FATAL TRAIN ACCIDENTS ON EUROPE'S RAILWAYS: 1980-2019

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Summary

This paper presents an analysis of fatal train accident rates and trends on Europe's main line railways from 1980 to 2019. The paper is one of an annual series starting with 1980 to 2009. The data cover the 28 countries of the European Union as in 2019, together with Norway and Switzerland. The estimated overall trend in the number of fatal train collisions and derailments per train-kilometre is –5.6% per year from 1990 to 2019, with a 95% confidence interval of –7.1% to -4.2%. The estimated accident rate in 2019 is 0.85 fatal collisions or derailments per billion train-kilometres, which represents a fall of 78% since 1990. This gives an estimated mean number of fatal accidents in Europe in 2019 of 3.89. The actual number of fatal train collisions and derailments in 2019 was 2, which is well below its mean, and indeed the lowest such figure on record. The estimated mean number of fatalities in 2019 was 16.4; the actual number was 9, which is low because of the low number of accidents. That contrasts with 2016, for example, in which there were 51 fatalities from 6 accidents. There are statistically significant differences in the fatal train accident rates and trends between the different European countries, although the estimates of the rates and trends for many individual countries have wide confidence limits. The distribution of broad causes of accidents appears to have remained unchanged over the long term, so that safety improvements appear to have been across the board, and not focused on any specific cause. The most frequent cause of fatal train collisions and derailments is signals passed at danger. In contrast to fatal train collisions and derailments, the rate per train-kilometre of severe accidents at level crossings fell slowly and only just statistically significantly in 1990-2019.

Keywords

Railways, safety, accidents, fatalities, Europe.

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1 INTRODUCTION

This paper presents an analysis of fatal train accident rates and trends on Europe's main line railways from 1980 to 2019. The paper is one of a series by the author; the first covered the period 1980-2009 and was published in the journal *Accident Analysis and Prevention* (Evans 2011). The methods in this paper are similar to those of the previous version, but the data have been updated to include accident data up to 2019, and train-kilometre data for 2018. The broad results are similar to the previous pattern.

The original paper used a new set of data assembled partly under the auspices of the European Railway Agency (ERA, now named The European Union Agency for Railways (EUAR)), and partly on the author's own account. Collaboration with the EUAR has continued in assembling the data analysed in this paper. The data analysed cover all fatal train collisions and derailments, and most other severe railway accidents, but they do not cover the majority of level crossing accidents nor personal accidents, such as persons struck by trains. The countries covered are the 28 member states of the European Union as in 2019 (of which two – Cyprus and Malta – do not have railways), together with Norway and Switzerland. These are labelled EU28+NO+CH.

The principal aims of the analyses are to provide an understanding of the present quantitative patterns of severe railway accidents and of the trends leading to them. That should inform what might be expected in the future and what savings in accident and fatalities might be expected from potential safety measures. Train-kilometres are used as the measure of exposure to risk.

The paper continues as follows. Section 2 outlines the data sources on accidents and train-kilometres. Section 3 analyses the data on fatal train collisions and derailments for both for Europe as a whole and for each country separately. Section 4 considers severe accidents at level crossings. Section 5 considers multiple-fatality accidents.

2 DATA SOURCES

2.1 Fatal accident data

The types of accidents included in this analysis are the following.

(1) Fatal train collisions and derailments other than at level crossings.
(2) Level crossing accidents with at least one on-train fatality.
(3) Fatal train fires (other than after collisions or derailments, with which they are included).
(4) All other accidents with four or more fatalities (which are mostly level crossing accidents with four or more road user fatalities).

The current principal source of accident and train-kilometre data is the European Union Agency for Railways The European Railway Safety Directive (RSD) (2004/49/EC) requires the National Safety Authorities (NSAs) of EU member states to send each year to the ERA specified information about their rail safety performance, called Common Safety Indicators (CSIs). The CSIs include annual classified counts of fatalities and serious injuries, and estimates of train-kilometres. Another part of the RSD requires EU member states to establish independent National accident Investigation Bodies (NIBs), who are required to investigate serious train accidents and to send information about them to the EUAR. They may also investigate less serious accidents and send reports to the EUAR. The EUAR publishes both the CSIs and the accident reports on its website and in annual reports (for example, ERA 2018). The coverage includes main line railways, but not metros, tramways, or heritage railways. The information required by the RSD began flowing in 2006, but it was some years before it was reasonably complete and reliable. The author continues to supplement the EUAR data with information from other sources, notably press reports.

Before the establishment of the ERA, there was no source of regular and comprehensive railway accident data in Europe. Therefore all the data from 1980 until the late 2000s were assembled retrospectively. Some of the data were assembled in a project for the ERA, and some on the author's own account. There were two general sources of retrospective data: first, press reports, and second, the NSAs or NIBs in member states. The method was first to identify all eligible accidents from a systematic search of press reports in the period 1980-2007. Then the resulting lists were sent to the NSAs or NIBs, with the request that they check them against their own information. The NSAs and NIBs were generally helpful, but not all had information covering the whole period. In addition to these two general sources, many other sources were used, some specific to particular countries. Details are given in Evans (2011) and in earlier versions of this paper.

Despite the use of many sources, there is no guarantee that the accidents identified are complete, and there is evidence presented below that some accidents in the 1980s are missing. In this paper the same assumptions are made about the completeness of data as were made in the original analysis (Evans 2011). These assumptions are the following.

- All eligible accidents (1) to (4) above are complete from 1990.
- In addition, fatal train collisions and derailments in 1980-1989 are complete for Germany, France, UK, Netherlands, Sweden, Norway and Ireland.
- In addition, accidents of any type with four or more fatalities are complete for 1980-1989.

The assumption of the completeness of fatal train accidents for the seven countries above rests on the existence of specific national sources for those countries. The assumption that accidents with 4 or more fatalities are complete is based on the assumption that press coverage is likely to be wide for such accidents. Since Evans (2011) was written, both the author and the ERA have done more work on the 1980s data. This has the effect of reducing the estimated number of missing accidents. It is possible that the data may be complete from 1980 for more than the seven countries above, but that is not assumed.

2.2 Train-kilometre data

In order to analyse accident data, some measure of exposure to the risks giving rise to accidents is required. For train collisions and derailments the obvious measure is train-kilometres per year. However, again there is no simple source. As noted in section 2.1, the Common Safety Indicators provide train-kilometres, but only from 2006. Prior to 2006 the only source is the International Union of Railways (UIC), which has published data going back to 1970. The members of the UIC are railway companies, not countries, and the UIC data are based on activities of companies. The distinction between countries and companies did not matter much in the era when most countries had a single nationalised railway operator, but in the present era of multiple operators the UIC data have become more complicated. Nevertheless, the UIC data and the CSIs appear to match well, and the writer has constructed a set of train-kilometres for each year and country based on both sources, and generally ending with the CSI values. This includes smoothing out some oddities in the data and imputing values for countries that did not exist in their present form at the start of the time period.

A further complication is that Article 2 of the Railway Safety Directive permits countries to exclude from its scope – and thus also from the CSIs – railways that are “functionally separate” from the national network and provide only local passenger services. Thus the train-kilometres given by the CSIs may exclude such lines. On the other hand, this paper includes accidents on such lines. Thus there may be a slight mismatch between accidents and train-kilometres, which will be different for different countries.

At the time of writing, no train-kilometre data have been published for 2019, so the 2019 data are taken to be a repeat of 2018.

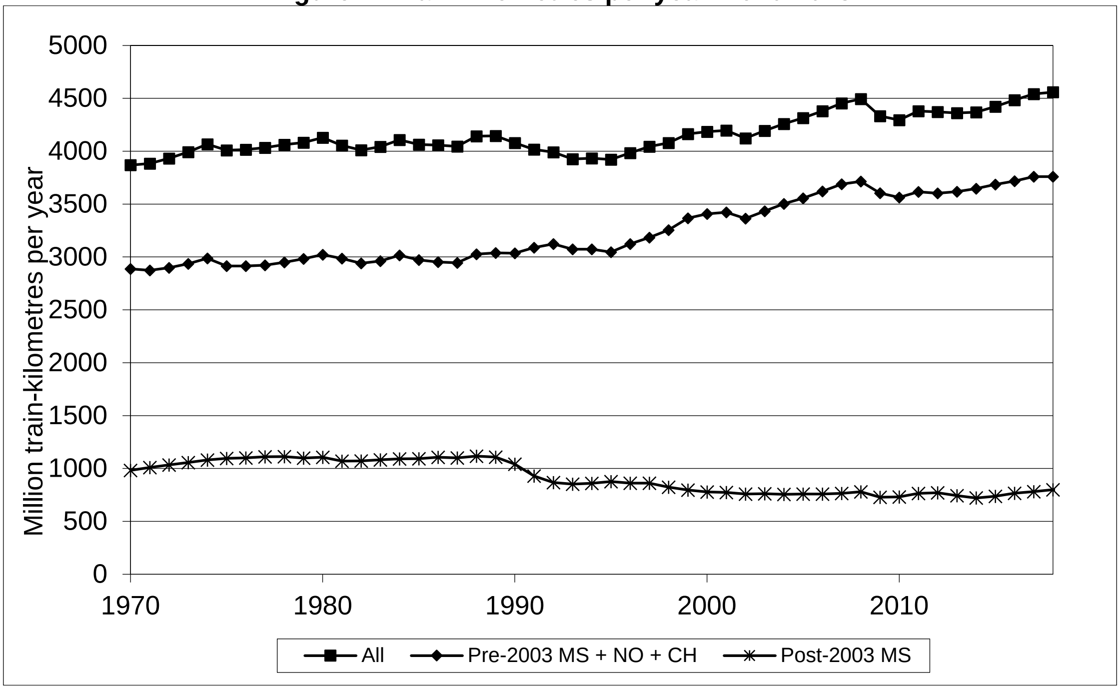
Table 1 gives train-kilometres in five- year periods for each country from 1980 to 2019. The countries are arranged in order of decreasing total train-kilometres in 1990-2009. Germany’s train-kilometres are more than two orders of magnitude greater than Luxembourg’s. Table 2 (in section 3.1) shows annual train-kilometres in EU28+NO+CH as a whole from 1980 to 2018. Figure 1 plots annual train-kilometres from 1970 to 2018 for EU28+NO+CH as a whole and separately for the member states (MS) that joined the EU before 2003 (+NO+CH) and those that joined after 2003. Train-kilometres have been remarkably stable over the long term, especially compared with the massive increases in road and air traffic. The numbers in 1990 were much the same as in 1970 for both groups of countries. Between 1990 and 2019, train-kilometres rose by 24% in the pre-2003 MS, fell by 23% in the post-2003 MS, and rose by 12% overall.

