the base case. Especially the risk for third parties would be higher. The second measure tested is a regulation that HGVs have to keep a minimum distance of 150 meters to the vehicle driving ahead. The risk reduction potential is rather high and significant for incidents with more than seven fatalities.

Since August 2003 a section control is in operation in the Kaisermühlentunnel (ASFINAG, 2004). This instrument reduces the accident rate dramatically. No accidents were observed since the installation of the section control. Detailed data are not yet available. For the QRA it was assumed that the section control reduces the accident rates by a factor of ten. In Figure 4 the QRA results for this scenario are marked with crosses. A combination of the 150-meter regulation and the section control has the potential to bring the risk near to the threshold for tolerable risk.

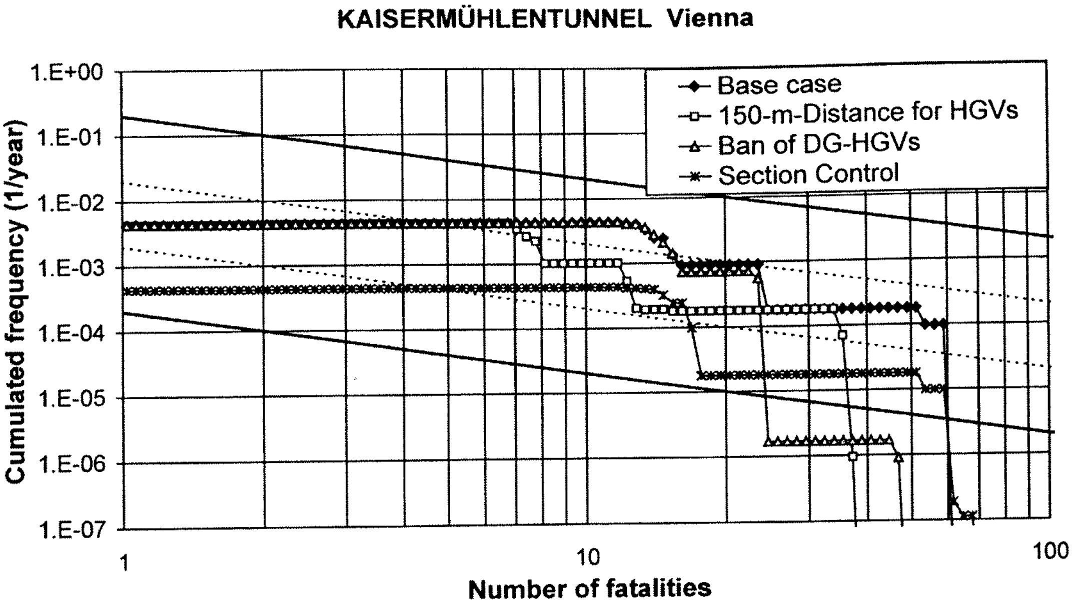

Figure 4: F/N curves Kaisermühlentunnel Vienna

3.3. Schönbergtunnel

The Schönbergtunnel is a one bore tunnel on a rural trunk road. The tunnel is rather new (opened in November 1999) and the traffic volumes are low (about 8,500 vehicles per day). Nearly the complete F/N-curve is below the threshold for tolerable risk. Therefore no additional scenarios were calculated for the Schönbergtunnel.

