HOW FREQUENT ARE FIRES IN TUNNELS – ANALYSIS FROM AUSTRIAN TUNNEL INCIDENT STATISTICS

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ABSTRACT

The paper combines vehicle fire data, accident data and traffic data from all tunnels within the Austrian primary road network. As a result, a number of key numbers typically required for tunnel risk analyses is derived. This includes the rate of tunnel fires per vehicle kilometre and the distribution of fires intensities as well as the conditional fire probability given vehicle breakdowns or accidents and a number of other relevant results.

Keywords: Vehicle fire, tunnel fire, fire intensity, fire statistics

1. INTRODUCTION

From an international perspective, there has long been a lack of reliable statistics on vehicle fires in road tunnels. The reasons for this are manifold: Small datasets as well as incomplete or inconsistent datasets – often caused by regionally varying data collection practices – account for some of the challenges. Another issue is the lack of a suitable basis of comparison, i.e. the total travelled distance inside all tunnels (both in tunnels with and in tunnels without observed vehicle fires).

Since 2006, the state-owned highway operator ASFiNAG has been collecting vehicle fire data for all Austrian highway and expressway tunnels in a standardised and detailed way, including information on fire causes, fire development, detection, extinguishment and many more. This dataset is compared to a complete accident dataset and a complete traffic dataset from the same period, allowing for a number of new and more precise statements on tunnel fires.

The present paper addresses a number of issues, including

- the rate of vehicle fires in tunnels per travelled kilometre and vehicle type
- the rate of spontaneous vehicle fires per vehicle breakdown
- the rate of crash-induced fires per accident and vehicle type
- the probability of stopping a burning vehicle in front of the tunnel or driving the burning vehicle out of the tunnel
- the distribution of different fire intensities and their correlation with fire brigade deployment times
- the contribution of different types of fire detection and fire extinguishment

2. DATA

2.1. Fire incident data

The analysis is based on the tunnel fire database of the Austrian motorway and expressway operator ASFiNAG. It covers the period between May 2006 and January 2013, i.e. roughly 2006-2012. During this period, ASFiNAG registered 67 independent occurrences of vehicle fires in tunnels, excluding trivial events.

2.2. Traffic data

Traffic data are needed in order to estimate the fire rate in tunnels per travelled vehicle kilometre. Annual average daily traffic (AADT) values are taken from the ASFiNAG road section register for the year 2010 and scaled to the duration of the observation period for fire incidents. The road section register indicates separate AADT values for vehicles up to 3.5 tonnes (cars) and vehicles above 3.5 tonnes (HGVs and busses), respectively.

2.3. Breakdown data

The applied rate of breakdowns per vehicle kilometre is based on observations at the Tauern and Katschberg tunnels in Austria and has been validated against other European road tunnels. The underlying data were collected and analysed as part of the previous version of Guideline RVS 09.03.11 TuRisMo (FSV, 2008).

2.4. Accident data

Data on vehicle accidents in motorway and expressway tunnels are needed in order to estimate the conditional fire probability in case of a vehicle accident. For the present analysis, a dataset from ASFiNAG covering the years 2006-2009 is used (scaled to the duration of the observation period for fire incidents).

3. FREQUENCY OF VEHICLE FIRES IN TUNNELS

The vehicle fires observed in 2006-2012 are roughly split in two halves between car fires on one hand and HGV and bus fires on the other hand (Table 1). Approximately 90 % of the events can be categorised as spontaneous ignitions, whereas 7 % were caused by accidents, i.e. collisions.

In the case of car fires, 13 % of the events were caused by accidents, whereas only 3 % (1 event) of the HGV and bus fires occurred in the aftermath of a collision. In fact, the only case of an accident-induced HGV fire occurred after a collision with a car, where the car caught fire in the first place and the fire subsequently flashed over to the HGV.

Table 1: Total number of vehicle fires in Austrian motorway and expressway tunnels (2006-2012)

Fire cause	Cars (vehicles ≤ 3.5 tonnes)	HGVs and busses (vehicles > 3.5 tonnes)	Total[1]
Spontaneous ignition	32	28	60
Accident	5	1	6
- single vehicle accident	*2*	*0*	*2*
- collision front-front	*2*	*1*	*3*
- collision front-rear end	*1*	*0*	*1*
Unknown	1	1	2
Total	38	30	68

[1] In one of the events, both a car and an HGV caught fire. Thus, the total value is not always equal to the sum of car and HGV/bus fires.