Table 1: Train-kilometres (million): 1980-2019

	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019*	1990-2019*	2019 *
Germany	4524	4326	4327	4347	4755	5095	5198	5351	29073	1085
France	2487	2372	2401	2485	2664	2600	2487	2336	14973	443
UK	2029	2128	2160	2335	2587	2695	2666	2839	15282	569
Italy	1428	1472	1572	1700	1672	1830	1621	1863	10258	387
Poland	1889	1963	1569	1437	1247	1108	1100	1219	7680	258
Spain	718	781	844	872	971	1020	970	999	5676	200
Czech Republic	894	906	795	731	715	804	803	837	4685	174
Switzerland	688	758	817	828	891	1010	1077	1132	5755	226
Austria	494	518	653	670	711	767	761	792	4354	165
Netherlands	563	579	598	611	629	682	764	799	4083	163
Sweden	510	522	482	519	567	675	715	781	3739	160
Romania	822	822	625	580	483	471	489	429	3077	86
Hungary	570	555	497	502	500	541	539	581	3160	116
Belgium	471	464	462	461	498	498	492	498	2909	102
Denmark	278	281	315	329	356	403	420	412	2235	82
Slovak Rep	366	372	327	303	271	248	233	259	1641	53
Finland	221	206	203	214	234	255	253	244	1403	50
Bulgaria	294	314	247	221	181	173	147	150	1119	30
Portugal	181	193	203	220	193	202	187	185	1190	36
Norway	170	161	175	184	201	230	237	258	1285	52
Croatia	185	187	122	132	134	143	120	112	763	24
Latvia	141	145	122	100	87	92	91	86	578	17
Slovenia	95	95	92	91	95	96	100	105	579	20
Greece	79	81	80	89	83	98	64	54	468	11
Lithuania	120	120	111	81	71	74	72	72	481	15
Ireland	63	69	70	73	79	86	90	93	491	19
Estonia	45	45	44	41	44	41	37	35	242	7
Luxembourg	20	22	33	35	37	37	44	45	231	9
EU28+NO+CH	20345	20457	19946	20191	20956	21974	21777	22566	127410	4484

*Train-kilometre data for 2019 are not available at the time of writing, so the 2019 data are taken to be a repeat of 2018.

Figure 1: Train-kilometres per year: 1970-2018



3 FATAL TRAIN COLLISIONS AND DERAILMENTS

3.1 Data

Table 2: Train-kilometres, observed fatal train collisions and derailments and fatalities: EU28+NO+CH: 1980-2019

	Train-kilometres (Million)	Fatal train collisions and derailments	Fatalities in collisions and derailments
1980	4,129	(17)	(178)
1981	4,055	(20)	(84)
1982	4,011	(19)	(62)
1983	4,043	(24)	(56)
1984	4,107	(19)	(102)
1985	4,064	(13)	(167)
1986	4,058	(9)	(30)
1987	4,046	(20)	(63)
1988	4,143	(26)	(181)
1989	4,146	(19)	(64)
1990	4,078	19	77
1991	4,017	20	52
1992	3,991	20	74
1993	3,926	14	43
1994	3,934	10	65
1995	3,922	13	46
1996	3,984	11	22
1997	4,044	13	67
1998	4,078	5	114
1999	4,163	4	36
2000	4,185	17	57
2001	4,196	3	20
2002	4,122	14	42
2003	4,194	13	40
2004	4,259	6	9
2005	4,314	7	28
2006	4,379	8	22
2007	4,454	5	9
2008	4,494	9	21
2009	4,333	6	42
2010	4,295	11	42
2011	4,380	6	18
2012	4.372	7	24
2013	4,361	6	91
2014	4,369	4	5
2015	4,422	4	5
2016	4,484	6	51
2017	4,542	4	7
2018	4,559	4	7
2019	4,559	2	9
1980-1989	40,802	(186)	(987)
1990-1999	40,137	129	596
2000-2019	87,273	142	550

Figures in brackets are not assumed to be complete.

Table 2 gives train-kilometres, observed fatal train collisions and derailments, and fatalities in these for the EU28+NO+CH for each year 1980 to 2019. Acts of terrorism are excluded, but malicious acts, such as objects placed on the track, are included. All the figures for accidents and fatalities in 1980-1989 are shown in brackets because, as discussed in section 2, they are not assumed to be complete.

Four fatal train collisions and derailments occurred in 2018 with 7 fatalities, and two accidents occurred in 2019 with 9 fatalities. These are typical of years with good performances, and contrast with 51 fatalities in 2016. The accidents are identified individually in Appendix 1, along with the other 83 fatal accidents that occurred in 2005-2019 A fuller version of this table would show all the 457 individual accidents identified since 1980, but that would be long and is not included.

It will be noted that the accidents in Appendix 1, and the analysis below, exclude the important derailment of a high-speed test train at Eckwersheim, near Strasbourg, in France on 14 November 2015, with 11 fatalities. The reason for excluding that accident is that the line on which it occurred was still under test, and had not yet been opened to normal traffic. It may be added that the control system, which would normally prevent such accidents, had been temporarily disabled for test purposes.

3.2 Accident rates and trends for Europe

The model used to interpret these data assumes that accidents occur randomly in year t with a Poisson distribution with a mean rate λ_t per year; λ_t is assumed to be given by

$$\lambda_t = \alpha k_t \exp(\beta t) \qquad (1)$$

where

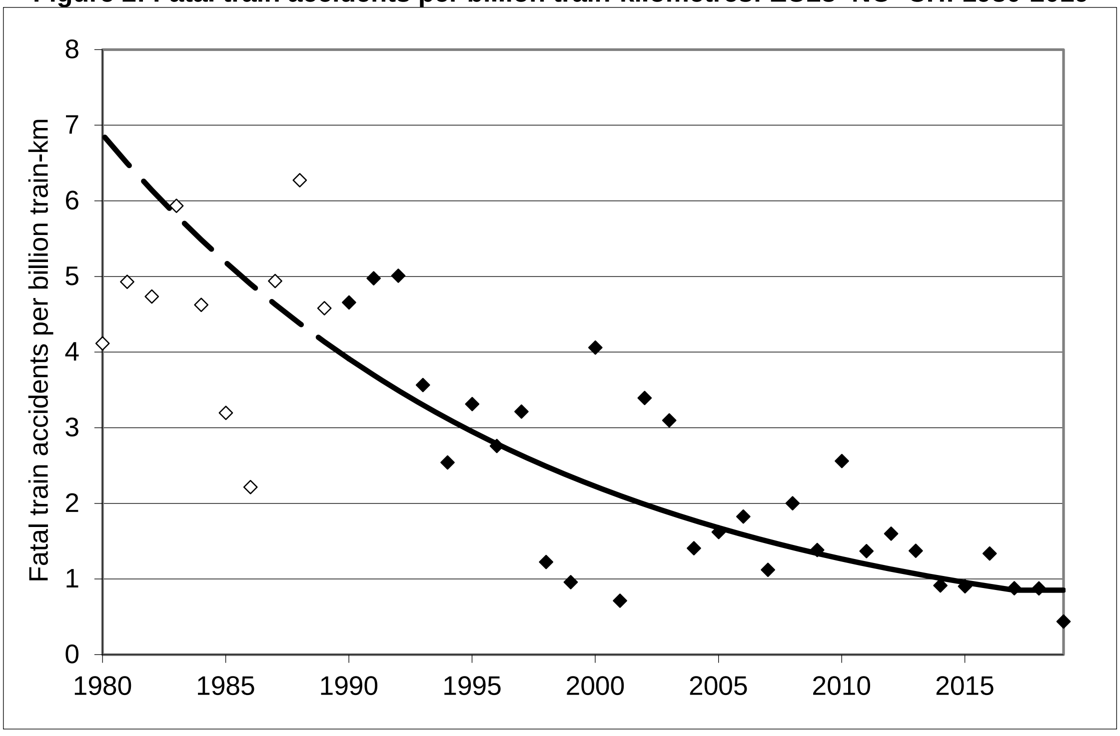
k_t = train-kilometres in year t.