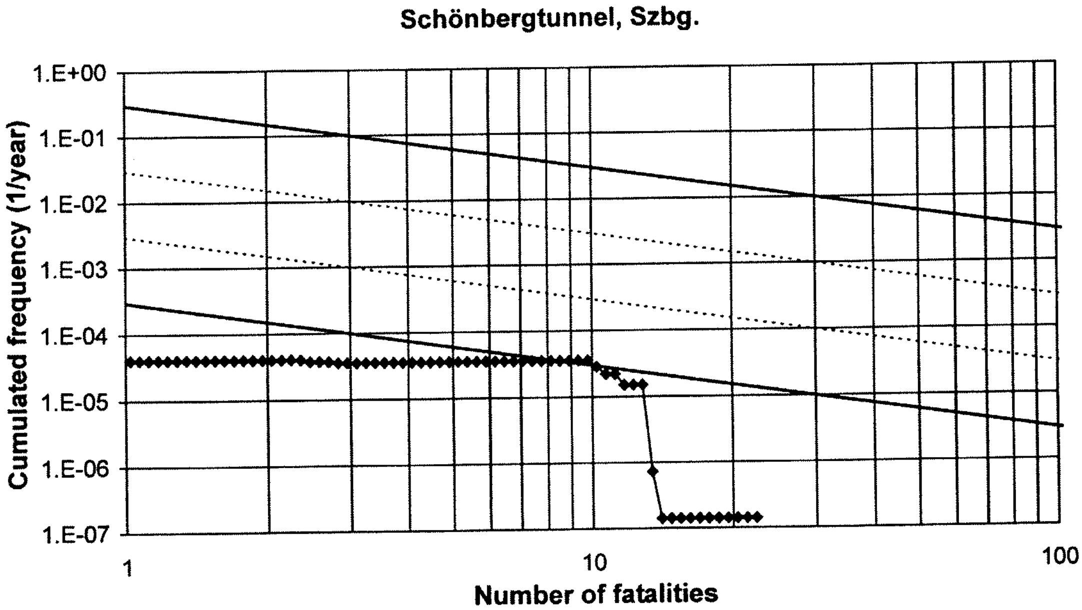

Figure 5: F/N curves Schönbergtunnel, Salzburg

3.4. Bosrucktunnel

The Bosrucktunnel is a one bore tunnel on a rural stretch of the highway A9. The Bosrucktunnel has a share of HGVs of nearly 40%. The renewed Bosrucktunnel has a separated escape tunnel. About all 400 meters there are waiting rooms. In the case of emergency persons are escorted by the fire brigade from the waiting rooms through the escape tunnel. The ventilation system of the Bosrucktunnel was modified during renovation. In the old ventilation system air was extracted through slots of one ventilation segment which was half of the tunnel length (Figure 6, left). In the modified ventilation system there are 51 discrete openings (jalousies 3x3 m) along the whole tunnel. In case of emergency all will be shut, except the one nearby the fire where the air will be extracted (Figure 6, right).

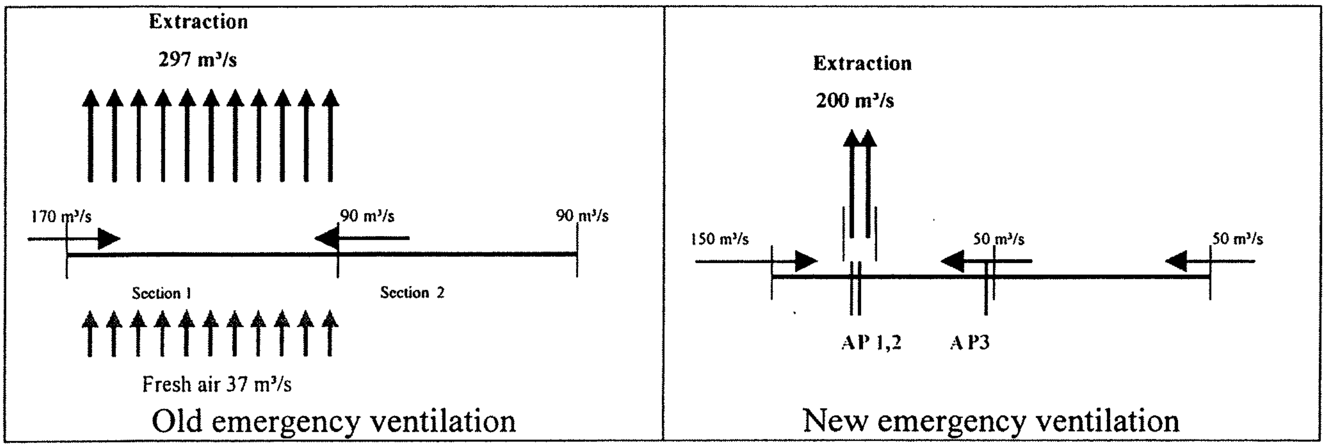

Figure 6: Ventilation systems Bosrucktunnel

The effect of the new ventilation regime was tested in the QRA (Figure 7). The base case with the old ventilation regime is depicted by black diamonds. The new ventilation regime is shown using triangles. A considerable risk reduction appears only for incidents with more than ten fatalities. As in section 3.2 the effect of a regulation, forcing HGV-drivers to keep a minimum 150-meter distance to vehicles ahead, was tested. In Figure 7 the result for the combination of the old ventilation regime and this regulation is shown with black circles. The risk mitigating effect is substantial. The last scenario tested the combination of the new ventilation system with the distance regulation for HGVs. Under these assumptions the risk mitigating effect of the new ventilation is much higher. The combination of both measures moves the F/N-curve quite near to the threshold for tolerable risk.

