Norwegian Public Roads Administration
Directorate of Public Roads

Studies on Norwegian Road Tunnels

an Analysis on Traffic Accidents and Car Fires in Road Tunnels, 1997

Road Transport and Safety Department
Transport Analysis Division

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Summary:

This report covers information from three earlier reports written in Norwegian. The three reports deals with tunnel statistics, analysis of traffic accidents and data on car fires in tunnels.

The number of tunnels has increased by 82 during the last four years. The accumulated length of tunnels on the national road network today is almost 600 km. Of the 702 tunnels 405 tunnels are 500m or shorter and 40 tunnels are longer than 3 000m. The average AADT in the tunnels is about 3 500.

Traffic accidents with personal injury are reported to the police, and local road offices make geographical references to where the accident happened and records the data in our accident data bank (STRAKS). In this accident analysis 588 tunnels opened in 1992 or earlier were studied. In this five year period 499 accidents were recorded. Two thirds of the tunnels had no accidents. Accidents were divided into a zone of 50m outside the tunnels (zone 1), then the first 50m of the tunnel (zone 2), then the next 100m (zone 3) and then the rest of the tunnel (zone 4). 26% of the accidents were recorded in zone 1, 19% in zone 2, 19% in zone 3 and 36% in zone 4. The accident rates (accidents pr year pr 1 mill veh.km) is 0.30 in zone 1, 0.23 in zone 2, 0.16 in zone 3 and 0.10 in zone 4. Accidents in tunnels are somewhat more serious compared to accidents on the open road. Of the different accident types, accidents between vehicles with same direction is overrepresented in one way tunnels, and accidents between meeting vehicles and single vehicle accidents in tunnels with two way traffic.

There is no mandatory reporting of fires in Norwegian tunnels. The Public Roads Administration has therefore asked local road offices and fire departments to collect data. This contact gave a record of 41 fires during the last 7 years. 8 fires were initiated by a collision. In 6 cases PolyEthylen-lining material in the tunnels had caught fire.

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FOREWORD

Norway is one of the countries in Europe that has been building the largest number of road tunnels. Tunnel statistics is of interest when assessing the extent of tunnel development and when reviewing how equipment and standards are being improved. This report also provides a basis for undertaking various analysis. Two of the studies that are documentet in this report covers traffic accidents and carfires in road tunnels.

The overview is based on data from the National Road Data Bank. A special data program has been prepared to produce relevant tunnel data reports. These reports represent the basis for this overview. In the overview each tunnel tube is defined as a tunnel. Thus dual tube tunnels are being considered as two tunnels. Furthermore, ramp tunnels are defined as tunnels in their own right. Thus the Oslo tunnel is considered to include five road tunnels since it encompasses dual tubes and three ramp tunnels. This special definition, however, affects very few road tunnels. This is also easily discerned from studying the tunnel listing as such tunnels are being listed under the same name.

The first study of road accidents in tunnels i Norway was prepared for the Public Road Adminstration in 1980. The study that are documented in this report was made by the Division of Transport analysis of the Public Roads Administration.The same division has also collected data on car fires in tunnels.

This report has been prepared at the Division of Transport Analysis by Finn H. Amundsen, Guro Ranes and Pål Melvær.

Public Roads Administration
Oslo, 1997-11-03

1. TUNNEL REVIEW

1.1 Tunnel lengths

Compared to the previous review in 1992/1993 there are now 702 road tunnels on record for the national network against 620 in 1992/93. There are thus recorded 82 additional road tunnels over a period of about four years. Additionally there are 142 county road tunnels. Most of these are relatively short. Table 1 shows the number of tunnels and lengths for the various tunnel length groups (in meters).

Tunnel length	Number 1992	Number 1996	Length 1992	Length 1996
Under 100m	113	114	6 435	6 703
100-500m	259	291	65 880	72 795
500-1000m	116	132	79 189	90 915
1000-3000m	102	125	174 670	217 624
Over 3000m	30	40	151 451	198 005
Sum	**620**	**702**	**476 825**	**586 042**

Table 1: Number of tunnels in the various length groups

The table shows that the number of tunnels have increased by 13.2% and the overall tunnel length by 22.9% in four years. The average tunnel length is now 835m against 770m in 1992/93. The number and lengths for the tunnel groups "Over 3000m" (33%) and "1000-3000m" (22.5%) have increased more than average. Lengths for these two groups have increased by 31% and 25% respectively.

Most tunnels opened to traffic during the last few years are in the "100-500m" (32) and "1000-3000m" length groups.

Since 1988 the number of road tunnels have increased by 173 from 529 to 702. During the same period the average tunnel length has increased from 550m to 835m, or by 52%.

As mentioned in the foreword some of the shorter tunnels carry ramps as part of the urban road network of Oslo, Bergen and Arendal (the Blødekjær tunnel). Similarly, some tunnels represent parts of dual or triple tube tunnel facilities. It is anticipated that nationwide there are about 10 ramps and 20 tunnels with two or more tubes. Tunnels given individual names number approximately 670.

Table 2 gives the number of tunnels in the various traffic volume (AADT) groups. This information is taken from the National Road Data Bank supplemented with data from the National Traffic Data Bank.

AADT-group	Number1992	Number 1996	Length 1992	Length 1996
Under 100	0	1	0	280
100-500	107	123	77 652	87 003
500-1000	171	188	161 545	205 184
1000-5000	224	243	167 453	196 512
Over 5000	118	147	70 174	97 063
Sum	**620**	**702**	**467 825**	**586 042**

Table 2: AADT in the tunnels

Table 2 shows that a number of tunnels with low traffic volumes i.e. 100 to 500 AADT have been opened. In spite of this, traffic volumes in tunnels have increased since a number of tunnels with traffic exceeding 1000 AADT have been opened.

1.2 Tunnel design

Table 3 shows roadway widths and AADT for the tunnels

Roadway widths in meters	AADT					
	Under 100	100-499	500-999	1000-5000	Over 5000	Total
0 - 4.0	1	17	28	14	1	61
4.1-5.0	0	21	29	15	2	67
5.1-6.0	0	75	102	108	11	296
6.1-8.0	0	7	25	84	89	205
8.1-10.0	0	0	1	5	15	21
Over 10	0	0	0	0	12	12
Unknown	0	3	3	17	17	40
Total	**1**	**123**	**188**	**243**	**147**	**702**

Table 3: Roadway widths for tunnels in various AADT groups

There are now only 128 road tunnels (about 18%) with less thant two lanes. Some of these are one-way tunnels such as ramps and other single lane tunnels. Most tunnels are in the width group where two lane tunnels predominate. The remaining tunnels probably have three lanes. The tunnel indicated with one lane and an AADT above 5000 is a tunnel carrying public transportation vehicles in Hordaland county. There seems otherwise to be a connection between roadway width and AADT. From the overview made in 1992/93 it appears that approximately 53% of the tunnels did not have two lanes of acceptable width, i.e. did not qualify to be marked with a center line.

Table 4 shows free hight in relationship to tunnel length

Free Hight in meters	Tunnel length					
	Under 100m	100-499m	500-999m	1000-3000m	Over 3000m	Total
3.1-3.5	9	4	0	2	0	15
3.6-4.0	27	45	25	26	9	132
4.1-4.2	19	32	20	21	3	95
4.3-4.6	40	166	73	72	28	379
Over 4.6	19	44	14	3	0	80
Unknown	0	0	0	1	0	1
Total	**114**	**291**	**132**	**125**	**40**	**702**

Table 4: Free height for the various tunnel length groups

There are still a large number of tunnels with a vertical clearance of 4.2m or less. This number is at least 242 (34%). In 1992/93 this proportion was 38%. As it is assumed that all new tunnels are provided with a minimum of 4.5m vertical clearance there does not appear to have been done any improvements to older tunnel.

1.3 Technical tunnel equipment

Table 5 shows the number of tunnels that are ventilated. In Norway all tunnels with mechanical ventilation are longitudinally ventilated.

	Ventilated				Not ventilated			
	Number		Total length (m)		Number		Total length (m)	
Tunnel length	1992	1996	1992	1996	1992	1996	1992	1996
Under 100m	1	0	11	0	90	114	5 175	6 703
100-499m	14	24	4 142	6 808	215	267	54 415	65 987
500-999m	23	31	16 752	22 260	85	101	68 391	68 655
1000-3000m	38	60	71 564	115 098	59	65	94 723	102 526
Over 3000m	27	39	138 836	194 775	3	1	12 615	3 230
Total	**103**	**154**	**231 305**	**338 941**	**452**	**548**	**235 319**	**247 101**

Table 5: Tunnels with and without longitudinal ventilation for various length groups

Compared with 1992 there are now additionally 51 ventilated tunnels. Thus at present about 22% of the tunnels are now provided with ventilation equipment. About 58% of the total tunnel length is now being artificially ventilated. The proportion varies with tunnel length and traffic volumes.

Table 6 shows the number of tunnels that are illuminated.

	Illuminated				Not illuminated			
	Number		Total length (m)		Number		Total length (m)	
Tunnel length	1992	1996	1992	1996	1992	1996	1992	1996
Under 100m	12	25	750	1 402	80	89	4 499	5 301
100-499m	152	231	40 294	58 690	82	60	20 014	14 105
500-999m	81	123	54 922	84 626	30	9	21 082	6 289
1000-3000m	80	121	138 855	210 420	21	4	34 597	7 204
Over 3000m	26	40	134 725	198 005	4	0	16 726	0
Total	**351**	**540**	**369 547**	**553 143**	**217**	**162**	**96 918**	**32 899**

Table 6: Tunnels with and without illumination for various length groups

In recent years the district road offices have undertaken to provide lighting for all tunnels exceeding 100m in length. That there appear to remain as many as 73 that are not illuminated may have resulted from a delay in the recording of relevant data with the Road Data Bank, or that some tunnels are only marginally exceeding 100m and therefore do not need lighting. According to available data at present about 90% of tunnels that warrant lighting are now so equipped. The proportion of the total tunnel length now illuminated is 95% compared with 80% in 1992/93.