α is a scale parameter.

β is a parameter measuring the long-term annual rate of change in accidents per train-kilometre.

This model assumes that the mean number of accidents per unit time is proportional to train-kilometres and to an exponential function of time, which represents the effects of the general improvements in railway safety taking place over the long term.

Figure 2: Fatal train accidents per billion train-kilometres: EU28+NO+CH: 1980-2019



The principal results in this section are based on fitting model (1) to the annual data in Table 2 for 1990-2019, disregarding the data for 1980-1989. That is because, as discussed in section 2, the 1980s' data are likely to be incomplete. Figure 2 shows in the solid data points the observed train collisions and derailments per billion train-kilometres for each year 1990-2019, and the solid curve is the trend (1) fitted to these data. The estimate of β, the annual rate of change in the accident rate, is –5.6% per year, with a standard error of 0.7%, so it is highly statistically significantly different from zero. The central estimate of the European accident rate in 2019 is 0.85 fatal train collisions and derailments per billion train-kilometres, which is a reduction of 78% on the corresponding rate of 3.91 in 1990. Combining these rates with the train-kilometres implies that the estimated mean numbers of train collisions and derailments were 16.0 in 1990 and 3.9 in 2019. Table 2 shows that the actual numbers of accidents in those years were 19 and 2 respectively.

These results are broadly similar to those obtained in the previous paper in this series. At 2, the actual number of accidents in 2019 was the lowest of any year on record. This has the effect of making the downward trend somewhat steeper than in the previous version of this paper.

The open data points on the left-hand side of Figure 2 are the observed accidents per billion train-kilometres for 1980-1989, and the dashed line is the extrapolation backwards of the trend fitted to the 1990-2019 data. It can be seen that with the exception of 1988, all the 1980-1989 data points are close to or below the extrapolated trend. It is possible that the true trend was flatter in the 1980s than later, but it is also likely that the data for 1980-1989 are incomplete. The expected total number of accidents in 1980-1989 implied by the back extrapolated trend is 220; the observed number is 186. This suggests that the number of missed accidents is of the order of 40. Further evidence in support of this order of magnitude is presented in section 3.5.

3.3 Accident rates and trends by country

Table 3: Fatal train collisions and derailments by country: 1980-2019

	1980 -84	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	1990-2019	1980-2019
EU28+NO+CH	(99)	(87)	83	46	53	35	34	20	271	(457)
Germany (DE)	12	15	11	10	4	0	5	3	33	60
France (FR)	7	8	8	0	3	1	2	0	14	29
UK (UK)	13	9	6	5	3	1	0	0	15	37
Italy (IT)	(3)	(5)	7	6	9	9	3	2	36	(44)
Poland (PL)	(5)	(6)	9	1	1	2	3	0	16	(27)
Spain (ES)	(16)	(6)	7	4	5	2	2	3	23	(45)
Czech Republic (CZ)	(4)	(3)	1	4	4	5	2	2	18	(25)
Switzerland (CH)	(2)	(3)	3	1	4	1	4	0	13	(18)
Austria (AT)	(3)	(5)	6	4	4	1	1	2	18	(26)
Netherlands (NL)	3	1	1	0	1	1	1	0	4	8
Sweden (SE)	5	2	1	0	0	0	1	0	2	9
Romania (RO)	(0)	(0)	1	3	1	2	0	2	9	(9)
Hungary (HU)	(4)	(2)	3	0	1	2	0	0	6	(12)
Belgium (BE)	(2)	(4)	1	1	3	1	3	2	11	(17)
Denmark (DK)	(1)	(2)	3	1	2	0	0	1	7	(10)
Slovak Republic (SK)	(5)	(1)	3	2	1	0	1	0	7	(13)
Finland (FI)	(0)	(0)	0	2	0	0	1	0	3	(3)
Bulgaria (BG)	(0)	(8)	2	0	1	0	1	1	5	(13)
Portugal (PT)	(2)	(3)	5	1	4	2	0	0	12	(17)
Norway (NO)	0	0	3	0	1	0	1	0	5	5
Croatia (HR)	(1)	(1)	0	0	0	1	1	0	2	(4)
Latvia (LV)	(0)	(1)	0	0	0	2	0	0	2	(3)
Slovenia (SI)	(4)	(0)	0	0	0	0	0	0	0	(4)
Greece (EL)	(4)	(2)	1	0	0	2	1	1	5	(11)
Lithuania (LT)	(0)	(0)	0	0	1	0	0	0	1	(1)
Ireland (IE)	2	0	1	0	0	0	0	0	1	3
Estonia (EE)	(1)	(0)	0	0	0	0	1	0	1	(2)
Luxembourg (LU)	(0)	(0)	0	1	0	0	0	1	2	(2)

Note: Figures in brackets are not included in the analysis because they are not assumed to be complete. Other figures, including all those from 1990, are assumed complete.

Analysing the accident rates and trends by country is useful and interesting, but is made difficult by the (fortunately) low frequency of fatal collisions and derailments at the level of individual countries. Indeed, most countries have zero fatal train collisions or derailments in most years. Therefore estimates of national accident rates and trends have relatively high standard errors and wide confidence intervals. Nevertheless, there are enough data to carry out an analysis at the national level.

Table 3 gives the numbers of recorded fatal train collisions and derailments for each country of EU28+NO+CH in five-year periods from 1980 to 2019. Five-year periods are adopted to avoid the presence of too many zeros. As noted in sections 2 and 3.2, for some countries the data for 1980-1989 are likely to be incomplete and so cannot be used for the analysis of rates and trends; on the other hand, it is reasonable to assume that the data for 1980-1989 are complete for seven countries, and these data have been used in the analysis. In Table 3, the figures not used are shown in brackets; all other figures are used.

A further qualification is that some countries have had so few accidents that their rates and trends cannot be estimated from these data. The adopted minimum requirement is that a country should have at least three fatal accidents distributed between at least two time periods. It will be seen from Table 3 that six countries do not meet this condition: Croatia, Latvia, Slovenia, Lithuania, Estonia and Luxembourg. These countries have been grouped together and labelled "others". Table 2 shows that most of these countries have small numbers of train-kilometres.

For the analysis of these data the same model (1) is adopted as for the European-level analysis, but now using the five-yearly data rather than annual data. The number of observations in the analysis is 152, made up of 56 from the seven countries each with eight periods, and 96 from the remaining 16 countries each with six periods (counting "others" as a single country for this purpose). Train-kilometres are given in Table 1.

To test whether the countries collectively have statistically significantly different accident rates and trends, different variants of model (1) were fitted, first forcing the parameters α and β to be the same for each country, and then looking to see whether the fit of the model to the data significantly improves when each country is allowed to have its own separate values. Further details are in Appendix 2. The conclusion is that the model fits best when each country has its own value of α and β. That implies that a separate version of model (1) should be fitted for each country.

From the results of these models, Table 4 gives the estimated mean number of fatal accidents per billion train-kilometres in 2019 and the estimated annual rate of change for each country, each with its 95% confidence limits. The values for EU28+NO+CH as a whole are taken from the analysis in section 3.2.

Figure 3 plots the central estimates of fatal train collisions and derailments per billion train-kilometres for each country from Table 4, with the countries arranged in order of increasing estimated accident rates. This figure is simple to read, but is perhaps misleading in giving the impression that the results are more precise than they really are. Therefore Figure 4 plots the 95% confidence intervals for the mean accident rates in 2019 for each country on a logarithmic scale. Because of the form of the model, the central estimate is at the centre of these bars. It can be seen that there is very substantial uncertainty in the results for individual countries, and many of the confidence intervals overlap. The larger countries have shorter confidence intervals because they have more data.

The country with the widest confidence interval and also the lowest central estimate of the mean accident rate is Ireland, which at the end of 2019 had suffered no fatal train collisions or derailments since 1991. The three largest systems – those of Germany, France and the UK – are all in the upper part of the figure: the estimated mean fatal accident rate for the UK in 2019 was 0.1 fatal accidents per billion train-kilometres; that for the France was 0.3, and that for Germany was 0.4. All these are well below the Europe-wide figure of 0.85.

Most countries have central estimates of accident rates that decline over time. Some decline at rates that are statistically significantly below zero, which are indicated by negative upper confidence limits for the trends in Table 4. However, five countries and "others" have central estimates of increasing accident rates, though none of these are statistically significantly different from zero, indicated by the fact that all the lower confidence limits for the trends are negative.