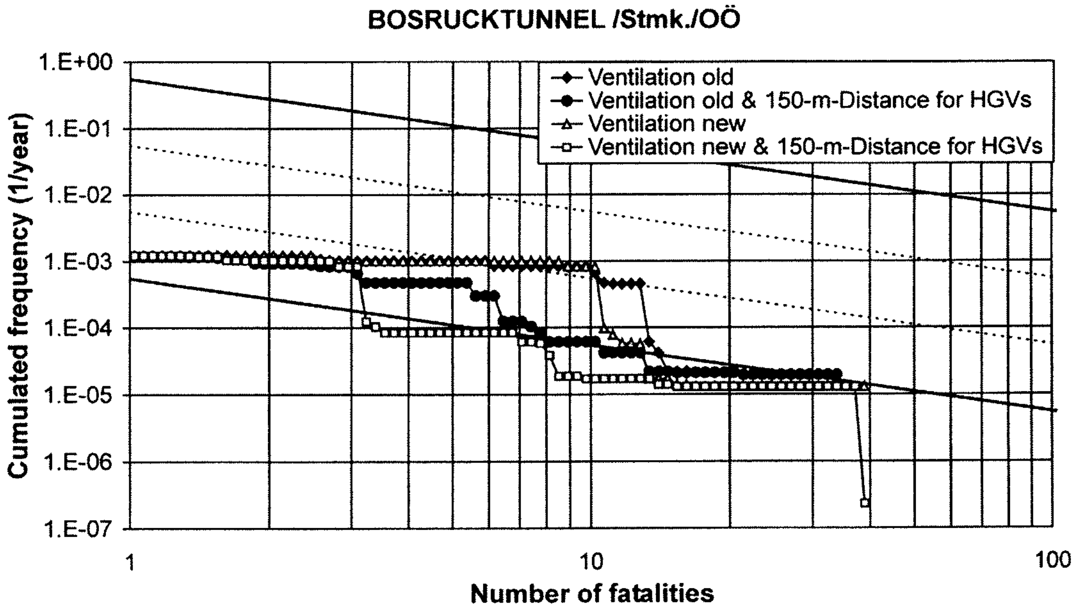

Figure 7: F/N curves Bosrucktunnel

3.5. Gleinalmtunnel

The Gleinalmtunnel is a one bore tunnel on a rural stretch of the highway A9. The ventilation system of the Gleinalmtunnel was modified similar to the Bosrucktunnel (see Figure 6). In the old system air could be extracted from six sections. In the modified ventilation system there are 84 discrete openings (jalousies 3x3 m) along the whole tunnel. In Figure 8 the old and the new system are depicted by black and white triangles respectively. The F/N-curves are quite near or even under the threshold for tolerable risk. Again there is a mitigating effect for incidents with more than ten fatalities. An additional scenario tested what would happen if the total traffic volumes increase by 40% while the share of HGVS doubles. The results for the two ventilation systems in this scenario are shown with black and white diamonds.