1.4 Tunnel safety equipment

In recent years most new road tunnels are provided with safety equipment in accordance with handbook-021 Road Tunnels. This handbook requires that tunnels exceeding 500m shall be equipped with fire extinguishers and other equipment. At present 186 of 297 (62,6%) road tunnels are provided with fire extinguishers, against 102 (41,1%) in 1992/93.

During the last four years the proportion equipped with fire extinguishers has increased with 16,6%, while the proportion with emergency telephones has increased with 7%. There are now 75 (25,3%) road tunnels with antenna cables, against 49 (19,8%) in 1992.

Otherwise, the review shows that 119 road tunnels have had alternating red light systems installed and 74 have gates for closing the tunnel. Of these 41 are controlled remotely and 33 manually at the tunnel.

2 TRAFFIC ACCIDENTS IN ROAD TUNNELS

2.1 Background information

Driver behavior and traffic accidents are of major importance when designing road tunnels and revising tunnel design guidelines. Insight into tunnel operation ensures that tunnels can be built to a high level of safety at reasonable costs. In that manner low cost tunnels can be built and equipped to a high level of safety without excessive use of equipment and costly design standards.

Know-how on road tunnel safety in Norway is mainly based on two studies from the 1980s. Findings from these studies are reasonably consistent with similar foreign studies. All such studies show that traffic safety in road tunnels is at a similar level to that of twolane motorways. In spite of this, safety in road tunnels is being questioned. In particular in cases involving serious person injury accidents and especially if these occur within road tunnels. For many motorists tunnels are special facilities associated with a feeling of unease when entering into the darkness inside a mountain combined with concern of ones personal safety. Sub-sea tunnels with sharp vertical curvatures tend to increase such feelings.

The purpose of this study is to improve our insight into traffic accidents in road tunnels in general and in sub-sea and dual tube tunnels in particular. Of major interest is also to unveil causes of accidents that might be useful in conjunction with the selection of accident prevention measures. It is also of interest to learn what effects weather and road conditions, traffic volumes and tunnel lengths might have on accident types and location relative to entrance, transition and exit zones.

2.2 Previous Norwegian studies

As previously mentioned two major road accident studies have been undertaken in Norway. The first one was done by Magne Mo in 1979/80 as his graduation theses at NTH (now NTNU). The data was later reworked by SINTEF Vegteknikk (Asbjørn Hovd 1981). The study covered 361 road tunnels in 16 counties. The tunnels included in the study were relatively short (72% less than 500m) and narrow (35% less than 6m) with low traffic volumes (85% with an AADT of less than 1500). Almost 80% of the tunnels were without lighting. Over a 10 year period from 1970 to 1979 as many as 221 person injury accidents were reported in these tunnels. Traffic counts from 1974 were used to estimate tunnel AADTs. All tunnels studied had been open for more then three years and all accidents occurring 100m beyond the tunnel openings were included in the study. The data were divided into transition zone and mid-zone accidents. Of the total of 221 accidents, 72 took place beyond the transition zone (i.e. on the approach 50 to 100m from the tunnel entrance), 100 in the transition zone and 49 in the mid-zone.

Study results revealed the following:

- single vehicle accidents made up about 52% of the total
- head-on collisions made up about 20% of the accidents
- rear-end collisions made up about 13% of then accidents
- miscellaneous type accidents made up about 15% of the total

Rear-end accidents occurred most frequently in the wider tunnels with high traffic volumes, while frontal collisions were most common in the narrower tunnels. Two lane tunnels (with lane widths of 6 to 7m) had the largest number of passing accidents.

Accident rates (Ar) were estimated based on length and AADT (in annual person injury accidents per million vehicle kilometers):

- the entire study section (extending 100m beyond tunnel) Ar = 0,52
- transition zone (50m on either side of tunnel openings) Ar = 0,86
- mid-zone Ar = 0,17

The accident rate in the transition zones is thus five times as high as that in the mid-zone. A similar difference in accident rates between transition and mid-zones are also documented in a number of foreign studies.

A supplementary study was also made to ascertain any differences in accident rates of tunnels as compared with those of approaching roads. A total of 772 km of national road and 58 km of tunnel was included in this study that revealed similar accident rates in both situations, of 0.5 and 0.52 for open road and tunnels (including transition zones) respectively.

The second study was undertaken in 1988 at Hordaland District Road Office (Hvoslef 1988). This study covered four road sections with a total length of 31.45km that included 36 road tunnels. The average tunnel length was 875m with most tunnels (23) in the 100 to 700m range The transition zone include 50m of the roadway on either side of the tunnel openings. During the 1980-86 period a total of 57 person injury accidents were reported at these tunnels. Accident rates in transition zones were estimated at 0.78 (annual person injury accidents per million vehicle kilometers), while that in the mid-zone was 0.14. Relative accident rates between transition and mid-zones are then in excess of six which is a bit higher than found in the previous study. The study has also looked into the effects of road conditions that revealed a clear overrepresentation of wet pavement accidents (38%) and with snowy conditions (35%) in the transition zones when compared with countywide figures (28% in wet and 24% during snowy conditions).

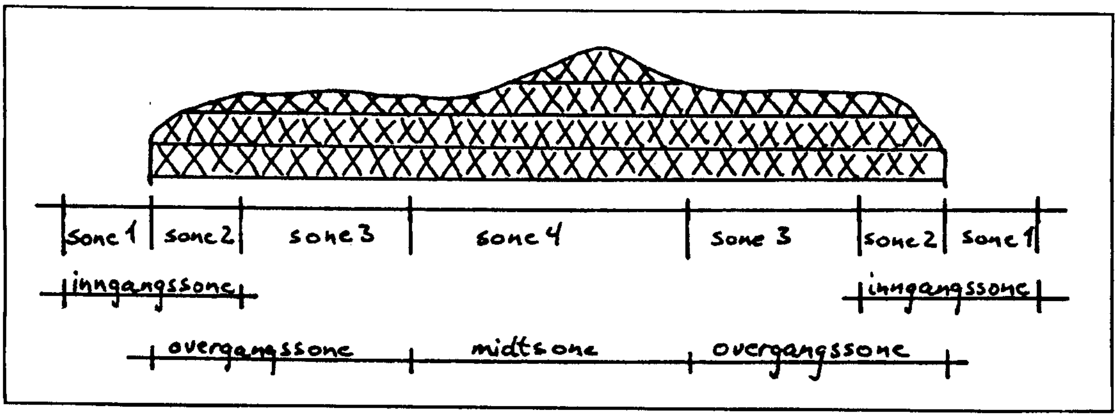
2.3. Data basis

This study is based on police reported person injury accidents on the national road network. The precise locations of all road tunnels on the national road network have been identified in the National Road Data Bank. Output from this data bank for tunnels opened in 1992 and earlier were used in this study along with data for a few tunnels opened one or two years later (this is corrected for in the study). Public Roads Administration statistics for 1992 were used to check the opening year. District roads offices were asked to verify opening years if needed.

A total of 587 road tunnels were selected for this study. According to official statistics only 520 national road tunnels were opened to traffic in 1992. Consequently 67 of these tunnels have been opened later than 1992. Relevant tunnel data such as traffic, lengths, widths, number of tubes and other information were taken from the Road Data Bank.

Data on accidents and location were retrieved from the Road Data Bank for the years 1992 to 1996 and grouped into the following four categories:

- zone 1 the first 50m in front of the tunnel openings
- zone 2 the first 50m inside the tunnel
- zone 3 the next 100m inside the tunnel
- zone 4 the mid-zone, i.e. the remainder of the tunnel



Figur 1 : Tunnelsoner

Tunnels shorter than 100m will only have zones 1 and 2. Tunnels shorter than 300m will not have a mid-zone (zone 4).

To verify accident locations a check was made for all tunnels with more than five accidents. For this purpose the various district roads offices were asked to provide copies of all police reported accident forms. Few discrepancies were found. The only exception were eleven person injury accidents reported to have happened in the Oslo tunnel that in fact had taken place on the surface streets that previously were carrying the tunnel traffic. Such errors were made up to the end of 1994. After 1994 very few of the tunnel accidents were wrongly recorded because the police normally note the tunnel name in their reporting forms.

2.4 Results

The study findings are based on data from 587 road tunnels of which most were opened to traffic in 1992 or earlier. No person injury accidents were reported during a five year period for 388, or 66%, of these tunnels. All tunnels including those without accidents were covered by the study.

The accident data for the five year study period included 499 person injury accidents. These were distributed amongst the various tunnel zones in the following manner:

- zone 1 (the first 50m beyond the tunnel openings) 127 accidents

- zone 4.(the mid-zone, i.e. the rest of the tunnel) 181 accidents

Figure 2 shows that a quarter of the total number of accidents take place in zone 1, i.e. in the zone up to 50m beyond the tunnel opening. Half of the accidents that take place inside the tunnel occur within 150m from the opening equally split between zones 2 and 3. The remaining half take place in the tunnel mid-zone.

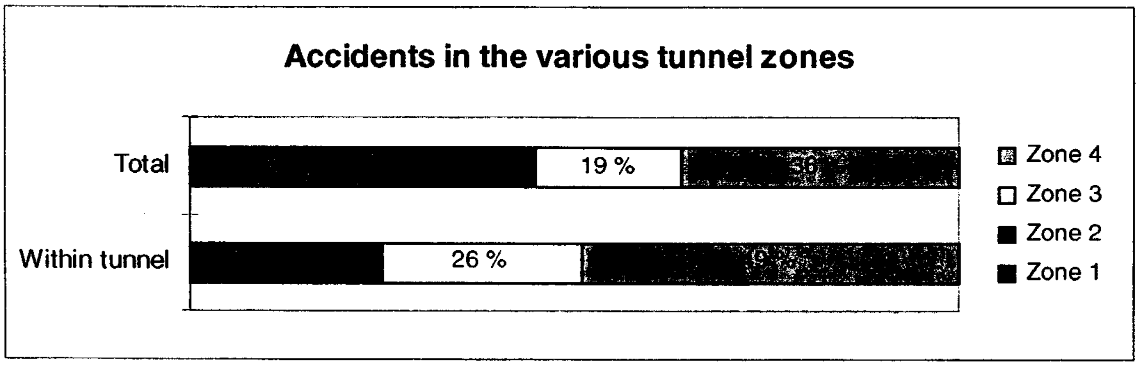


Figure 2 : Accident distribution by tunnel zone

2.4.1 Accident severity

A total of 745 persons were injured in the 499 person injury accidents included in this study. How serious the injuries were in the various tunnel zones is shown in Table 7 below.