Table 4: Estimated mean fatal train collisions and derailments per billion train-kilometres in 2019 and annual rates of change in accident rates with 95% confidence limits by country

Country	Period estimated	Estimated mean fatal accidents per billion train-kilometres in 2019 (95% confidence limits in brackets)	Estimated annual rate of change in fatal accident rate over given period (95% confidence limits in brackets)
EU28+NO+CH	1990-2019	0.85 (0.64, 1.14)	–5.6% p.a. (–7.1%, –4.2%)
Germany	1980-2019	0.45 (0.23, 0.88)	–5.6% p.a. (–8.1%, –3.2%)
France	1980-2019	0.25 (0.08, 0.78)	–7.3% p.a. (–11.2%, –3.5%)
United Kingdom	1980-2019	0.14 (0.04, 0.45)	–10.7% p.a. (–14.6%, –6.9)
Italy	1990-2019	1.95 (0.93, 4.09)	–3.8% p.a. (–7.7%, +0.2%)
Poland	1990-2019	0.54 (0.13, 2.30)	–7.5% p.a. (–14.2%, –0.8%)
Spain	1990-2019	1.76 (0.66, 4.70)	–5.3% p.a. (–10.3%, –0.2%)
Czech Republic	1990-2019	3.64 (1.48, 8.98)	–0.4% p.a. (–5.7%, +5.0%)
Switzerland	1990-2019	1.28 (0.39, 4.15)	–3.8% p.a. (–10.3%, +2.6%)
Austria	1990-2019	1.23 (0.36, 4.16)	–7.3% p.a. (–13.3%, –1.4%)
Netherlands	1980-2019	0.41 (0.07, 2.57)	–6.0% p.a. (–12.6%, +0.6%)
Sweden	1980-2019	0.07 (0.00, 1.16)	–13.0% p.a. (–21.8%, –4.2%)
Romania	1990-2019	3.05 (0.80, 11.6)	+0.3% p.a. (–7.3%, +7.8%)
Hungary	1990-2019	0.37 (0.03, 3.97)	–9.4% p.a. (–20.5%, +1.6%)
Belgium	1990-2019	5.31 (1.84, 15.4)	+2.5% p.a. (–4.5%, +9.6%)
Denmark	1990-2019	0.64 (0.08, 5.33)	–9.4% p.a. (–19.4%, +0.6%)
Slovak Republic	1990-2019	0.75 (0.07, 8.50)	+9.4% p.a. (–1.5%, +20.3%)
Finland	1990-2019	1.07 (0.08, 14.5)	–4.5% p.a. (–18.3%, +9.4%)
Bulgaria	1990-2019	4.56 (0.71, 29.2)	+0.1% p.a. (–10.1%, +10.4%)
Portugal	1990-2019	1.86 (0.31, 11.1)	–9.4% p.a. (–17.5%, –1.2%)
Norway	1980-2019	1.91 (0.31, 11.8)	–2.5% p.a. (–10.1%, +5.1%)
Greece	1990-2019	22.72 (4.57, 113)	+5.5% p.a. (–5.7%, +16.7%)
Ireland	1980-2019	0.02 (0.00, 37.6)	–19.4% p.a. (–41.2%, +2.5%)
Others combined*	1990-2019	5.23 (1.60,17.1)	+4.8% p.a. (–3.6%, +13.3%)

*Croatia, Latvia, Slovenia, Lithuania, Estonia and Luxembourg

Figure 3: Central estimates of mean fatal train collision and derailment rates per billion train-km: EU28+NO+CH: 2019

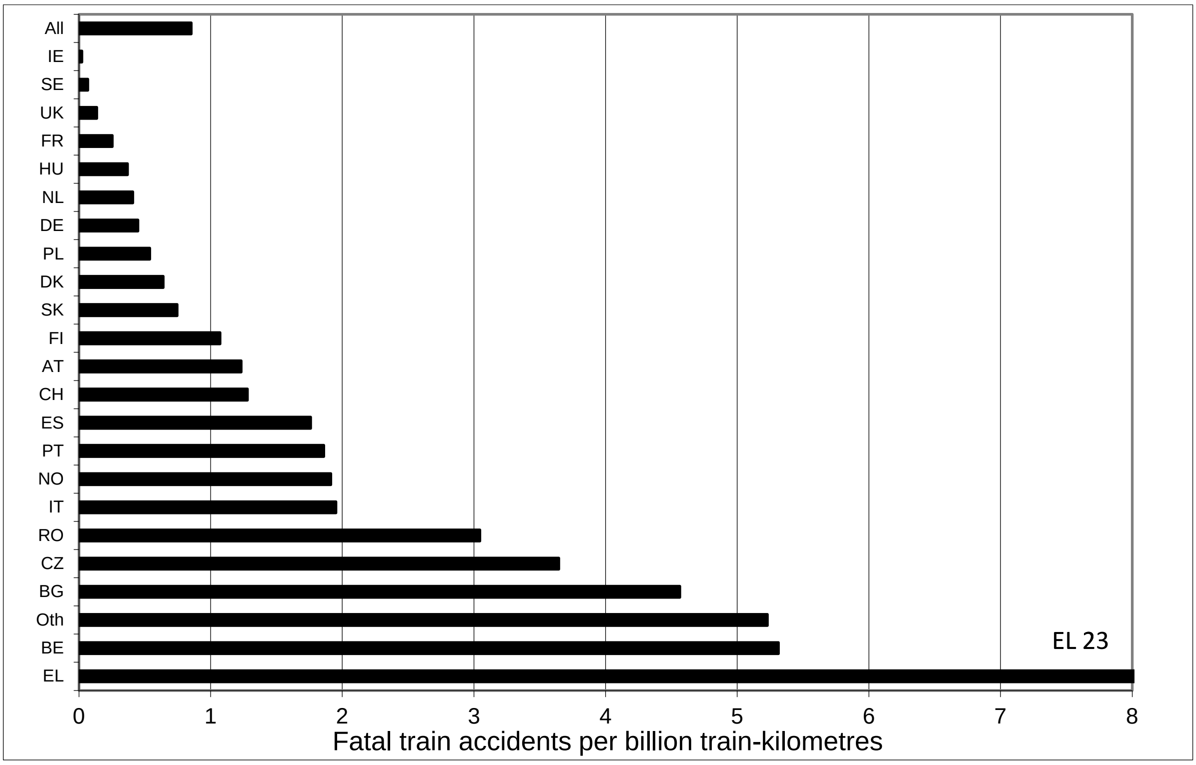
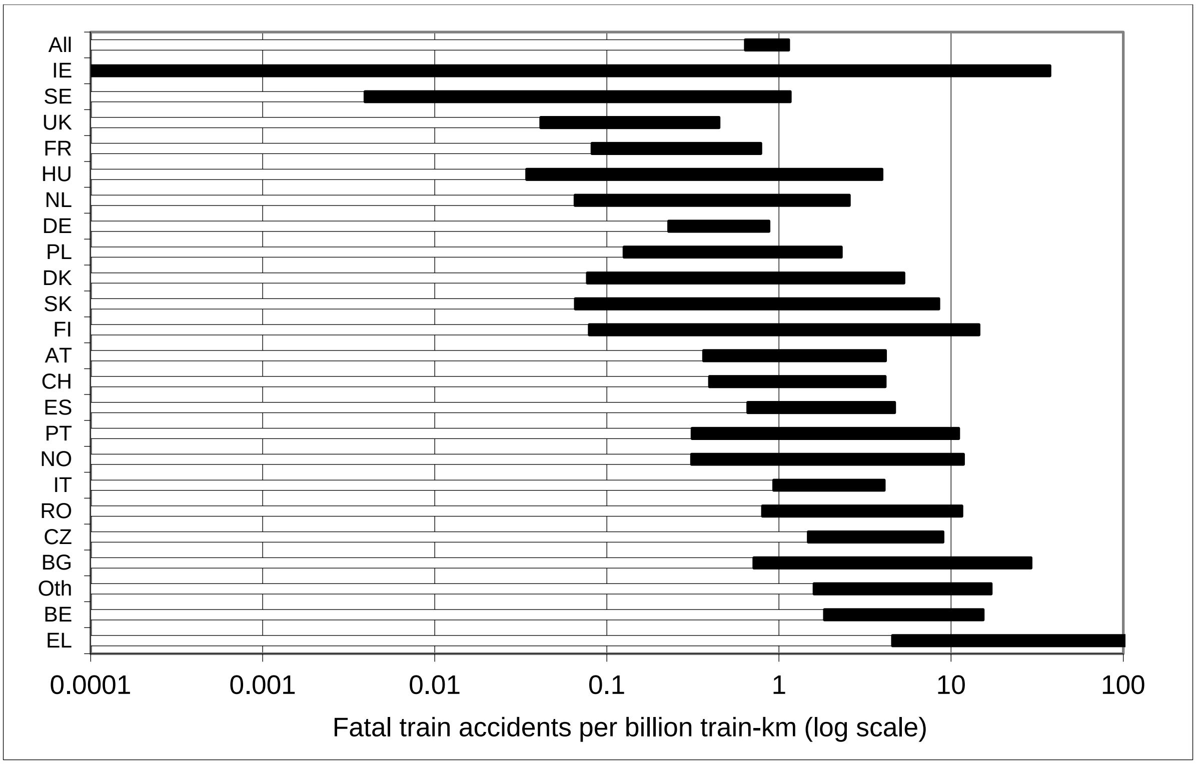


Figure 4: 95% confidence intervals for mean fatal train collision and derailment rates per billion train-km: EU28+NO+CH: 2019



3.4 Accident causes

Fatal train collisions and derailments are often the outcome of complex sequences of events, and there may be several ways in which they might have been prevented. Furthermore, every contributory cause may have many antecedents. These form the subject of accident investigations, which may recommend a number of safety measures to reduce the frequency or consequences of similar types of accident. Despite this complexity, it is useful and interesting to explore the distribution of the immediate causes of accidents. Therefore the writer has gone through all accidents in the database assigning a broad cause to all those for which the data allow this. For some accidents no immediate cause is known: typically these are accidents identified by a press report written before the accident was investigated and without any follow-up information.