The numbers include vehicle fires at and next to the portals (11 out of the 67 events). These events need to be treated as regular tunnel fires; if the driver had not intentionally stopped the burning vehicle in front of the tunnel, or if he/she had not intentionally driven the burning vehicle out of the tunnel, most cases would have ended as fires inside the tunnel. The probability of stopping inside the tunnel depends on the vehicle type, as discussed below (Section 3.4).

3.1. Fires per travelled vehicle kilometre

In order to determine the fire rate in tunnels, the number of travelled vehicle kilometres in all motorway and expressway tunnels needs to be known, including tunnels where no fires have been observed. In Table 2, this number is compared to the number of fires for different vehicle types. Apparently, HGVs and busses are 6 times more susceptible to catching fire than cars.

Table 2: Rate of vehicle fires in Austrian motorway and expressway tunnels

Vehicle type	Number of fires	Travelled vehicle km in tunnels (2006-2012)	Fires per billion km
Cars (vehicles ≤ 3.5 tonnes)	38	9.1 billion	4.2
HGVs and busses (vehicles > 3.5 tonnes)	30	1.2 billion	25.0
All vehicles	67	10.3 billion	6.5

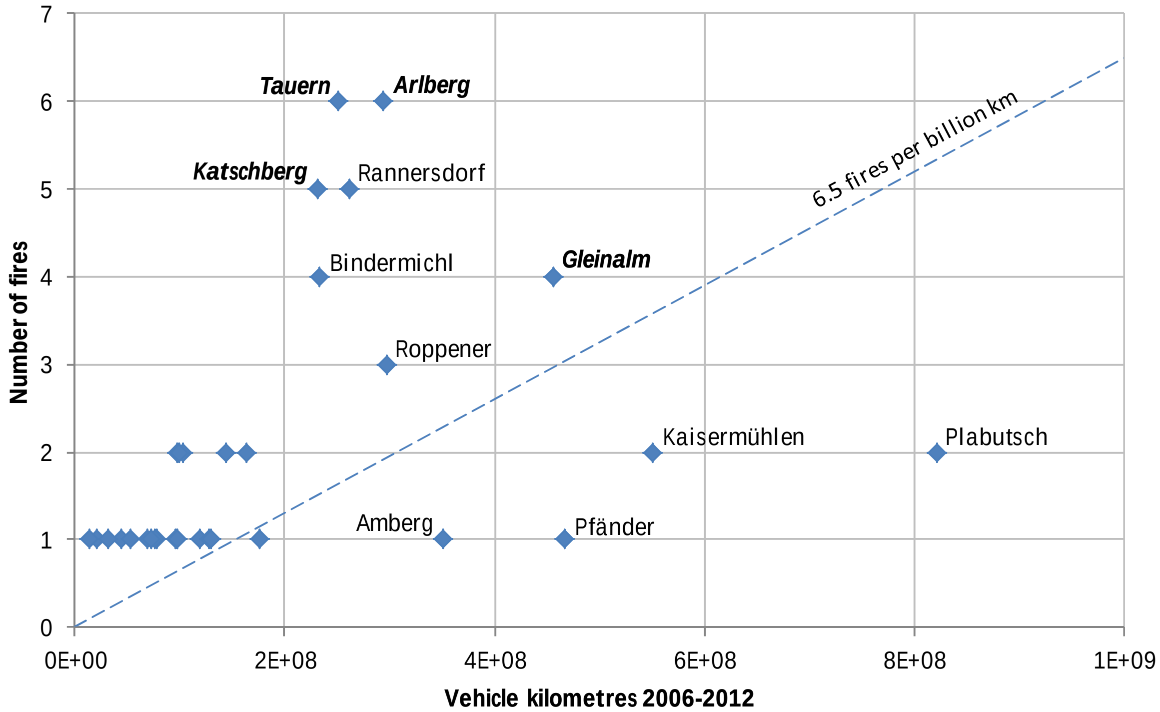

Figure 1: Number of fires vs. travelled vehicle kilometres in different Austrian tunnels (tunnels with long and steep approaches *in italics*)

Figure 1 illustrates the relationship between travelled vehicle kilometres and number of fires for all tunnels with at least one fire. It appears that tunnels with long and steep approaches have an above-average incidence of tunnel fires. Here, HGVs run at the limit of their engine capacity and are thus subject to the risk of overheating.