Severity	Zone 1	Zone 2	Zone 3	Zone 4	Total	Within tunnel	National roads outside tunnel *
Killed	6	1	2	17	**26**	20 (3.6 %)	185 (2.8 %)
Very seriously injured	1	5	2	5	**13**	12 (2.1 %)	118 (1.8 %)
Seriously injured	21	15	20	30	**86**	65 (11.6 %)	655 (9.9 %)
Slightly injured	155	121	123	221	**620**	465 (82.7 %)	5 643 (85.5 %)
No. killed or injured	**183**	**142**	**147**	**273**	**745**	**562**	**6 601**
Sum pers.injury accidents	127	94	97	181	**499**	372	4 545

* Average for the years 1992-96 (STRAKS)

Table 7 : Number injured by severity and tunnel zone

The proportion severely injured in tunnel accidents is higher than for road accidents on the national road network in general. In tunnels 3.6% of the injured are killed and 2.1% severely injured, while the corresponding proportion on the national network is 2.8% and 1.8% respectively. A similar pattern is also found for the number injured per accident which is 1.51 in tunnels compared with 1.45 on the national road network as a whole. Table 8 gives an overview of the number of persons injured per accident by road category.

As indicated in the table the number injured per accident is similar for both tunnels and rural roads. The lowest value is found for urban road accidents that can be explained by the lower speeds found on such roads.

	Tunnel accidents on the national road network*	Total number of accidents on the national road network *	All accidents**	Urban road accidents **	Rural road accidents **
Number injured per accident	1.51	1.45	1.38	1.28	1.54

* Source : STRAKS (Public Roads Administration accident data base)
** Source : SSB (Road accidents 1995)

Table 8 : Number injured per accident

Figure 3 illustrates that when accidents first happen the most severe injuries are found in accidents taking place in the tunnels' mid-zones. Zone 2 shows the lowest number killed, while zone 3 has the lowest proportion killed and very severely injured.

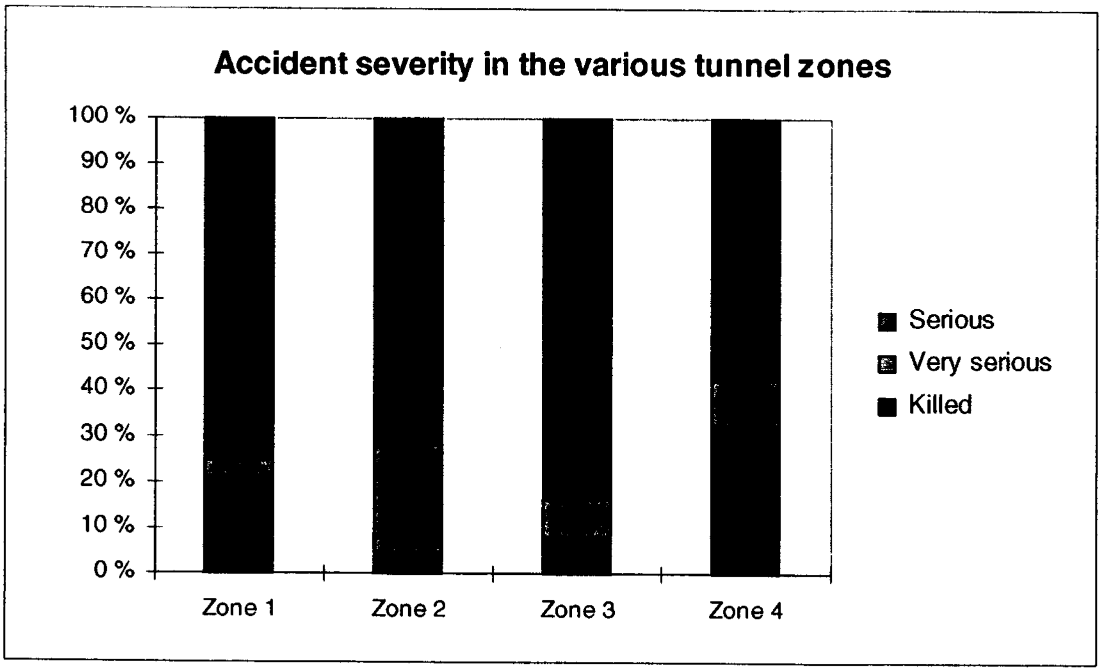


Figure 3 : Severity of injuries by tunnel zone

2.4.2 Traffic accidents in tunnel zones

The accident rates shown in Table 9 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. Adjustments were made for those tunnels that were not open for the entire five year period.

Table 9 shows that the accident rate in zone 1 (up to 50m beyond the tunnel opening) is three times higher than that of the mid-zone; 0.30 against 0.10. Zone 3 (50-150m inside the tunnel) has an accident rate of nearly half of that of zone 1; 0.30 against 0.16. This is an indication that the transition zone actually extends from 75 to 100m into the tunnels.

Tunnel zone	Length (km)	AADT (average) (veh./day)	Travel (mill veh.km/yr)	Accidents	Accident rates (acc/mill veh.km)	Accident density (acc/km/yr)
Zone 1	58.7	4 000	85.4	127	**0.30**	0.43
Zone 2	54.1	4 000	82.5	95	**0.23**	0.35
Zone 3	77.14	4 500	122.5	94	**0.16**	0.24
Zone 4 (mid-zone)	328.6	4 300	362.1	176	**0.10**	0.11
Entire tunnel (excl. zone 1)	**460.1**	**4 000**	**567.1**	**365**	**0.13**	**0.16**
All zones	**518.8**	**4 000**	**652.5**	**492**	**0.15**	**0.19**
Transition zone (zone 1 + 2)	112.8	4 000	167.9	221	**0.26**	0.39
Entrance zone (zone 2 + 3)	131.5	4 000	205.0	189	**0.18**	0.29

Table 9 : Accident rates in the various tunnel zones

When sorting the various tunnel zones in sequential order there is a clear decline in the accident rate when proceeding into the tunnels as indicated by the numbers below:

zone	**accident rates**
zone 1	0.30
transition zone	0.26
zone 2	0.23
entrance zone	0.18
zone 3	0.16
zone 4, mid-zone	0.10

Average accident rates both for the tunnels themselves (0.13) and for all zones (0.15) are well below accident rates assumed for two lane roads in the Norwegian Roads and Road Traffic Plan (NVVP)1998-2007 (0.25). Tunnels in other words are not especially accident prone compared to corresponding road sections.

A direct comparison of recent accident rates with those from about 15 years ago will be inconclusive because there has been a considerable general accident risk reduction in the intervening period (from 0.50 to 0.25). Even so, when studying tunnel accidents it appears that there has been a more favorable accident development in tunnels (0.52 in 1979/80 to 0.15 in this study) than on the road network as a whole. Early studies also show larger accident rate differences for transition zones compared with mid-zones (0.86/0.17 in 1979/80 against 0.26/0.10 in this study). This is an indication that improved lighting and tunnel entrance design have contributed positivly to a significant reduction in tunnel transition zone accidents. However, there is still room for additional tunnel entrance lighting improvements to further tunnel traffic safety.

The estimated accident density, i.e. the annual number of accidents per road km, shows a pattern similar to those of the estimated accident rates. The accident density is 0.43 acc/km in zone 1 compared to 0.11 acc/km in the mid-zone. Average for the tunnels as a whole is 0.16 acc/km, while the average for all zones is 0.19 acc/km.

2.4.3 Accident types

All accidents recorded in the National Road Data Bank are classified by accident type. Figure 4 shows the distribution of national road accidents within and outside tunnels by accident type.

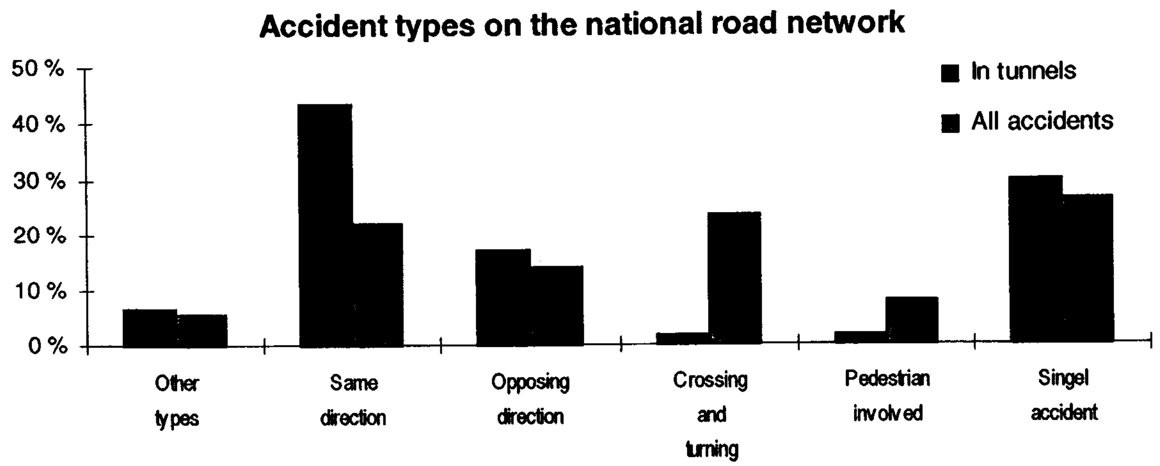


Figure 4 : Accident types within and outside tunnels

Understandably there are very few pedestrian accidents and vehicle turning accidents in tunnels. Most tunnels do not allow pedestrian traffic. The proportion of frontal, single vehicle and other type accidents in tunnels are similar to those on the road network as a whole. Rear-end collisions, however, are relatively twice as common in road tunnels as on the open road. The distribution of tunnel accidents by type is shown in Table 10.