Table 5 gives the numbers of accidents by broad cause and by decade for 1980-2019 for the seven countries for which the 1980s data are considered complete. Table 6 gives similar information by 5-year period for 1990-2019 for the remaining countries.

Table 5: Number of fatal train collisions and derailments by broad cause: DE, FR, UK, NL, SE, NO and IE: 1980-2019

Broad cause	1980-1989	1990-1999	2000-2019	Total
Signal passed at danger	21	16	6	43
Overspeeding	9	5	1	15
Signalling or dispatching error	12	4	5	21
Other operational error	12	5	5	22
Rolling stock failure	5	3	0	8
Infrastructure, track or points failure	8	5	6	19
External to railway	1	2	3	6
Total excluding unknown	68	40	26	134
Unknown	9	6	2	17
Total including unknown	77	46	28	151

Table 6: Number of fatal train collisions and derailments by broad cause: Rest of EU28 and CH: 1990-2019

Broad cause	1990-1994	1995-1999	2000-2004	2005-2009	2010-2019	Total
Signal passed at danger	12	8	11	9	8	49
Overspeeding	4	5	2	4	12	27
Signalling or dispatching error	7	2	5	4	6	24
Other operational error	3	1	2	1	6	13
Rolling stock failure	1	0	3	4	2	10
Infrastructure, track or points failure	1	3	4	6	4	18
External to railway	2	1	4	0	0	7
Total excluding unknown	30	20	31	28	39	148
Unknown	22	11	10	4	2	49
Total including unknown	52	31	41	32	41	197

The accident causes in Tables 5 and 6 span a wide range, and there is a correspondingly wide range of countermeasures, ranging from aids to prevent errors such as automatic train protection to improved safety management. It is useful to explore whether the proportions of accidents with different causes differ between the two sets of countries above, and whether the proportions of accidents with different causes change over time. Both of these questions can be answered using χ^2 contingency table statistical tests. The answers are that there is no evidence that the proportions of accidents with different causes differ between the groups of countries and there is no evidence of changes over time in either group of countries. The conclusion from this analysis and from previous sections is that it is clear that train accident rates have fallen substantially over time, but the improvement is widespread and not focused on any specific causes or group of causes. Safety has improved across the board, and this is presumably due to a wide range of safety measures.

The most common cause of fatal collisions and derailments in Tables 5 and 6 is signals passed at danger, accounting for 91 accidents of the 282 with known causes (32%). The second most common cause is signalling or dispatching errors, accounting for 45 accidents (16%). These occur typically when a signaller or station staff member authorises a train to proceed, but its path conflicts with that of another train. The frequency of both types of accident has fallen over time. This is likely to have been due both to the increased presence of aids (automatic train protection, improved signalling systems) and to improved operational management. It may be noted that railway technical innovations typically take many years to be extended to a whole system from their first use.

3.5 Accident consequences

Table 7: Observed numbers of fatal train collisions and derailments with given number of fatalities: EU28+NO+CH: 1980-2019

Number of fatalities	1980-1989	1990-2019	1980-2019
1	64	120	184
2	31	52	83
3	22	26	48
4	15	14	29
5	11	10	21
6	7	10	17
7	4	6	10
8	7	5	12
9	6	3	9
10		4	4
11	3	1	4
12	1	3	4
13	2		2
14	1		1
16	2	3	5
17		2	2
18	1	1	2
19		4	4
23		1	1
25	1		1
28	1		1
≥30	7	5	12
Total 1 to 3	117	198	315
Total 4 or more	69	73	142
Total accidents	186	271	456
Total fatalities	987	1146	2133

In this paper the consequences of fatal accidents are measured by the number of fatalities. No distinction is made between the types of victims: passengers, staff, or members of the public. The distribution of fatalities in train collisions and derailments is skew: most accidents have a small number of fatalities, but a few have large numbers. Table 7 shows the distribution of fatalities in accidents for 1980-1989 and 1990-2019. Table 7 shows that there were 12 collisions and derailments with 30 or more fatalities between 1980 and 2019. Table 8 identifies these (and also includes the two level crossing accidents with 30 or more fatalities). The most serious accident in the whole period was at Eschede in Germany in 1998 with 101 fatalities; the derailment at Santiago de Compostela in Spain in 2013 had 80 fatalities.

Table 8: Accidents with 30 or more fatalities: EU28+NO+CH: 1980-2019

Date	Cou-ntry	Location	Type of accident	Brief description	Fatal-ities
19/08/1980	PL	Otłoczyn	FCD	Passenger/freight train collision	67
12/09/1982	CH	Pfaffikon	LC	Passenger train/bus collision, fire	39
14/07/1984	SI	Divača	FCD	Passenger/freight train collision	31
03/08/1985	FR	Flaujac	FCD	Two passenger train collision	35
31/08/1985	FR	Argenton-sur-Creuse	FCD	Pass train derailment, then collision	43
11/09/1985	PT	Nelas-Alcafache	FCD	Two passenger train collision, fire	45
27/06/1988	FR	Paris Gare de Lyon	FCD	Two passenger train collision	56
12/12/1988	UK	Clapham Junction	FCD	Three passenger train collision	35
02/12/1994	HU	Szajol	FCD	Passenger train derailment	31
03/06/1998	DE	Eschede	FCD	Passenger train derailment	101
05/10/1999	UK	Ladbroke Grove	FCD	Two passenger train collision, fire	31
08/05/2003	HU	Siófok	LC	Passenger train/bus collision, fire	33
29/06/2009	IT	Viareggio	FCD	Freight train derailment, fire	32
24/07/2013	ES	Santiago de Compostela	FCD	Passenger train derailment	80

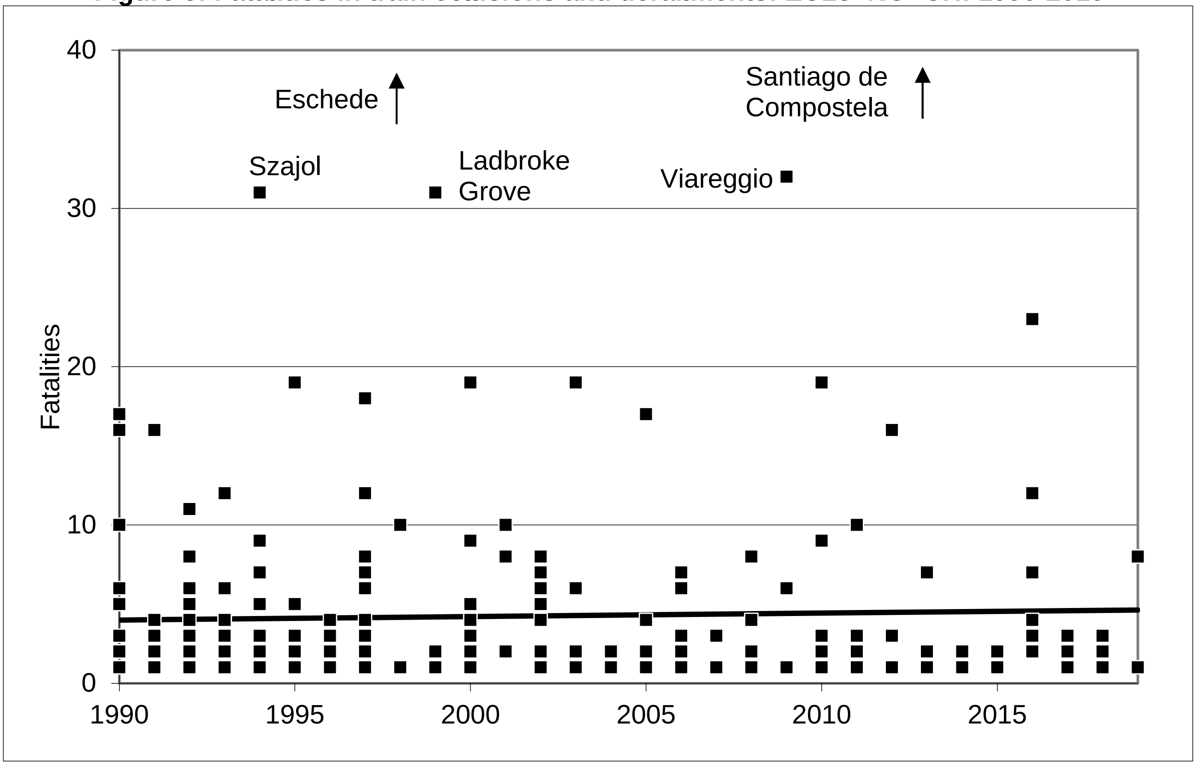
FCD = Fatal train collision or derailment; LC = level crossing accident

As noted previously, the accidents in the 1980s are almost certainly under-recorded. Furthermore, given the data sources, it is to be expected that the under-recording is selective. It is unlikely that the data sources would miss any serious multiple-fatality accident, because these are so newsworthy; on the other hand, it is much more likely that some of the accidents with small numbers of fatalities would be missed, especially if fatalities were only to staff, as in collisions or derailments of freight trains. An indication of this is that the observed mean number of fatalities per accident is 5.31 in 1980-1989 and 4.23 in 1990-2019. The higher mean in the 1980s probably does not reflect a real difference in the fatalities per accident in that decade, but arises simply because a number of the smaller accidents have been missed.