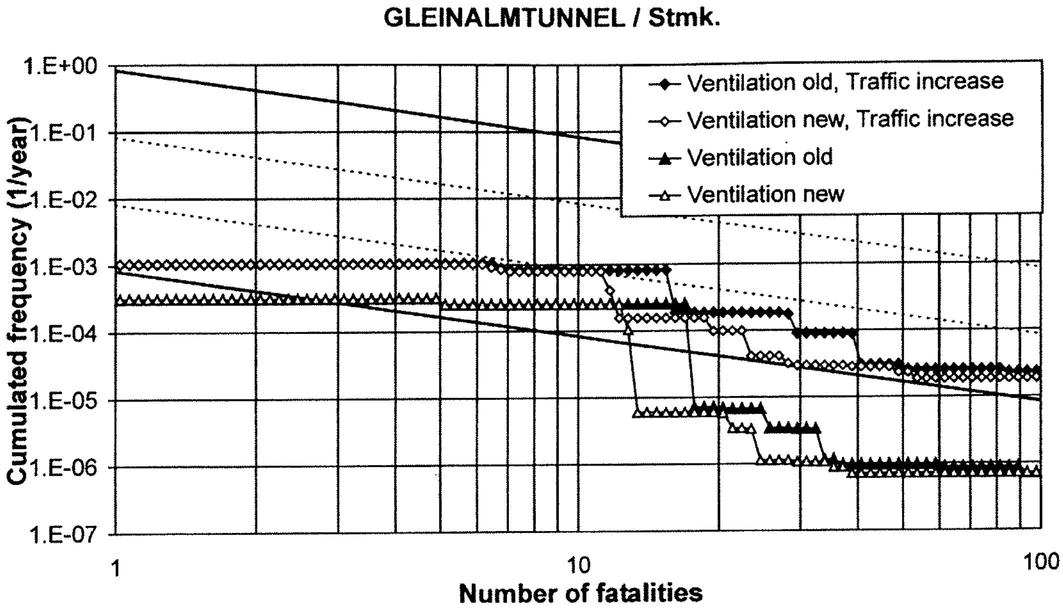

Figure 8: F/N curves Gleinalmtunnel

3.6. Tanzenbergtunnel

The Tanzenbergtunnel is a two-bore tunnel on a rural stretch of the dual carriageway S6. A noticeable characteristic of the Tanzenbergtunnel is that during the observed period the accident rate in both bores differed by a factor of ten. The accident rate in the Northern bore was about 0.232 accidents with personal injury per million vehicle kilometres while it was about 0.023 in the Southern bore (Knoflacher et al., 2003). Therefore an additional scenario reducing the accident rate in the northern bore by 50% was tested.

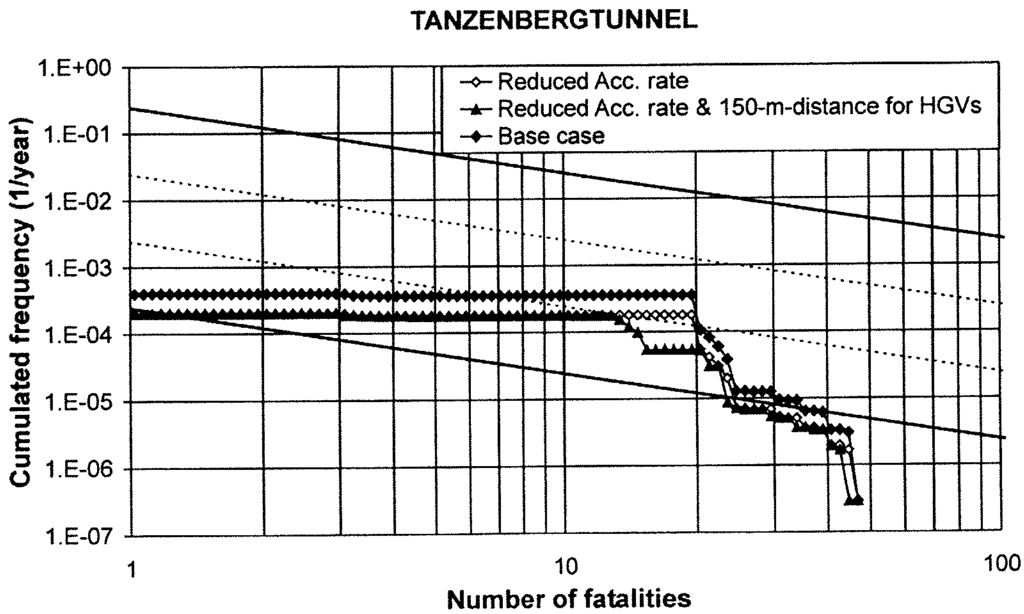

Figure 9: F/N curves Tanzenbergtunnel

4. CONCLUSIONS

The QRA software developed in a joint OECD, PIARC and EU project is a useful tool to rationalise decisions concerning road tunnel safety. The main result of the presented study is that in none of tested tunnels the risk caused by HGV traffic reaches the threshold of non tolerable risk. The F/N curves of all analysed tunnels are situated in different positions within the ALARP region. At the time of the study the need for mitigation measures was highest in the Kaisermühlentunnel. The responsible authorities already responded to this finding with the implementation of a section control. As the period of observation is still short, it was not possible to assess the effect of the section control in detail. The most effective other measure was the regulation, forcing HGV-drivers to keep a minimum 150-meter distance to vehicles ahead. The policing of this instrument could be included in future section control systems. The risk reducing effect of other, more costly infrastructure measures like changes in the ventilation system or the distance between emergency exits was smaller. A combination with the 150-meter regulation improved the effectiveness. The use of a section control measuring speed and distance and enforcing the compliance with their limits could be recommended for all major road tunnels.

5. GLOSSARY

AADT....... Annual Average Daily Traffic (Veh/d)
ALARP..... As Low As Rationale Possible
DG .... Dangerous Goods
HGV .... Heavy Goods Vehicles
QRA .... Quantitative Risk Assessment

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