Accident type	Zone 1	Zone 2	Zone 3	Zone 4	Inside tunnel	National roads outside tunnel *
Other accident types	3.9 %	7.4 %	9.3 %	4.4 %	6.5 %	5.4 %
Same direction	44.1 %	33.0 %	47.4 %	46.4 %	43.3 %	22.2 %
Opposing directions	7.9 %	16.0 %	15.5 %	18.8 %	17.2 %	14.3 %
Crossing and turning	9.4 %	2.1 %	0 %	2.2 %	1.6 %	23.7 %
Pedestrian involved	5.6 %	4.3 %	1.0 %	0.6 %	1.6 %	8.1 %
Vehicle leaving road	29.1 %	37.2 %	26.8 %	27.6 %	29.8 %	26.3 %
Sum accidents	**127**	**94**	**97**	**181**	**372**	**4 917**

* Average for the years 1992-96

Table 10 : Accidents in road tunnels by accident type

As indicated by Figure 5 the share of accidents between vehicles moving in the same direction is roughly the same in the various tunnel zones except for zone 2 which has slightly fewer accidents. For single vehicle accidents the opposite is the case with a somewhat higher share of accidents in zone 2. Both frontal and other type accidents increase with the distance from the tunnel entrance. Crossing and turning accidents occur most frequently in zone 1. As far as pedestrian accidents are concerned this is connected with the fact that it is the shorter tunnels that are open to pedestrians. Crossing and turning accidents understandably predominate in the area outside tunnel openings as intersections within tunnels are rare.

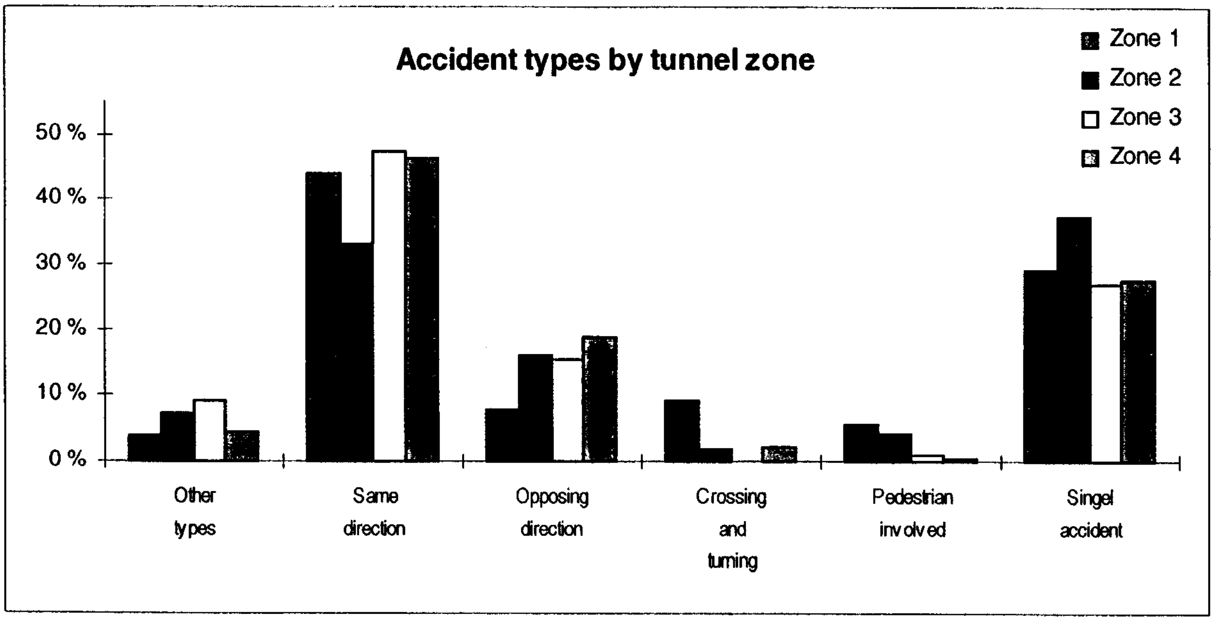


Figure 5 : Distribution of accident types by tunnel zones

A comparison of accident type differences for one and two directional tunnels was undertaken.

For one-way two lane tunnels the share of accidents between vehicles in the same direction predominates and represent as much as 62% of the total number of accidents. The other major group in such tunnels is single vehicle accidents that make up 23% of the total. For tunnels with two-way traffic the proportions of accidents with vehicles moving in the same direction and of single vehicle accidents are of similar size, 33% and 34% respectively, while the share of frontal accidents is 21%. On the national road network the share of single, crossing/ turning and same directional accidents are of similar magnitude, 26%, 24% and 22% respectively. Frontal accidents represent 14% of the total. Reference is made to Figure 6.

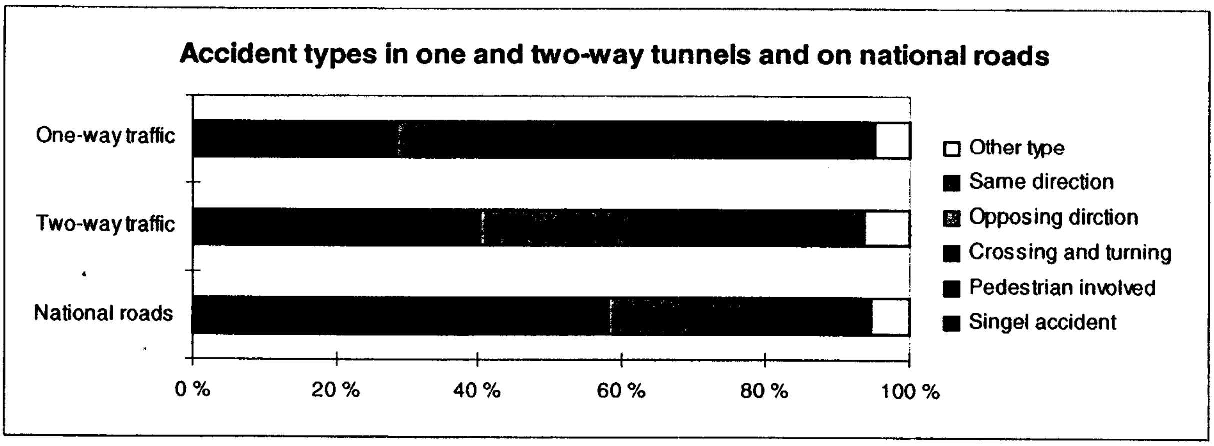
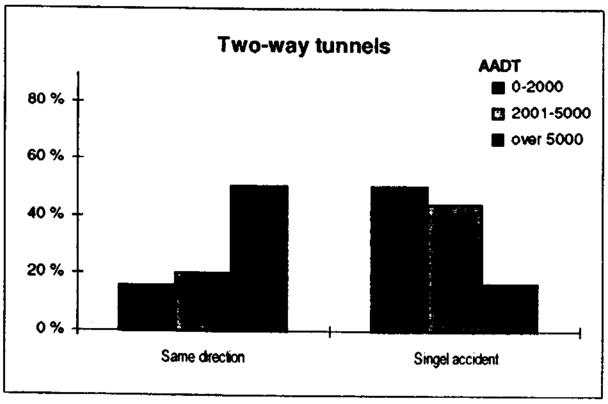


Figure 6 : Accident types in one-way and two-way tunnels and on the national road network

For both tunnel types the proportion of accidents between vehicles moving in the same direction increases with traffic volume. With two-way traffic the share increases from 16% with traffic below 2000 AADT to 50% with traffic exceeding 5000 AADT, while with one-way traffic there is an increase from 48% with an AADT below 30 000 to 79% for an AADT above 50 000.

Correspondingly, with two-way traffic the share of single accidents declines from 50% with an AADT below 2000 to 17% with an AADT above 5000. For one-way traffic the proportions are 28% and 14% for AADTs below 30 000 and above 50 000 respectively. Reference is made to Figure 7.



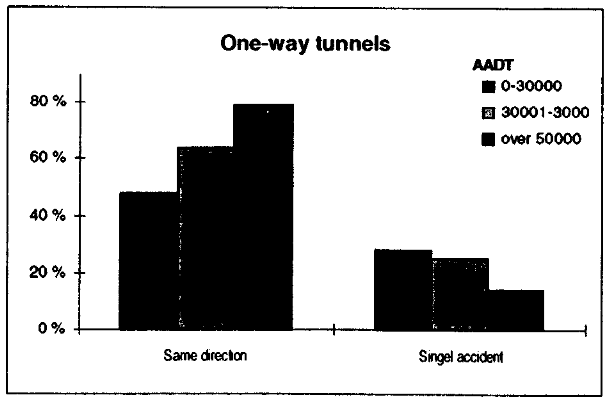


Figure 7 : Connection between AADT and single vehicle accidents and accidents with vehicles moving in the same direction

2.4.4 Accidents and tunnel lengths

To investigate the relationship between tunnel lengths and accidents, tunnels were sorted in five length groups. Vehicle km of travel was estimated by adding up the number of vehicle km for all tunnels within each length group. The estimated accident rates apply to the tunnels themselves (i.e. zones 2, 3 and 4). Corrections were made for tunnels that had not been open for the entire five year study period. The results are shown in Table 11. Accident rates are given as annual accidents per million vehicle km.

As shown in Table 11, accident rates decline with increasing tunnel length. This is to be expected as entrance zone accident rates are higher than those for the mid-zones. There are as many as 29 road tunnels in the above 3000m group and the accident rates for these tunnels are similar to those of four lane motorways.