An estimate of the number missed can be made using the data at the bottom of Table 7. If we assume (a) that the data for 1990-2019 are correct, (b) that the number of accidents with 4 or more fatalities in the 1980s is also correct, and (c) that the true ratio of the numbers of smaller to larger accidents in the 1980s was the same as in 1990-2019, the estimated number of 1-fatality to 3-fatality accidents in the 1980s would be 69*198/73 = 187. The observed number is 117, which gives a shortfall of 70. This is similar to of the shortfall of about 40 made by back extrapolation of the trend in section 3.2. Thus we have two separate estimates that the number of missed accidents in the 1980s is of the order of 40-70.

We now consider whether there is any trend over time in the mean number of fatalities per accident. In order to avoid complications from under-recording, the analysis is confined to the data for 1990-2019. Figure 5 plots the number of fatalities in each of the 271 individual accidents by year. Note that many of the 1- and 2-fatality points represent more than one accident. The graph shows the preponderance of accidents with small numbers of fatalities, together with a scattering of more serious accidents. There is no obvious indication in the graph that accidents are becoming either more or less severe over time. The line is the least-squares regression line. It is almost flat, and its slope is not significantly different from zero. It is concluded that the mean number of fatalities per fatal collision or derailment is constant at the overall average of 1146/271 = 4.23 fatalities per fatal accident. This may be compared with the corresponding average of 4.26 reported in the 2017 version of this paper. The slight decrease from 2017 to 2019 was due to the relatively small number of fatalities in the six accidents in 2018 and 2019.

Figure 5: Fatalities in train collisions and derailments: EU28+NO+CH: 1990-2019



The combination of the estimated mean number of accidents per year in 2019 of 3.89 (section 3.2) with 4.23 fatalities per accident implies an estimated mean of 16.4 fatalities per year in Europe in train collisions and derailments in 2019. Table 2 shows that the actual number was 9, reflecting mainly the small number – 2 – of fatal train collisions and derailments in 2019. Thus 2019 was a year in which the actual number of fatalities in train collisions and derailments was well below its mean. This contrasts with 2016 in which the number of fatalities was well above its mean.

3.6 Evolution of estimated train accidents and fatalities for Europe

This paper is one of a series of analyses of fatal train collisions and derailments in Europe carried out by the author, starting with the published paper (Evans 2011) covering 1990-2009.

It is useful to examine how the principal risk estimates have changed between successive analyses. Table 9 gives the principal results for Europe-wide train collisions and derailments, ending with the estimates made in this paper. For accidents, Table 9 shows that the central estimates have been slowly declining apart from in 2010. The 2010 results show a flattening of the trend relative to 2009, and modest increase in the central estimates of accidents. The reason is the relatively poor safety performance in 2010, in which there were 11 fatal accidents (see Table 2), compared with an estimated mean of about 6. That was the highest number of accidents in a single year since 2003. 2014, 2015, 2017 and 2018 each saw four fatal accidents, and 2019 saw only 2, which is the lowest figure on record.

For fatalities, the mean number of fatalities per fatal accident remained at just over 4 until 2013, when it rose by 7% to 4.31, following the derailment at Santiago de Compostela. That in turn caused the estimated mean number of fatalities per year to rise by 6% from 22.3 in 2012 to 23.7 in 2013. However, the mean number of fatalities per year had fallen to 16.5 by 2019.

Table 9: Evolution of estimated mean fatal train accident rates, accidents and fatalities: EU28+NO+CH*

Period of analysis	Train-km (billion) in penultimate year†	Estimated trend in mean accident rate since 1990	Estimated mean accidents per billion train-km in last year	Estimated Mean accidents in last year	Mean fatalities per accident since 1990	Estimated mean fatalities in last year
1990-2009	4.452	–6.3%p.a.	1.35	6.02	4.10	24.7
1990-2010	4.274	–5.4%p.a.	1.45	6.21	4.08	25.3
1990-2011	4.245	–5.7%p.a.	1.34	5.68	4.04	23.0
1990-2012	4.343	–5.7%p.a.	1.27	5.53	4.04	22.3
1990-2013*	4.349	–5.4%p.a.	1.26	5.49	4.31	23.7
1990-2014	4,361	–5.4%p.a.	1.18	5.16	4.25	21.9
1990-2015	4,369	–5.5%p.a.	1.10	4.80	4.20	20.2
1990-2016	4,422	–5.3%p.a.	1.07	4.73	4.30	20.4
1990-2017	4,484	–5.4%p.a.	1.00	4.49	4.26	20.2
1990-2018						
1990-2019	4,559	–5.6%p.a.	0.85	3.89	4.23	16.5

*From 1990-2013 Croatia is included, with its retrospective accident data. Previously it was omitted.
†Train-kilometre data for the last year are not available at the time of analysis, so data for the penultimate year are used instead.

4 SEVERE LEVEL CROSSING ACCIDENTS

4.1 Data

Accidents at level crossings are important. Fatal level crossing accidents are more numerous and account for more fatalities than fatal train collisions and derailments. The CSIs for the ten years 2009 to 2018 record 3,213 fatalities in level crossing accidents, or 321 per year. Most level crossing fatalities occur in single-fatality accidents, so there must be about three hundred fatal level-crossing accidents per year, but there is apparently no published series. It is not practicable to assemble data on all fatal level crossing accidents within the present work, partly because many are not well recorded, and partly because the volume of accidents would be overwhelming.

Nevertheless, the present work does include some specifically defined level crossing accidents. As noted in section 2, these comprise all level crossing accidents with on-train fatalities (passengers or staff), and all level crossing accidents without on-train fatalities but with four or more fatalities to road users. In this paper we refer to these included accidents as “severe” level crossing accidents. (In some previous papers, these were referred to as "serious" level crossing accidents.)

Table 10 gives the recorded numbers of severe level crossing accidents and the fatalities in these for each year from 1980 to 2019. As in the case of train collisions and derailments, the accidents in 1980-1989 are likely to be under-recorded, so these data are enclosed in brackets and not included in the analysis of this section. The number of fatalities in the severe level crossing accidents recorded in Table 10 for 2000-2019 is 127, which is only 4.0% of the CSI total mentioned above. This indicates that the severe level crossing accidents in Table 10 are only a small fraction of all level crossing accidents, even smaller than 4.0%, because the severe accidents in Table 10 should include all the high-fatality level crossing accidents.

Table 10 shows that there were seven severe level crossing accidents in 2018 and 2019 taken together, leading to 27 fatalities.

Table 10: Train-kilometres and observed severe level crossing accidents and fatalities: EU28+NO+CH: 1980-2019

	Train-kilometres (million)	Severe level crossing accidents	Fatalities in severe level crossing accidents
1980	4,129	(4)	(56)
1981	4,055	(3)	(33)
1982	4,011	(7)	(77)
1983	4,043	(6)	(43)
1984	4,107	(3)	(25)
1985	4,064	(8)	(49)
1986	4,058	(2)	(17)
1987	4,046	(2)	(10)
1988	4,143	(4)	(25)
1989	4,146	(2)	(16)
1990	4,078	3	15
1991	4,017	3	19
1992	3,991	3	27
1993	3,926	9	46
1994	3,934	7	33
1995	3,922	6	23
1996	3,984	8	48
1997	4,044	3	18
1998	4,074	5	13
1999	4,163	10	36
2000	4,185	10	28
2001	4,196	6	29
2002	4,122	4	19
2003	4,194	6	55
2004	4,259	6	23
2005	4,314	4	12
2006	4,379	4	11
2007	4,454	4	18
2008	4,494	7	29
2009	4,333	5	33
2010	4,295	4	10
2011	4,380	3	9
2012	4,372	4	24
2013	4,361	1	11
2014	4,369	5	11
2015	4,422	6	21
2016	4,484	3	3
2017	4,543	3	11
2018	4559	4	14
2019	4559	3	13
1980-1989	40,802	(41)	(351)
1990-1999	40,137	57	278
2000-2019	87,274	92	384