3.2. Probability of fire after vehicle breakdown

Table 3 relates the number of spontaneous fires in tunnels to the number of breakdowns. Unfortunately, no separate breakdown statistics for cars and HGVs/busses have been available.

Table 3: Fires per vehicle breakdown in tunnels

Vehicle type	Spontaneous fires per million km travelled in tunnels	Breakdowns per million km travelled in tunnels	Fires per 1,000 vehicle breakdowns
Cars (vehicles ≤ 3.5 tonnes)	0.0035		1.5
HGVs and busses (vehicles > 3.5 tonnes)	0.0234	2.372	9.9
All vehicles	0.0058		2.5

3.3. Probability of fire after accidents with casualties

Table 4 relates the number of accident-induced vehicle fires to the number of accidents with casualties. The reasons for referring to accidents with casualties rather than to all accidents are twofold:

- Using only accidents with casualties excludes trivial accidents that are unlikely to result in a fire.
- Accidents with casualties require a police record and are generally registered in a more consistent and reliable way.

In the case of cars, roughly one percent of the accidents with casualties lead to a fire. In the case of HGVs and busses, the number is approximately 0.4 %. Since the latter result is based on a single event, the 95 % confidence interval is relatively large (0.1 to 2.2 %).

Splitting the five observed cases of accident-induced car fire up into different accident categories for further analysis may appear delicate; nevertheless, the resulting conditional fire probabilities are in line with the intuitive ranking of accident hazardousness: Front-front collisions (2.0 % fire probability) are followed by single-car accidents (1.2 %) and front-rear end collisions (0.6 %).

Table 4: Fires per accident with casualties in tunnels

Vehicle type	Fires due to accidents	Accidents with casualties (scaled up to 2006-2012)	Fires per 1,000 accidents with casualties
Cars (vehicles ≤ 3.5 tonnes)	5	523	9.6
HGVs and busses (vehicles > 3.5 tonnes)	1	245	4.1

3.4. Probability of stopping inside the tunnel given spontaneous vehicle fire

As discussed at the beginning of this section, vehicle fires at and next to the portals need to be included in the fire statistics, since they are only prevented from occurring inside the tunnel by intentional and responsible action of the respective driver. For risk analyses, it is relevant to know the likelihood of such behaviour. Table 5 describes the conditional probability of a vehicle stopping inside the tunnel given spontaneous vehicle fire.

It is striking that HGV and bus drivers (75 % of the burning vehicles stopped inside the tunnel) generally react more appropriately than car drivers (almost 100 % stopped inside the tunnel). Considering the high hazard potential of HGV and bus fires, this is an important finding.

Table 5: Probability of stopping inside the tunnel given spontaneous vehicle fire

Stopped inside tunnel?	Number		Fraction	
	Car	HGV/bus	Car	HGV/bus
Yes	30	21	94 %	75 %
No	2	7	6 %	25 %
Total	32	28	100 %	100 %

4. FIRE INTENSITY

4.1. Fire intensity distribution

The analysis of the distribution of fire intensities is limited to spontaneous vehicle fires. The number of vehicle fires due to accidents is too small for a sensible investigation. Due to the high mechanical energy released during accidents with casualties it can be assumed that the ensuing fire is generally in the highest intensity class (fully-developed fire).

Tables 6 and 7 describe the intensity distribution of spontaneous fires in tunnels for cars and HGVs/busses, respectively. In the case of cars, two intensity classes have been introduced (fully- and non-fully-developed fire). In the case of busses and HGVs, fully-developed fires have been subdivided further into fire of the cabin including the engine compartment (typically 10-15 MW) and fire of the entire vehicle (typically beyond 30 MW and sometimes up to 100 MW and more).

More than a third of all spontaneous car fires and half of the HGV/bus fires are categorised as fully developed. In the case of HGVs and busses, 11 % of the fires (21 % of the fully-developed fires) belong to the highest category where the entire vehicle is on fire.

Table 6: Intensity of spontaneous car fires in tunnels

Maximum intensity	Number of events	Fraction
Fully-developed fire	12	37 %
Non-fully-developed fire	20	63 %
Total	32	100 %

Table 7: Intensity of spontaneous HGV and bus fires in tunnels

Maximum intensity	Number of events	Fraction
Fully-developed fire (entire vehicle)	3	11 %
Fully-developed fire (cabin only)	11	39 %
Non-fully-developed fire	14	50 %
Total	28	100 %

4.2. The effect of the approach duration of the fire brigade

Another relevant aspect is the effect of the fire brigade and its approach duration. The approach duration is defined as the period of time between fire detection (roughly equal to the alarm time) and the arrival of the first fire engine at the fire site.