Length (metre)	Number of tunnels	Lengths (km)	AADT (average) (veh./day)	Travel (mill veh.km/yr)	Accidents	Accident rates (acc/mill veh.km)
0 - 100	108	6.2	1 700	4.0	7	0.35
101 - 500	244	61.5	5 200	115.2	123	0.21
501 - 1000	105	71.8	4 300	111.5	84	0.15
1001 - 3000	101	171.9	3 500	211.5	119	0.11
over 3000	29	148.7	2 700	124.9	32	0.05
Sum	**587**	**460.1**	**4 000**	**567.1**	**365**	**0.13**

Table 11 : Accident rates and tunnel lengths

A special study was made on accident frequencies in tunnel zones when tunnels are sorted into five length groups. A statistical analysis indicated that the accident frequencies in the entrance zones where higher for shorter than for longer tunnels.

2.4.5 *Accidents and AADT*

To investigate the relationship between traffic volumes and traffic accidents the various tunnels were grouped into five groups according to AADT. Assumptions made when estimating extent of travel, accident rates and tunnel opening years are the same as in Table 5. Study results are shown in Table 13.

AADT	Number of tunnels	Lengths (km)	AADT (average) (veh/day)	Travel (mill veh.km/yr)	Accidents	Accident rates (acc/mill veh.km)
0 - 500	108	83.7	400	11.3	13	0.23
501 - 1000	167	159.0	800	44.5	40	0.18
1001 - 5000	206	149.6	2 200	108.5	76	0.14
5001 - 10000	49	29.8	7 400	78.2	50	0.13
over 10000	57	38.0	23 600	324.6	186	0.11
Sum	**587**	**460.1**	**4 000**	**567.1**	**365**	**0.13**

Table 12 : Accident rates and ADT

Study results show that accident rates are highest in tunnels with an ADT below 1000. However, these tunnels are also most likely to be built to the lowest standard. The accident rate differences are probably also a result of standard variations and not only traffic volumes.

Tunnels were also sorted in AADT groups to see if entrance zone accident frequencies differed in different AADT group. No such relationsships were found.

2.4.6 *Accidents and lane widths*

To investigate the relationship between lane widths and accidents the tunnels were sorted into three lanewidth groups; less that two lanes, two lanes and more than two lanes. The basis for estimating travel, accident rates and tunnel opening years are the same as shown in Table 5. Study results are given in Table 13.

Lane widths	Number of tunnels	Length (km)	AADT (average) (veh/day)	Travel (mill veh.km/yr)	Accidents	Accident rates (acc/mill veh.km)
Under 6 m	213	149.2	1 400	61.6	79	0.26
6 - 8 m	338	267.1	4 200	358.6	202	0.11
Over 8 m	36	43.8	17 000	146.9	84	0.11
Sum	**587**	**460.1**	**4 000**	**567.1**	**365**	**0.13**

Table 13 : Accident rates and lane widths

Table 13 shows that narrow tunnels have a higher accident rate than wider ones. Since there is a close relationship between tunnel widths and designstandards, it is unclear which is the most important factor. Anyway, there is good reason to assume that tunnel widths will affect accident rates, but not necessarily to the extent indicated by the table. The difference between two-lane and multilane tunnels is neglectable.

2.4.7 Accidents versus weather and road conditions

A study was also made to ascertain under which weather and road conditions accidents happened. Understandably, by far most accidents took place on dry pavement (60%). Of accidents occurring within 50m of a tunnel opening (zone 1 and 2) 51% took place on wet or snow or ice covered pavement, while the proportion was 32% within tunnels(zones 3 and 4). This is an indication that most tunnels are dry and ice free. Winter month accidents are clearly overrepresented outside tunnels. Most tunnel accidents occur during periods with good visibility (70%), while low visibility within the tunnel zone 3 and 4) were indicated for 12% of the accidents.

2.4.8 Light conditions

Light conditions during accidents are of major interest. The results shown in Table 14 indicate wheter the accidents happened in the transition zone, 50m on either side of the tunnel entrance (zone 1 and 2) or within the tunnel (zone 3 and 4).

Light conditions	- 50 m to +50 m (transition zone)	Within tunnel
Daylight	58.8 %	16.5 %
Dusk	6.3 %	2.9 %
Dark without lighting	26.7 %	68.7 %
Dark with lighting	5.9 %	4.7 %
Unknown	2.3 %	7.2 %
Number of accidents	**221**	**278**

Table 14 : Accidents and light conditions

The large number of daylight tunnel accidents recorded may be a result of the large number of short tunnels or misinterpretations during recording. Few accidents have been recorded to take place in darkness with illumination. Most tunnels included in the study are now illuminated but might not have been for the entire five year study period. It is also possible that tunnels with low levels of illumination have been judged as being very dark.

2.4.9 Accidents in sub-sea road tunnels

Amongst the study tunnels there are 13 sub-sea tunnels. The average length of these tunnels is 3400m with an average AADT of 1800. Accidents have been recorded in nine of these tunnels with a total of 14 for the entire five year period. The average accident rate is estimated to 0.07 annual person injury accidents per million vehicle km. This is a comparatively low accident rate considering that all tunnels are built to a gradient of between 6 and 10%. However, with all tunnels being fairly long the effects of entrance zones will have little impact on the average values.

2.4.10 Accidents in dual tube tunnels

The study include 28 road tunnels with one-way traffic in two or more tubes. These tunnels have a total length estimated at about 20km with an average AADT of 24 700. The accident rate in these tunnels is 0.12. This is a higher rate than should be expected in such high standard tunnels without the hazard of opposing traffic. Two aspects might be of particular interest in this connection.

Firstly, most one way tunnels are relatively short and consequently their accident rates will be higher than average, see Table 11. Secondly, such tunnels carry high traffic volumes with risks of congestion resulting in frequent rear-end collisions, see Figure 6 (same direction). Furthermore, some of the one-way tunnels are subject to CCTV traffic surveillance which will insure that a large proportion of the accidents are detected and reported. On the road network as a whole it is anticipated that no more than 50% of person injury accidents involving one or more vehicles are being reported. In tunnels with CCTV survailance near up to 100% of the accidents will probably be detected.

	Zone 1	Zone 2	Zone 3	Zone 4	Within tunnel
Accident rates in one-way tunnels	0.36	0.16	0.16	0.10	0.12
Accident rates in all tunnels	0.30	0.23	0.15	0.10	0.13

Table 15 : Accident rates in one-way tunnels

According to Table 15 the difference in accident rates between zone 2 and the remainder of tunnels is considerably less for one-way tunnels than for the study tunnels as a whole. The accident rate in zone 2 (0.23) for all study tunnels is more than double that of the mid-zone (0.10). This may be related to the fact that one-way tunnel entrances are of superior design and have high illumination levels compared to that of most two-way tunnels. The motorway accident rates in conjunction with NVVP 1998-2007 is set at 0.08. This is on a par with the accident rate of 0.10 in the mid-zone of one-way tunnels. The accident rate variation when proceeding inwards for one-way tunnels and all tunnels is illustrated in Figure 8.

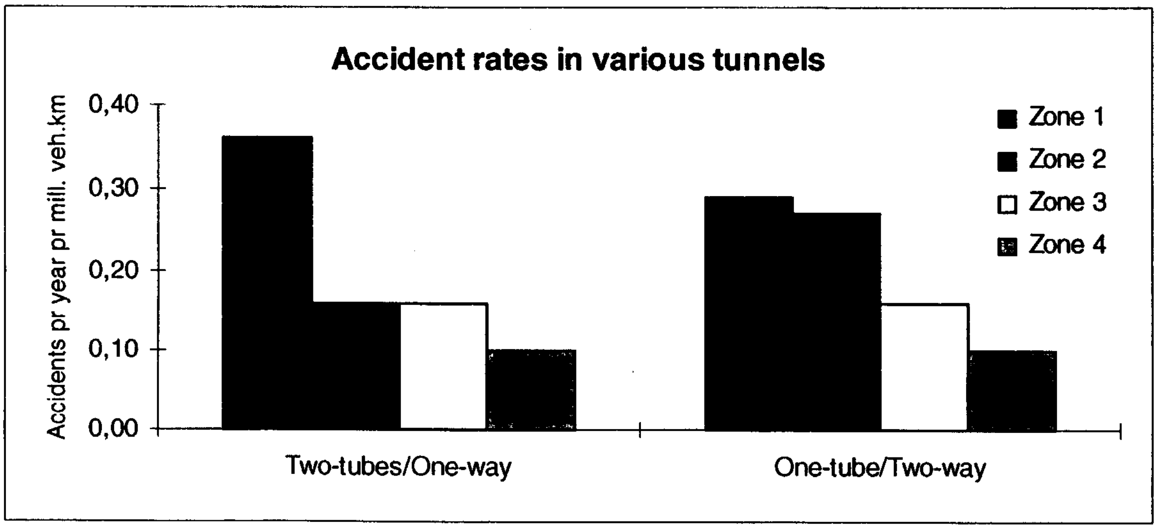


Figure 8 : Accident rates for one-way and two-way tunnels

Typically there are a concentration of accidents outside tunnel openings on roads with one-way traffic. In such cases rear end collisions predominate, often related to high traffic volumes and sometimes exacerbated by blinding sunlight and closely located traffic signals.

2.5. Discussion and conclusions

This study has been conducted using data from the National Road Data Bank at the Public Roads Administration. The district road offices are responsible for entering relevant information on police reported person injury accidents and the timing of road tunnel openings into the data bank. The study is based on 587 road tunnels of which most have been opened before 1992. When estimating accident rates, adjustments were made for tunnels opened in 1992 and early 1993.

For the five study years a total of 372 person injury accidents have been reported in the 587 tunnels on the national road network. In 66% of these tunnels there were no accidents reported.