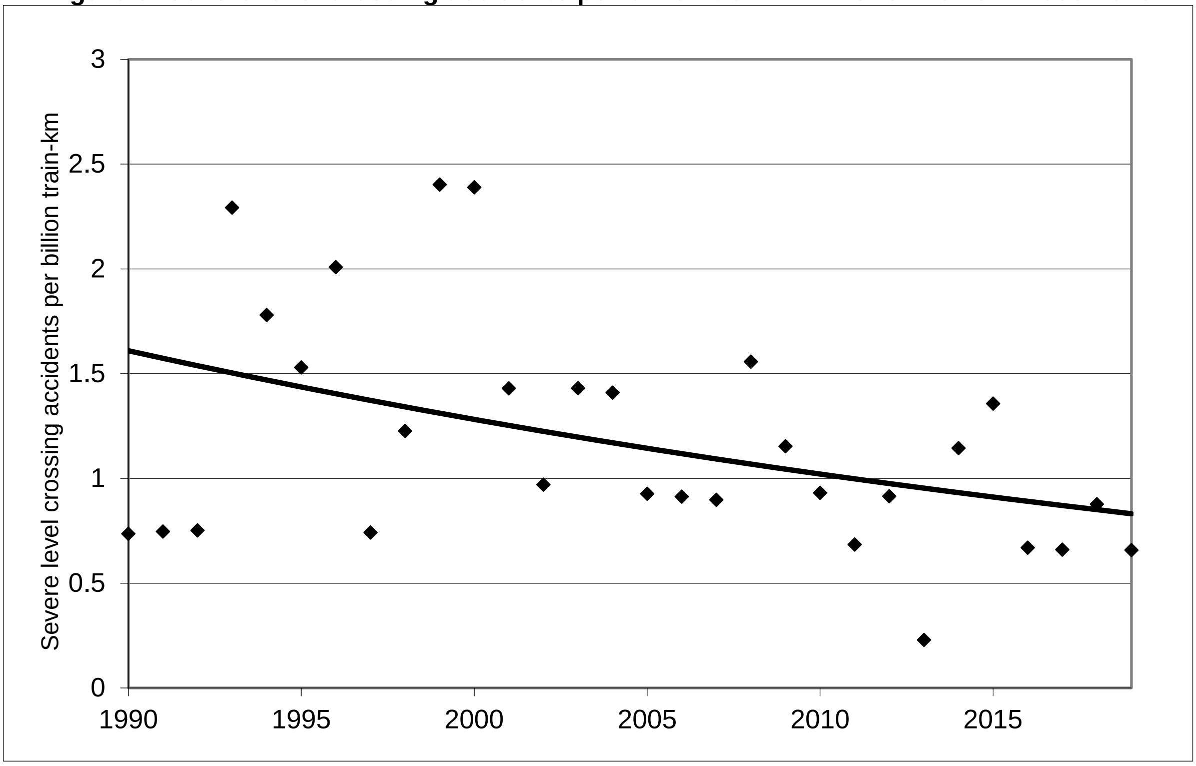
Figures in brackets are not assumed to be complete.

4.2 Accident rates and trend

The same form of model (1) has been fitted to the 1990-2019 severe level crossing accidents per billion train-kilometres in Table 10 as was fitted to the fatal collisions and derailments in section 3.2. The fitted trend is shown in Figure 6, together with the 30 data points. The curve is downward. The central estimate of the rate of change in the accident rate is –2.3% per year, with a standard error of 1.0% per year. The slope is therefore just statistically significantly different from zero.

Therefore, in contrast to the reduction in the rate of fatal train collisions and derailments shown in Figure 2, there appears to have been a slower reduction in the severe level crossing accident rate in the last 30 years. It is not possible to say whether the relatively slow long-term improvement also applies to the much larger number of less severe fatal level crossing accidents, because there are no comprehensive data, but it is plausible that they also have shown only slow improvement.

Figure 6: Severe level crossing accidents per billion train-km: EU28+NO+CH: 1990-2019



The causes of level crossing accidents are different from those of train collisions and derailments. Most major crossings in Europe have automatic warnings – lights, barriers and bells – operated by approaching trains, and most minor crossings have fixed warning signs only, with no indication when trains are approaching. The primary responsibility for operational safety thus rests with road users, either in obeying warnings or checking that no train is approaching before they cross. Therefore the great majority of level crossing accidents are caused by errors or violations by road users. Of the 149 severe level crossing accidents in 1990-2019 in Table 10, 119 have known causes, and of these 119, 116 were errors or violations by road users. The high proportion of road user causes is similar to rail industry findings (see for example, Rail Safety and Standards Board, 2009, p156). It follows that counter-measures include similar countermeasures to those for road accidents, particularly education and enforcement, as well as good level crossing management. The engineering and maintenance of level crossings is regarded largely as the responsibility of the railways, though sometimes shared with the highway authority.

5 MULTIPLE-FATALITY ACCIDENTS AND *FN*-CURVES

As noted in section 2, the data sought include all accidents with four or more fatalities. Most of these are either train collisions and derailments or level crossing accidents. Further small numbers of accidents with four or more fatalities are train fires (not following collisions and derailments) and groups of persons struck by trains, mostly track workers. Table 11 gives the distribution of fatalities in each type of accident with four or more fatalities in 1980-2019. The 1980s are included because multi-fatality accidents are newsworthy, and the data sources can be expected to have identified most, if not all, of the accidents with 4 or more fatalities in that decade.

A common form of illustration of accident size distributions are *FN*-curves. These plot the frequency *F* of accidents with *N* or more fatalities against *N*. *FN*-graphs usually have logarithmic scales. Figure 7 plots the empirical *FN*-curves for 1980-2019 from the data in Table 11 for train collisions and derailments, level crossing accidents, and train fires. The curve for train collisions and derailments is extended back from *N*=4 to *N*=1 by including the numbers of missed 1-, 2- and 3-fatality accidents estimated by the method used in section 4.5.

The *FN*-curves in Figure 7 are based on accident frequencies averaged over the 40-year period 1980-2019. Notional *FN*-curves for 2019 could be estimated by combining the shapes in Figure 7 with the estimated accident frequencies in 2019. This would have the effect of lowering the *FN*-curve for train collisions and derailments to about 50% of its present level, because, as shown in Figure 2, accident frequencies have fallen substantially over the long term. On the other hand, the *FN*-curve for level crossing accidents would fall by less, because, as shown in Figure 6, the frequency of severe level crossing accidents fallen only slowly. That would bring the 2019 *FN*-curves closer together. It demonstrates that level crossings, as well as train collisions and derailments, are an important source of severe accidents.

Table 11: Numbers of accidents with four or more fatalities: EU28+NO+CH: 1980-2019

Number of fatalities	Train collisions and derailments	Level crossing accidents	Train fires	Persons struck by rolling stock, etc	Total
4	29	47	2	5	83
5	21	32		1	54
6	17	13		2	32
7	10	5		1	16
8	13	7			20
9	9	3	1		13
10	4	1			5
11	4	2			6
12	4	6	1	1	12
13	2	3			5
14	1				1
15		1			1
16	5	2			7
17	2	1			3
18	2	1			3
19	4	1			5
23	1				1
25	1	1			2
27		1			1
28	1				1
≥30	12	2			14
Total ≥4	138	129	4	10	281

Figure 7: Empirical FN-curves for train accidents: EU28+NO+CH: 1980-2019

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REFERENCES

European Union Agency for Railways (2018). Report on Railway Safety and Interoperability in the European Union in 2018. ERA, Valenciennes, France.

European Railway Agency (2017). Railway Safety the European Union. Safety Overview 2017. ERA, Valenciennes, France.

Evans, A W (2011). Fatal train accidents on Europe's railways: 1980-2009. *Accident Analysis and Prevention* **43**(1), 391-401.

Rail Safety and Standards Board [of the UK] (2009). Annual safety Performance Report 2008. RSSB, London. (http://www.rssb.co.uk/sitecollectiondocuments/pdf/reports/ASPR%202008.pdf)

LIST OF ABBREVIATIONS

CSI	Common Safety Indicator
ERA	European Railway Agency
EU	European Union
EU28+NO+CH	Countries of the EU28, Norway and Switzerland
EUAR	European Union Agency for Railways
FCD	Fatal train collisions and derailments
LC	Level crossing
MS	Member state (of EU)
NIB	National accident Investigation Body
NSA	National Safety Authority
RSD	Railway Safety Directive
UIC	International Union of Railways
Country codes	See Table 3

APPENDIX 1: FATAL TRAIN COLLISIONS AND DERAILMENTS: EU28+NO+CH: 2005-2019

(Page 1: 2011-2019)