The relevant numbers are available for 11 out of 14 fully-developed HGV and bus fires in tunnels. Two of them covered the entire vehicle, whereas the remaining nine were limited to the cabin (Table 8). Although the statistical sample is rather small, the numbers appear to support the notion that shorter approach duration leads to fewer fires extending to the entire vehicle.

Table 8: Intensity of spontaneous HGV/bus fires vs. approach duration of the fire brigade

Maximum intensity	Number of events with known approach duration	Average approach duration [minutes]	Standard deviation [minutes]
Fully developed fire (entire vehicle)	2	17.0	4.0
Fully developed fire (cabin only)	9	13.9	6.6
Fully developed fire (total)	11	14.5	6.3

5. FIRE DETECTION AND EXTINGUISHMENT

Table 9 indicates the means of fire detection registered. In some of the events, more than one means of detection was used, which is why the number of fire detection reports is larger than the number of fires.

In 87 % of the car fires, professional services (operator personnel, automatic detection, emergency forces) detected the fire. In 48 % of the cases, the driver of the burning car or other traffic participants detected the fire. In the case of HGVs and busses, the respective numbers were 77 % for professional services and 30 % for drivers and other traffic participants.

Table 9: Detection of vehicle fires in tunnels

Means of fire detection	Number		Fraction	
	Car	HGV/bus	Car	HGV/bus
Operator personnel	11	6	29 %	20 %
Automatic detection	16	12	42 %	40 %
Police, fire brigade etc.	6	5	16 %	17 %
Manually actuated alarm	4	1	11 %	3 %
Emergency telephone	13	5	34 %	17 %
Mobile telephone	1	3	3 %	10 %
Others	4	6	11 %	20 %
Total number of reports	55	38	145 %	127 %
Total number of fires	38	30	100 %	100 %

In terms of extinguishment, there is only little difference between cars and HGVs/busses (Table 10). In both cases, one third of the fires were put out by the driver, while the rest were extinguished by professional services (fire brigade, operator personnel etc.).

Table 10: Extinguishment of vehicle fires in tunnels

Extinguished by…	Number		Fraction	
	Car	HGV/bus	Car	HGV/bus
Driver	11	10	29 %	33 %
Professional services (fire brigade etc.)	27	20	71 %	67 %
Total	38	30	100 %	100 %

6. IMPLEMENTATION OF THE RESULTS IN GUIDELINE RVS 09.03.11 (TURISMO)

Many of the findings described in this paper have been directly incorporated into the latest version of Guideline RVS 09.03.11 Tunnel Safety/Methodology of Risk Analysis (TuRisMo) issued by the Austrian Association for Research on Road-Rail-Transport (FSV, 2014). This includes

- the rate of vehicle fires in tunnels per travelled kilometre
- the probability of fire given vehicle breakdown
- the probability of fire given an accident
- the probability of stopping inside the tunnel given vehicle fire
- the intensity distribution of spontaneous vehicle fires

Other findings, such as the effect of the fire brigade approach duration, have informed the methodological set-up or the choice of parameters in the guideline.

7. CONCLUSIONS

The paper combines vehicle fire data, accident data and traffic data from all tunnels within the Austrian primary road network. The comprehensiveness and consistency of each of these datasets provides a unique opportunity to derive reliable key numbers on vehicle fires in tunnels. This includes the rate of tunnel fires per vehicle kilometre as well as the conditional fire probability given vehicle breakdowns or accidents and a number of other relevant results that were presented in the paper.

However, dividing a sample of 67 tunnel fires into sub-sets turned out to be delicate in a few cases where it lead to a very small number of events (e.g. number of HGV fires after accidents, number of fully-developed fires of an entire HGV with known fire brigade approach duration). Nevertheless, the ensuing results are consistent with general reasoning even in those cases. Apart from this, they, too, are based on what is one of the most complete datasets available, also from an international perspective. Thus, they can truly be called best estimates – not only in the statistical, but also in the literal sense.

8. REFERENCES

FSV (Österreichische Forschungsggesellschaft Straße-Schiene-Verkehr) (2008) RVS 09.03.11 Tunnel-Risikoanalysemodell.

FSV (Österreichische Forschungsggesellschaft Straße-Schiene-Verkehr) (2014) RVS 09.03.11 Tunnel-Risikoanalysemodell.