Compared with a similar study undertaken by SINTEF about 15 years ago, the present study show a significantly lower accident rate (from 0.86 to 0.26 in the entrance zone and from 0.17 to 0.11 in the mid-zone, zones 3 and 4 in our study). The large accident reduction in the entrance zone may be related to an improved tunnel entrance design, markings and illumination. In this context it should be mentioned that there has been a general decline in the risk of accidents on the national road network in the intervening period. In dual tube tunnels with adequate entrance zone illumination there are now small accident rate differences between the various tunnel zones. Just outside tunnel openings, however, accident rates are relatively high (blinding sunlight, congestion etc.).

At present about 25% of all study tunnel accidents take place in the first 50m, about 25% in the next 100m and the remaining 50% in the mid-zone.

Accident severity is somewhat higher in tunnels than what is the case on the national road network in general. This is especially the case for the tunnel mid-zone. This might be the result of the higher accident rate of the more severe head-on accidents.

Multi-vehicle accidents with vehicles moving in the same direction (rear-end and lane change) are overrepresented in road tunnels. This is particularly the case for one-way dual tube tunnels. Single tube two-way tunnels have somewhat more head-on and single accidents than what is the case for national roads as a whole, see Figure 6.

Accident rates decline noticeably with increasing tunnel length, wider roadway and higher traffic volumes. In the first case this is probably related to the fact that entrance zone accidents predominate in shorter tunnels. High traffic volume tunnels will normally be built to a higher design and equipment standard. To test these relationships a simple regression analysis was undertaken. This analysis showed a correlation between accident rate and tunnel length and roadway width at a significance level of 0.1% while the effect of AADT was not significant.

Only 23 tunnels had more than five or more person injury accidents during the study period. In such studies a number of uncertainties must be assessed. The most obvious aspect is related to a lack of precision when reporting and recording accidents. This assessment entailed checking all accident report forms for all tunnels with five or more accidents. With the exception of the Oslo tunnel, wrongly recorded accident locations were barely found. This is probably so because the police normally record the tunnel name on the report form.

A similar check on tunnel location has previously been made twice by the district roads offices in conjunction with the review of the tunnel data bank. A third element of uncertainty is the accuracy of recorded tunnel traffic volumes. A check of this has not been possible. The estimate of accident rates have been based on approved methods. It is recommended that the accident rates used should be considered to be within +/- 10% the actual value.

It could be desirable to evaluate the effect that alignment, illumination and tunnel equipment might have on accident rates. At present the data with the National Road Data Bank is not sufficiently precise. Such study would require that data were gathered from the various district roads offices.

3. VEHICLE FIRES IN GENERAL

3.1 Problem statement

The problem with fires in road tunnels is a question that road authorities in all countries take very seriously. Compared to the funding of road tunnel safety measures, investments in fire prevention are very large in Norway.

In Norway where road tunnels normally are rock tunnels with limited traffic, reduction in person injuries is considered more important than the reduction in property damage to vehicles, structures and tunnel equipment.

Vehicle fires seldom represent major problems as long as no hazardous or inflammable cargo is involved even though smoke creation can be scary and some times dangerous. The Norwegian practice of using polyethylene panels for frost and water protection represent a special problem. If such panels start burning or melting the fire may represent a significantly bigger problem. Therefore work is in progress to secure high risk sections with a layer of concrete

Since road authorities and other public institutions (also private) are required to spend society's resources in a manner that will ensure maximum rate of return, all investments must be based on an understanding of the risks of incidents and what their consequences can be. In view of this a thorough review and analysis of vehicle fire data is essential.

3.2 Norwegian experiences

3.2.1 Vehicle fires reported by insurance companies

At present there are no comprehensive statistics on motor vehicle fires in Norway. The best information is available in the annual statistics TRAST from the Norwegian Insurance Association. These statistics cover about all insurance companies on the Norwegian market. Today we have access to TRAST information for the years 1995 and 1996. The number of motor vehicle fires reported to these insurance companies is given in Table 16. These numbers do not include fires caused by collisions or ran-off-road accidents. We know from studies made in Great Britain and Germany that fires caused by traffic accidents represent from one to five percent of the total.

Since TRAST excludes fires caused by traffic accidents the number of person injuries will be relatively low.

Vehicle type	Total		Fires reported	
	1995	1996	1995	1996
Passenger car	443 310	504 749	2 107	2 473
Truck	32 289	31 625	291	241
Bus	3 717	5 557	12	31
Moped	3 198	3 244	28	24
Light motor cycle	104	141	2	0
Heavy motor cycle	2 062	3 202	28	29
Other vehicles	19 879	19 816	563	673
Total	**504 560**	**571 288**	**3 031**	**3 470**

Table 16: Total number of TRAST damage and fire damage cases reports for 1995 and 1996

Table 16 shows that there was a big difference (+14.5%) in the number of traffic related fire damage cases reported in 1995 and 1996. Fire damage reports show that the number of passenger car fires have increased even more (17.4%). The increase in the number of passenger car was 12.2%. As far as trucks are concerned the reduction was 17.2% while the number of reported bus fires nearly tripled. For both trucks and buses the trend was in the opposite direction from 1994 to 1995. The numbers given for 1996 correspond well with earlier numbers (1994 and 1993). Otherwise the data only show small differences. Damage compensation has increased from NOK 87.1 million in 1995 to NOK 100 million in 1996.

The TRAST overview only provide the summary information given above. This indicates that annually there are about 3500 reported motor vehicle fire damage cases.

To obtain additional information on fires, individual insurance companies have to be approached. Such information has been collected from Gjensidige Insurance which covers about 27% of the Norwegian market both for light and heavy vehicles. Table 17 shows the development in the number of reported fire damage cases during the eight year period from 1989 to and including 1996.

Year	Passenger cars	Utility vehicles	Trucks
1989	670	64	72
1990	601	65	60
1991	593	60	43
1992	525	76	43
1993	544	84	57
1994	604	95	66
1995	657	103	62
1996	772	119	62
Sum	**4 966**	**666**	**465**

Table 17: Number of fire damage reports for various vehicle types 1989 - 96

Gjensidige Insurance's market share increased about 10% in 1992/93 as a result of the fusion with Forenede Insurance. This explains part of the increase in the number of fires reported after 1993. The records for the last eight years indicate that the number of passenger vehicle fires sank from 1989 to 1992, but since then there has been an increase. From 1992 to 1996 there has been an increase of as much as 47%. A corresponding increase in utility vehicle fires has been observed. Initially the numbers were fairly constant from 1989 to 1991, then nearly doubling the next five years. The number of truck fires have been relatively constant throughout the entire eight year period. It can be added as a curiosity that ten fire trucks have been reported damaged by fire in the same period.

Table 18 shows locations for light and heavy vehicle fires with percentages in parenthesis.

Fire location	Passenger cars	Heavy vehicles
In use	2 900 (58.4)	399 (64.0)
Parked	1 408 (28.4)	145 (23.2)
Repair shop	153 (3.1)	15 (2.4)
Unknown	505 (10.1)	65 (10.4)
Sum	**4 966**	**624**

Table 18: Reported fire locations for passenger cars and heavy vehicles

The table shows that 58% of the passenger car fires and 64% of heavy vehicle fires occur while the vehicles are being used. Excluding fires in repair shops and to parked vehicles, no more than 70-75% will take place in traffic. The percentage is higher for heavy vehicles than for passenger cars. The share involving arson (insurance fraud) might be somewhat higher for passenger cars than for heavy vehicles. There is, however, no documentation of this being the case.

Passenger car age distribution for all cars registered in Norway and for those for which fire damage have been reported are shown in Table 19. The numbers shown are for the entire eight year period given in percent.

Age in years	Percentage of registered passenger cars by age	Percentage of passenger car fire damage cases by age
1-5	20.7	9.2
6-10	27.3	27.8
11-15	33.4	40.6
16-20	13.6	18.1
Older than 21 years	5.0	4.4

Table 19: Age for registered cars and for those for which damage has been reported

The table indicates that vehicle fires are rare occurrences among newer passenger cars and that their frequency increases with age up to 20 years for then to decline. The development after 1989 seems to indicate that new cars, i.e. one and two years old, were more prone to fires in 1994-96 than for the years 1989 and 1990.

Economic insurance compensation has been on the increase. The average in 1992 was about NOK 15 000 increasing to NOK 19 000 in 1996. This might reflect both a price increase during the period and that newer cars are apt to catch fire more frequently.

3.2.2 Vehicle fires in connection with person injury accidents

Lately it has been focused on certain problems in conjunction with vehicle fires; in particular those taking place in road tunnels. Even though there are reported no person injuries due to the fires themselves, there have been cases of fires caused by collisions or other types of accidents. It is of interest to learn the frequency of such incidents.

Central Bureau of Statistics road accident records reveal that vehicular fires do occur in association with person injury accidents. The available data do not specify if the person injuries were caused by the accident or of a subsequent fire.

In the ten year period 1986 - 95 fires are reported in 65 police reported person injury accidents. Their numbers have varied around six per year. The last two years the number was six. There has been a variation from two (1988) to ten (1993). The highest number of such fires are found in the counties of Rogaland (8), Oppland (7), Møre og Romsdal (6) and Hedmark (6), while the numbers were lowest in the counties of Finnmark (0), Oslo (1), Vestfold (2), Aust-Agder (2), Sogn og Fjordane (2) and Sør-Trøndelag (2). Relatively low values were also found for the counties of Hordaland (3), Sogn og Fjordane (2) and Nordland (6) with the largest total length of road tunnel.

Of these fires (65) about 26 (40%) occurred after vehicles ran off the road, 14 (22%) after head-on collisions and 9 (14%) after collision in intersections. Compared to other road traffic accidents, these resulted in very serious person injuries. In these accidents 29 persons were killed, 22 seriously injured and 72 sustained slight injuries. This indicates a severity rate of more than ten times that of person injury traffic accidents in general.

With an annual average of about 8500 person injury accidents during the ten year period implies that fire will result in 0.08% of all person injury accidents (i.e. 1 of 1300). Insurance statistics include about 33 injuries annually that are caused by vehicle fires; at least 25% of these are not associated with road traffic. This means that one person injury will take place in about 0.2 to 0.4% of these fires.