Date	Country	Location	Brief description	Fatalities
08/02/2019	ES	Castellgali	Two passenger train collision	1
02/01/2019	DK	Great Belt Bridge	Passenger/freight train collision	8
20/11/2018	ES	Vacarisses	Passenger train derailment	1
07/05/2018	DE	Aichach	Passenger/freight train collision	2
12/02/2018	AT	Niklasdorf	Two passenger train collision	1
25/01/2018	IT	Pioltello	Passenger train derailment	3
13/05/2017	EL	Adendro	Passenger train derailment	3
08/04/2017	RO	Merisor-Banita	Freight train derailment	2
18/02/2017	BE	Leuven	Passenger train derailment	1
14/02/2017	LU	Dudelange	Passenger/freight train collision	1
10/12/2016	BG	Hitrino	Freight train derailment, fire	7
29/11/2016	RO	Bârseşti	Freight train/ light loco collision	2
09/09/2016	ES	O Porriño	Passenger train derailment	4
12/07/2016	IT	Andria – Corato	Two passenger train collision	23
05/06/2016	BE	Hermalle-sous-Huy	Passenger/freight train collision	3
09/02/2016	DE	Bad Aibling	Two passenger train collision	12
28/11/2015	DE	Bremerhaven-Speckenbüttel	Two freight train collision	1
30/10/2015	CZ	Řehlovice	Two freight train collision	1
30/09/2015	CZ	Světec	Two freight train collision	1
06/05/2015	AT	Waldstein	Two passenger train collision	2
13/08/2014	CH	Tiefencastel	Passenger train hit landslip	1
12/07/2014	BG	Kaloyanovets	Passenger train derailment	1
08/02/2014	FR	Annot	Passenger train hit by boulder	2
12/01/2014	IT	Firenze SMN	Train hit buffers	1
29/07/2013	CH	Granges-pres-Marnand	Two passenger train collision	1
20/07/2013	ES	Santiago de Compostela	Passenger train derailment	80
12/07/2013	FR	Brétigny-sur-Orge	Passenger train derailment	7
04/05/2013	BE	Schellebelle-Witteren	Freight train derailed; toxic goods release	1
27/03/2013	AT	Obereggendorf	Passenger train/works train collision	2
06/02/2013	DE	Reinbek	Passenger train/works vehicle collision	1
26/07/2012	DE	Hosena bei Senftenberg	Two freight train collision	1
14/06/2012	BE	Duffel	Passenger train/works crane collision	1
21/04/2012	NL	Amsterdam Sloterdijk	Two passenger train collision	1
13/04/2012	DE	Mühlheim am Main	Passenger train/works train collision	3
08/03/2012	CH	Chénens-Cottens	Freight train/works train collision	1
03/03/2012	PL	Szczekociny	Two passenger train collision	16
13/01/2012	DE	Bargum	Passenger train collision with cattle	1
12/08/2011	PL	Baby	Passenger train derailment	2
26/07/2011	PL	Strzelce Krajeńskie Wschód	Seven coal wagons ran away, hit building	3
07/04/2011	HR	Kupjak Tunnel	Freight train derailment	1
21/02/2011	FI	Nokia	Two freight train collision	1
02/02/2011	CZ	Vodňany – Čičenice	Passenger/freight train collision	1
29/01/2011	DE	Hordorf	Passenger/freight train collision	10

APPENDIX 1: FATAL TRAIN COLLISIONS AND DERAILMENTS: EU28+NO+CH: 2007-2019
(Page 2: 2005-2010)

Date	Cou-ntry	Location	Brief description	Fatal-ities
23/12/2010	EE	Kehra – Aegviidu	Empty passenger/freight train collision	1
09/12/2010	EL	Achladokampos	Passenger train derailment	1
12/09/2010	SE	Kimstad	Passenger train/works crane collision	1
06/08/2010	IT	Napoli	Passenger train derailment	2
23/07/2010	CH	Fiesch	Passenger train derailment	1
28/06/2010	CZ	Usti-nad-Labem	Passenger train derailment	1
12/04/2010	IT	Laces – Castelbello	Passenger train derailed by landslide	9
01/04/2010	SK	Spišská Nová Ves	Test locomotive/passenger train collision	3
26/03/2010	ES	Arevalo	Two freight train collision	1
24/03/2010	NO	Alnabru, Oslo	16 freight wagons ran away, hit buildings	3
15/02/2010	BE	Buizingen	Two passenger train collision	19
19/12/2009	IT	Scala di Giocca – Ploaghe	Passenger train hit landslide	1
19/11/2009	BE	Mons	Passenger train derailment	1
08/10/2009	ES	Lezama	Passenger train derailment	1
24/09/2009	NL	Barendrecht	Two freight train collision	1
24/07/2009	HR	Rudine	Passenger train derailment	6
29/06/2009	IT	Viareggio	Freight train derailment, petrol fire	32
08/08/2008	CZ	Studenka	Passenger train hit collapsed bridge	8
19/05/2008	CZ	Moravany	Locomotive/passenger train collision	1
10/05/2008	RO	Valea Calugareasca	Passenger train derailment	1
14/07/2007	CZ	Cercany	Passenger train/empty train collision	1
15/06/2007	IT	Bortigali – Birori, Sardinia	Two passenger train collision	3
23/02/2007	UK	Grayrigg	Passenger train derailment	1
12/02/2007	PT	Linha do Tua	Passenger train hit landslide	3
06/02/2007	HU	Almasfuzito – Komarom	Passenger/freight train collision	1
13/12/2006	IT	Borghetto sull'Adige	Two freight train collision	2
17/11/2006	PL	Zaryn	Two freight train collision	1
11/10/2006	FR	Zouffgen	Passenger train/freight train collision	6
21/08/2006	ES	Villada	Passenger train derailment	7
17/05/2006	CH	Thun	Runaway works train collision	3
11/05/2006	IT	Susa Valley	Freight train derailment	1
14/03/2006	IT	Milano	Two passenger train collision	1
08/03/2006	EL	Acharnon station	Passenger train/freight train collision	1
20/12/2005	IT	Roccasecca	Two passenger train collision	2
06/12/2005	EL	Aphidnon	Passenger train/freight train collision	1
01/10/2005	CZ	Želenice station	Two freight train collision	1
14/07/2005	PL	Gliwice	Two freight train collision	1
02/07/2005	AT	Bramberg − Muehlbach	Two passenger train collision	2
02/02/2005	LV	Riga	Passenger train/empty train collision	4
07/01/2005	IT	Bolognina di Crevalcore	Passenger train/freight train collision	17

APPENDIX 2: STATISTICAL ANALYSIS OF TRAIN ACCIDENT RATES AND TRENDS BY COUNTRY

As noted in sections 3.2 and 3.3, the assumed basic model (1) is that the number of accidents in period t is Poisson-distributed with mean λ_t given by

$$\lambda_t = \alpha\, k_t \exp(\beta t) \qquad (1)$$

where k_t = train-kilometres in period t, α is a scale parameter determining the general accident level, and β is a parameter measuring the long-term rate of change in accidents per train-kilometre. The mean number of fatal accidents per train-kilometre in period t is given by $\lambda_t/k_t = \alpha \exp(\beta t)$. If t is defined to be zero in 2019, α is the mean accident rate in 2019. If $\beta = 0$, there is no long-term change in the mean accident rate.

As noted in section 3.3, if the fatal train collisions and derailments for each country are grouped into 5-year periods, the data for fitting the model consist of 152 accident counts comprising eight 5-year counts for seven countries and six 5-year counts for 16 countries (counting "others" as a single country). In order to test whether different countries have statistically significantly different mean accident rates and trends, we fit five variants of model (1) to these 152 accident counts, each with different assumptions about the values of the parameters α and β. The model variants are the following

(a) Each country is assumed to have the same mean α in 2019 and no trend ($\beta = 0$).
(b) Each country is assumed to have the same mean α with a common trend $\beta \neq 0$.
(c) Each country i is assumed to have its own mean α_i and no trend ($\beta = 0$).
(d) Each country i is assumed to have its own mean α_i with a common trend $\beta \neq 0$.
(e) Each country i is assumed to have its own mean α_i and its own trend $\beta_i \neq 0$.

Table 12 gives statistical results from fitting each of these model variants. The number of degrees of freedom is the number of observations (152) less the number of fitted parameters. The scaled deviance is a measure of the goodness of fit of the model to the data. If the data really are generated in the manner assumed by the model variant, the scaled deviance would have an approximately χ^2 distribution with the given number of degrees of freedom. The mean of the χ^2 distribution is equal to its degrees of freedom. In comparing one model variant with another, the more detailed variant fits significantly better than the less detailed model if the reduction in the scaled deviance is significant when tested against the χ^2 distribution with degrees of freedom equal to the difference in degrees of freedom between the two variants.

Table 12: Statistical results for variants of model for means and trends in accident rates: Fatal train collisions and derailments by country: EU28+NO+CH

Variant of model	Degrees of freedom	Scaled deviance
(a) Common mean α; no trend ($\beta = 0$)	151	353.3
(b) Common mean α; common trend β	150	287.2
(c) Different means α_i; no trend ($\beta = 0$)	129	276.4
(d) Different means α_i; common trend β	128	172.8
(e) Different means α_i; different trends β_i	106	130.3

The important comparisons in Table 12 are those between variants (b) and (d) and between (d) and (e). Moving from (b) to (d) allows each country to have its own mean in the presence of a common trend. This reduces the scaled deviance by 114.4, to be tested against χ^2 with 22 degrees of freedom, whose upper 5% point is 33.9. Variant (d) therefore fits significantly better than (b). Moving further from (d) to (e) allows each country also to have its own trend. This reduces the scaled deviance by 42.5, also to be tested against χ^2 with 22 degrees of freedom. This reduction is also significant at 5%. Thus we accept model variant (e). The estimates of α_i and β_i for each country and their 95% confidence limits are given in Table 4.