3.2.3 Causes of fire

In conjunction with the planning of road tunnel fire prevention it is of interest to know the causes of fires. To that purpose Gjensidige Insurance provide the following information on vehicle fires from their records.

Table 20 shows the causes of fires for passenger cars and heavy vehicles in the eight year period. The table gives the number of reported fires with percentages in parenthesis. The table gives a clear indication that electrical system defects are the main cause of fires. The proportion is 10% higher for heavy than light vehicles. Fuel system defects are the cause of 10.7% of light vehicle fires, while only 3% on heavy vehicles. This may be a result of the fact that diesel fuel is less combustible than gasoline. These proportions do not seem to have changed from 1989 to 1996.

Cause of fire	Passenger cars	Heavy vehicles
Electrical system	2 749 (55,4)	406 (65,1)
Fuel system	531 (10,7)	19 (3,0)
Welding, soldering	110 (2,2)	5 (0,8)
Unknown	1 576 (31,7)	194 (31,1)
Sum	**4 966**	**624**

Table 20: Causes of fires for passenger cars and heavy vehicles (1989-96).

These data do not provide any basis for assessing any effects that catalytic converters or electronic fuel injection (i.e. newer cars) might have had on the risk of vehicle fires.

3.2.4 Road user reactions in case of fires

Experience from actual fires, vehicle fire drills and interview surveys (5) show that road users react rationally when approaching a vehicle fire in a tunnel. Actually, most drivers do slow down but pass the scene of the fire if there is room and visibility to do so. When interviewed most individuals claim they will extinguish the fire or notify the fire department.

3.2.5 Method for estimating the probable number of fires

In 1987 a method was developed for estimating the probable number of road tunnel fires based on data on road tunnel design and traffic. Information used included reported road tunnel fires in foreign countries, tunnel traffic and tunnel design. By and large, tunnel fires seemed largely to be a function of traffic volumes and tunnel length. More recent findings indicate, however, an increasing probability of fires in heavy vehicles on long and steep road sections. This will be taken into consideration in the next version of the model.

3.3. Reported vehicle fires in tunnels

To produce an overview over the number of fires in Norwegian road tunnels the district roads offices were requested to provide data covering the period from 1990 to 1996, i.e. seven years. The local fire departments in the districts where the tunnels are located were contacted. This did not ensure a complete overview of all fires and fires in progress, but most probably all fires of any size are included. Some roads offices enclosed descriptions of the progression of fires and of fire drills. These descriptions are recounted in the next two chapters.

3.3.1 A review of reported vehicle fires

In Oslo there are 32 road tunnels of which 12 are more than 500m in length. Dual tube tunnels are counted as two road tunnels (half the AADT in each tube). Seven fires have been reported in these tunnels.

* *Oslo tunnel 31.08.90 passenger car on fire w/fire personnel called*
* *Vålereng tunnel 24.08.92 passenger car on fire w/fire personnel called*
  Entire tunnel closed
* *Oslo tunnel 05.11.92 utility vehicle on fire w/fire personnel called*
  Right and middle lane closed
* *Oslo tunnel 29.09.94 passenger car on fire w/fire personnel called*
  Tunnel closed for 20 min. Collision cause of fire

* *Granfoss tunnel 11.12.94 passenger car on fire w/fire personnel called One lane closed. Vehicle fire extinguished before firemen arrived*
* *Granfoss tunnel 05.05.95 passenger car on fire w/fire personnel called One tunnel tube closed. Collision cause of fire*
* *Ekeberg tunnel 21.08.96 bus on fire, no person injuries, some property damage.*

In Vestfold there are four road tunnels, of which two are longer than 500m. Only one fire in progress has been reported.

* *Holmestrand tunnel 1991 fire in progress w/fire personnel called*

In Telemark there are 20 road tunnels, of which eleven are longer than 500m. One fire was reported.

* *Vågslid tunnel 15.03.94 Truck with calcium carbide. Fire put out with fire extinguisher*

In Vest-Agder there are 24 road tunnels (three on county roads), of which seven are longer than 500m. One fire was reported:

* *Winter 1996, small fire in passenger car put out with portable extinguisher*

In Hordaland there are 177 road tunnels (43 on county roads), of which 71 (eight on county roads) are longer than 500 m. Nineteen fires were reported.

* *Lyngfjell 21.01.90 Fire in 300 m^2 polyethylene panels intentionally lit*
* *Røldal 19.08.90 Fire erupted in VW transporter, one person with smoke inhalation*
* *Jernfjell 20.07.90 Intentionally lit fire affecting 40m^2 polyethylene panel*
* *Måbø 20.07.90 Fire in truck-trailer*
* *Måbø 24.04.91 Fire in truck-trailer*
* *Seljestad 22.11.91 Small vehicle fire*
* *Vallavik 12.04.92*
* *Kluftafjell 04.08.94 Strong smoke formation, small polyethylene panel section.*
* *Fløyfjell 21.11.94 Northbound*
* *Damsgård 29.11.94 Eastbound*
* *Fløyfjell 02.04 95 Northbound*
* *Fløyfjell 12.04.95 Northbound*
* *Røldal 14.07.95*
* *Røldal 15.08.95 Bus*
* *Damsgård 08.09.95 Eastbound*
* *Dalberg late summer 95, intentionally lit fire, one passenger car burned out*
* *Toppe (county road) 02.12.95, fire lit intentionally, 200 m2 polyethylene panel burned down*
* *Eikefett 06.12.95*
* *Arnanipa 15.05.96, collision between truck-trailer and passenger car, no person injuries*

As many as eight fires took place in 1995, but only one the following year. The large number in 1995 therefore probably only reflect natural variations and coincidences to be expected with such small numbers.

In Sogn og Fjordane there are 130 road tunnels (33 on county roads), of which 61 (16 on county roads) are longer than 500 m. Four fires were reported.

* *Tunnel on rv 53 (toward Øvre Årdal) fall of 1991. Fire started after vehicle drove into tunnel wall on sharp curve, no person injury.*
* *Lote 24.11.93 Passenger car fire, strong smoke generation, extinguished by firemen*
* *Hovden 13.06.93 Fire started after collision between two cars. 111m polyethylene panel burned up. Five persons injured in collision.*
* *Flenja Easter 1993, fire put out with fire extinguisher.*

In Møre og Romsdal there are 52 road tunnels (13 on county roads, of which 24 (five on county roads) are longer than 500 m. One fire was reported:

* *Fonnafonna 17.10.96*

In Sør-Trøndelag there are 11 road tunnels (two on county roads), of which six are longer than 500 m. Two fires were reported:

* *Hitra 24.01.95 Fire in mobile crane*
* *Hell 03.12.96, no person injuries*

In Nord-Trøndelag there are 21 road tunnels (one on county roads), of which two were longer than 500 m. One tunnel fire was reported.

* *Hell 01.11.95 Passenger car engine compartment fire, tunnel closed for 45 min.*

In Nordland there are 83 road tunnels (nine on county roads), of which 46 (three on county roads) are longer than 500 m. Two tunnel fires were reported.

* *Glomfjord 18.12.95 Passenger car on fire, no injuries*
* *Svartisen 19.08.96, Fire in camping vehicle put out with portable fire extinguisher*

In Troms there are 14 road tunnels (14 on county road), of which nine (eleven on county roads) are longer than 500 m. One fire has been reported:

* *Breitind 05.05.96, vehicle fire spread to tunnel insulation (45 m^2 polyethylene panel), no person injuries.*

In Finnmark there are six road tunnels, of which five are longer than 500 m. One fire reported.

* *Vardø 1993 (date uncertain)*

3.3 2 Summing up fires

The road traffic centers and district roads offices have made reports on 41 vehicle fires over a seven year period, of which one fire was in a county road tunnel. Precise records for such a long period are hard to come by because of personnel changes and the fact that records are not always properly kept. During the first four years about four fires were recorded annually. In 1994 six fires were recorded while in 1995 and 1996 the numbers were twelve and seven fires respectively. The extent to which this represent an actual increase is hard to say.

For 35 of the fires a description of their progress was given. It appears that fires are most likely to take place in November and December (12 of 35 fires). Moreover, passenger cars are in the majority. A total of 18 passenger cars and eight heavy vehicles caught fire. Compared to their share of the traffic, heavy vehicles seem to be overrepresented. Three of the fires were claimed to have been started intentionally, while eight were caused by collisions. Fires seem most often to start in the engine compartment. In one case a catalytic converter was the cause and in another a defective generator was mentioned. In only one case was there reported any injury to travelers from smoke inhalation. In additional three cases did firefighters suffer injury from smoke inhalation. In four collisions with person injury did the accident result in fires.

For 29 fires was information given on how the fire was extinguished. Of these, firefighters put out 18 of the fires, while extinguishers provided within the tunnel were used in only eleven cases. Firefighters were primarily involved in heavy vehicle fires and those caused by collisions.

Polyethylene panels were ignited in six of the fires. In two separate fires did $300m^2$ and $200m^2$ burn up. In some cases the fire went out by itself. In no circumstance were all polyethylene panels in any tunnel explicitly been told to have completely burned down. Melting and the falling of polyethylene panel remnants onto the roadway were reported in some cases.

LITTERATURE

Hovd A	Trafikkulykker i vegtunneler Rapport STF 64 A8102 (in Norwegian) SINTEF Trondheim, Norway, July 1981
Hvoslef H	Trafikkulykker i vegtunneler i Hordaland (in Norwegian) Public Roads Administration, Hordaland Bergen, Norway, 1988
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APPENDIX : REPORTS FROM FIRES

Fire in the Oslo tunnel

On 31.08.90 at 10:11 p.m. the local traffic control center observed brake lights and smoke development in the tunnel. The police was notified immediately and the eastbound tube closed. At 10:12 p.m. the fire was reported from an emergency telephone. Tunnel occupants were advised to leave the tunnel and at 10:13 p.m. a vehicle on duty drove to the scene of the fire. At 10:22 p.m. the fire was extinguished and ventilation turned off. At 10:56 p.m. the tunnel was again opened to traffic.

Fire in the Oslo tunnel

On 29.09.94 a passenger car fire was reported. The fire was initially reported by a taxi driver and subsequently from an emergency telephone. The fire could not be seen on the local traffic control center CCTV monitor, but traffic in the tunnel had come to a standstill. Fire extinguisher had been used. The fire had been reported at 5:48 p.m. and the tunnel opened to traffic again at 6:00 p.m.

Fire in the Granfoss tunnel

On 05.05.95 a fire in an unoccupied passenger car was reported in the Granfoss tunnel from an emergency telephone. The police had received the same call and firefighters also responded. Problems arose in the control of gates and fans. The fire was reported at 8:05 p.m. and the tunnel opened to traffic again at 8:45 p.m.

Fire in the Granfoss tunnel

On 11.12.94 a passenger car fire was reported in the Granfoss tunnel. The fire started inside the car. The local traffic control center received the message from the Sandvika fire station which in turn had gotten the message from the police. No smoke could be seen on the CCTV monitors at the road traffic control center.

Fire in the Vågslid tunnel (Telemark)

On 15.03.94 at 12:00 p.m. a fire erupted in the driver compartment of a truck waiting to join a westbound convoy on rv.11. The vehicle was loaded with calcium carbide. The fire was extinguished using two extinguishers from the truck and one from the tunnel. When the fire flared up again it was extinguished anew with assistance from a passing snow clearing vehicle. The truck was subsequently towed out of the tunnel.

Fire in the Lyngfjell tunnel (Hordaland)

On 21.01.90 a fire in the tunnel was detected by a taxi driver. At 3:20 a.m. he notified the road inspector who immediately notified the fire department. At 4:00 a.m. a detour was established and the fire extinguished at 5:30 a.m. The fire was lit on purpose and about $300m^2$ of polyethylene panels had burned up. No person injury was sustained. The tunnel is about 970m long of which 70-80% is covered with polyethylene panels.

Fire in the Røldal tunnel

On 19.08.90 a message was received from an emergency telephone located about 1km inside the tunnel. A fire had erupted in a VW Transporter with a trailer. The vehicle burned up and one person sent to hospital with smoke inhalation injuries. The fire was extinguished after about 50min without any damage to the tunnel.

Fire in the Jernfjell tunnel

On 20.07.90 at 5:30 p.m. a fire was discovered in the tunnel. The fire erupted in a passenger car located about 650m inside the tunnel (intentionally lit). Two smoke divers proceeded into the tunnel with powder type extinguisher. They reached the driver of the burning car and brought him out. They subsequently attempted unsuccessfully to extinguish the fire until additional fire extinguishers were brought inn. A total of 44kg of powder was used. An hour later a water truck arrived and the burned out car was cooled down. About 40m^2 of polyethylene panels and 25m^2 of asphalt pavement was destroyed. The fire lasted for two hours.

Fire in the Måbø tunnel

On 20.07.90 at 7:35 p.m. the road information center was informed about a fire in a Mercedes 2244 hauling a four wheeled trailer with fodder. The driver had noticed the fire at 6:30 p.m. and made an attempt to get out of the tunnel. Firefighters arrived on the scene at 7:50 p.m. A pedestrian road was cleared at 8:00 p.m. to allow passenger cars to get around the tunnel. Smoke initially escaped from the lower tunnel entrance. At 8:45 p.m. it was possible for smoke divers to drive through the tunnel to verify that no persons remained inside the tunnel. The process of covering the vehicle with foam started at 9:30 p.m. Not until 10:30 p.m. could the vehicle be removed from the tunnel. After initially having escaped through the lower tunnel entrance, the smoke suddenly reversed direction and drifted into the tunnel. As the smoke cooled it followed the direction of the draft downwards along the tunnel.

Fire in the Kluftafjell tunnel

On 4.08.94 the traffic control center in Bergen received notice that there had been a traffic accident with a vehicle on fire. The message that arrived at 4:15 p.m. said that there had been a fatal accident with three persons injured. One fire extinguisher did not suffice to extinguish the fire and fire personnel were called. When the tunnel was opened to traffic again at 7:50 p.m. one polyethylene panel was scorched and half of one burned up.

Fire in the Fløyfjell tunnel (northbound)

On 21.11.94 a traffic accident with a subsequent fire was reported. The accident happened at 1:29 a.m. One person was removed from the vehicle by fire personnel. One fire extinguisher had been used. The tunnel was opened at 3:35 a.m. with a reduced speed limit.

Fire in the Damsgård tunnel (eastbound)

On 29.11.94 a car was reported ablaze in the eastbound tunnel tube. The driver attempted to put out the fire with an emergency extinguisher inside the tunnel. He did not succeed and the fire department was called. The fire was reported at 1:13 a.m. and the tunnel opened again at 1:55 a.m.

Fire in the Fløyfjell tunnel (northbound)

On 02.04.95 a passenger car was reported on fire. The fire was put out by the driver using a fire extinguisher. The fire was reported at 3:16 a.m. and the tunnel opened again at 5:18 a.m.

Fire in the Fløyfjell tunnel (northbound)

On 12.04.95 a fire was reported in a photo box inside the tunnel.

Fire in the Røldal tunnel

On 14.07.95 a passenger car was reported on fire by emergency telephone. The driver managed to put out the fire with an extinguisher from the tunnel. The fire was reported at 8:03 p.m. and the tunnel opened to traffic again at 8:35 p.m.

Fire in the Røldal tunnel

On 15.08.95 a fire was reported in the engine compartment of a bus. Passing motorists assisted the bus passengers out of the tunnel. The fire was quickly extinguished. The fire was reported at 4:50 p.m. and the bus towed out at 6:00 p.m. after which traffic was again allowed through the tunnel.

Fire in the Damsgård tunnel (westbound)

On 08.09.95 a passenger car was reported on fire. The fire was extinguished by the driver.

Fire in the Eikefet tunnel

On 06.12.95 an accident in the tunnel with a subsequent fire was reported. When arriving, fire personnel pulled one person out of the car. The fire was reported at 2:55 a.m. and the tunnel opened again at 5:15 a.m.

Fire in the Fløyfjell tunnel (southbound)

On 19.12.95 a passenger car was reported on fire. The driver put out the fire using a fire extinguisher.

Fire in the Arnanipa tunnel

On 15.05.96 fire erupted in a passenger car following a collision with a truck-trailer. One person was killed in the collision. The local road center was notified at 11:50 a.m. and the fire put out by fire personnel at 12:20 p.m. At 4:20 p.m. the tunnel was again opened to traffic.

Fire in the Hovden tunnel (Sogn og Fjordane)

On 13.06.93 fire erupted in the tunnel following the collision involving two cars and a motor cycle. The collision occurred at 2:55 p.m. The anticipated cause was a catalytic converter igniting combustible material. Fire personnel managed to prevent the fire from spreading to the polyethylene panels. An arriving motorist assisted three persons out of the tunnel. Smoke development was so extensive that the motorist had to back up about 1200m to get out of the tunnel. Two others were able to get out of the tunnel on their own. The tunnel was subsequently closed by a second motorist.

The accident was reported at 3:09 p.m. Fire personnel were on the scene at 3:17 p.m. with rescue vehicle, fire truck, ambulance and nine men. The vehicle fires were extinguished using a powder extinguisher, foam and water from the fire truck. A pump was placed at the seashore and a hose was rolled out. By 4:30 p.m. polyethylene panels over a length of 400m had caught fire, and of which 111m was completely burned up.

Fire in the Lote tunnel

On 24.11.93 a passenger car was reported on fire. The fire was probably caused by a defective generator. The burning car was part of a platoon of vehicles having just disembarked a ferry. A following car passed and a second motorist attempted to find an extinguisher inside the tunnel. He did not locate a fire extinguisher closer than 4km away at a gas station. The fire department was alerted and smoke divers drove through the tunnel. The fire started at 8:45 p.m. and the tunnel opened to traffic again at 10:00 p.m. There were no emergency extinguishers provided inside the tunnel. The fire was quickly extinguished.

Fire in the Hitra tunnel

On 24.01.95 a fire erupted in a mobile crane moving through the tunnel. The fire started at 7:55 a.m. and the driver attempted to put out the fire with an extinguisher from the tunnel. The heat and smoke generated was so extensive that attempts to put out the fire had to be given up. By 8:05 a.m. Hitra fire department was alerted. One minute later the driver also called to inform the local road center about the fire which subsequently alerted Hitra and Orkla road stations. Personnel from a construction company at Sunde then drove to the tunnel and closed it. At 8:55 a.m. Snillfjord fire department arrived at the tunnel. At 9:05 a.m. Snillfjord fire department drove to the scene of the fire without being hampered by the smoke. Lacking fire prevention equipment they returned to the tunnel entrance. At 9:35 a.m. the ventilation fans were fully engaged and at 9:50 a.m. the fire was extinguished. The tunnel was opened again at 12:00 noon after being washed and hosed down.

Fire in the Hell tunnel

On 12.11.95 the road traffic center in Trøndelag was alerted by emergency telephone about a passenger car engine compartment fire. The fire was put out by the driver using three extinguishers. The fire department was summoned. Traffic moved freely during the incidence. After the fire the question of closing the tunnel was raised.

Fire in the Glomfjord tunnel

On 18.12.95 a passenger car was reported on fire. Other vehicles entering the tunnel had to turn back when approaching the scene of the fire. Large amounts of smoke was generated because there were four additional tires in the burning car. The driver walked out of the tunnel and the fire was reported by a passing motorist. It took a long time before the red signal lights at the tunnel came on and the light fixtures in the entrance zone were defective. The fire department was alerted at 10:05 a.m. and participated with rescue vehicle, fire truck, salvage vehicle and a private company (Hydro Agri Glomfjord) ambulance. There were no person injuries.