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# FATAL TRAIN ACCIDENTS ON EUROPE'S RAILWAYS: 1980-2009

Andrew W Evans
Imperial College and University College London

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## Abstract

This paper presents an analysis of fatal train accident rates and trends on Europe's main line railways from 1980 to 2009. The paper uses a new set of data for the European Union together with Norway and Switzerland, assembled partly under the auspices of the European Railway Agency and partly on the author's own account. The estimated overall trend in the number of fatal train collisions and derailments per train-kilometre is –6.3% per year from 1990 to 2009, with a 95% confidence interval of –8.7% to -3.9%. The estimated accident rate in 2009 is 1.35 fatal collisions or derailments per billion train-kilometres, giving an estimated mean number of fatal accidents in 2009 of 6.0. The overall number of fatalities per fatal accident in 1990-2009 is 4.10, with no apparent long term change over time, giving an estimated mean of 24.6 fatalities per year in train collisions and derailments in 2009. 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 serious accidents at level crossings remained unchanged in 1990-2009.The immediate causes of most of the serious level crossing accidents are errors or violations by road users.

**Keywords**

Railways, safety, accidents, fatalities, Europe.

Centre for Transport Studies
Department of Civil and Environmental Engineering
Imperial College London
London SW7 2AZ

e-mail: a.evans@imperial.ac.uk
Tel: 020 7594 6043
Fax: 020 7594 6102

## 1 INTRODUCTION

This paper presents an analysis of fatal train accident rates and trends on Europe's main line railways from 1980 to 2009. To the best of the writer's knowledge, the paper represents the first public analysis of train accidents at the European level. The principal obstacle to such analyses in the past has been the absence of data. This paper uses a new set of data assembled partly under the auspices of the European Railway Agency and partly on the author's own account. The data analysed cover all fatal train collisions and derailments, and the most serious other railway accidents, but they do not cover most personal accidents, such as persons struck by trains. The countries covered include the 25 member states of the European Union that have railways, together with Norway and Switzerland.

The principal aims of the analyses are to provide an understanding of the present quantitative patterns of serious 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.

The paper continues as follows. Section 2 and Appendix 1 outline the data sources and retrieval methods. Section 3 presents data on train-kilometres, used as the measure of exposure to accidents in each country. Section 4 and appendix 2 analyse the data on fatal train collisions and derailments for Europe as a whole and for each country separately. Section 4 also considers broad accident causes. Section 5 considers serious accidents at level crossings. Section 6 considers accident consequences, measured in this paper by the number of fatalities; the section considers fatalities in train collisions and derailments, and then high-consequence accidents as a whole. Section 7 presents the conclusions.

## 2 DATA SOURCES

The principal obstacle to a comprehensive analysis of European railway safety performance is that until recently there was no single source of accident data. The situation changed with the creation of the European Railway Agency (ERA) in 2004 and the requirement under the Railway Safety Directive (2004/49/EC) that the National Safety Authorities (NSAs) of EU member states should send annually 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 Safety Directive 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 ERA. They may also investigate less serious accidents and send reports to the ERA. The ERA publishes both the CSIs and the accident reports on its website and in annual reports (for example, ERA 2010). The coverage includes all main line railways, but not metros, tramways, or heritage railways.

At the time of writing CSIs are available for 2006, 2007 and 2008 (with a few gaps). The date from which the NIBs were formally required to submit accident reports was April 2006, but in practice some NIBs began earlier, or submitted retrospective reports, and some later. A problem about the accident data is that serious railway accidents are (fortunately) infrequent, so unless retrospective data are collected it would be a long time before sufficient data for analysis are available. For that reason in 2007 the ERA let a consultancy contract to assemble data on specified types of serious accidents from 1990 to 2007, using all available sources. The countries included were the 25 EU members with railways, plus Norway and Switzerland, which are abbreviated henceforth as EU+NO+CH. The project was completed in 2009, and the data assembled are now publicly available in an archive on the ERA website. The present writer was a member of the contracting team, and this paper makes much use of the data collected. The writer has also extended the data on his own account forward to 2009 and backward as far as possible to 1980, though it is clear that for some countries the data for 1980-1989 are incomplete.

The types of accidents included in the ERA archive project were the following.

(1) Fatal train collisions or 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).

(4) All other accidents with 4 or more fatalities (which are mostly level crossing accidents with 4 or more road user fatalities).
(5) Train accidents without fatalities but with 5 or more serious injuries.
(6) Other accidents with high damage costs (≥ €2 million at current prices).
(7) Other accidents in which dangerous goods were released.

This paper focuses entirely on the fatal accidents (1) to (4), with most attention devoted to the fatal train collisions and derailments (1). The writer considers that the data on the non-fatal accidents (5) to (7) may not be complete enough to justify statistical analysis.

The strategy for assembling data was based on the observation that serious railway accidents, especially fatal train collisions and derailments, are newsworthy. Therefore one might expect such events to be reported in the press. Furthermore, there exists a commercial searchable database of news items entitled Nexis® which assembles reports from a large number of leading news agencies and newspapers, and which – with suitable search terms – can be used to identify accounts of relevant events[1]. Nexis was used commercially for the ERA work and through university libraries for the research extensions. The first and second paragraphs of Appendix 1 list the news agencies and the newspapers respectively whose reports contributed to identifying accidents. The sources contributing to Nexis have expanded steadily: the earliest items are from the late 1960s; there is only a little material in the 1970s; two major news agencies (AP and UPI) and some newspapers are present throughout the 1980s; many European agencies and newspapers joined in the early 1990s.

The news reports in Nexis are good for identifying accidents, but not every relevant accident is reported in the press. Furthermore, press reports are less good at providing accurate rail-related information. This is because reports are not usually written by rail experts, and because stories are typically unfinished and still evolving at the time reports are made. Therefore under the auspices of the ERA, the NIBs were sent details of all the accidents that we had found from Nexis in 1990-2007, and were asked to correct errors and to identify any accidents known to them that we had missed. Most NIBs helpfully did so. This resource was not available to the writer for the data in 1980-1989. For that reason and because Nexis' coverage was then smaller, the accident data for 1980-1989 are almost certainly incomplete. However, other known sources were also used to supplement Nexis and the NIBs. In particular, national sources have been found for seven countries which may reasonably be regarded as complete for the 1980s. These countries are Germany, France, UK, Netherlands, Sweden, Norway and Ireland. The national sources are listed in Appendix 1, together with other sources used in the project. The seven countries represent 51% of Europe's train-kilometres in 1980-1989.

**Table 1: Numbers of fatal train collisions and derailments by source: EU+NO+CH: 1980-2009**

| **Source** | **1980-1984** | **1985-1989** | **1990-1994** | **1995-1999** | **2000-2004** | **2005-2009** | **Total** |
|---|---|---|---|---|---|---|---|
| Reported in a Nexis source | 66 | 71 | 67 | 44 | 47 | 32 | 327 |
| Not in Nexis, but identified by NIB or NIB report | 3 | 0 | 12 | 1 | 3 | 1 | 20 |
| Not identified by Nexis or NIB, but found in another source | 7 | 2 | 2 | 0 | 3 | 1 | 15 |
| Total | 76 | 73 | 81 | 45 | 53 | 34 | 362 |

Table 1 shows that 362 fatal train collisions and derailments are identified in 1980-2009, of which 149 occurred in 1980-1989 and 213 in 1990-2009. Of the 213 in 1990-2009, 190 (89%) have reports in Nexis; after scrutinising the output from Nexis, the NIBs identified a further 17 (8%) not in Nexis; a further 6 (3%) were found in other sources. The fact that the NIBs did not identify more missing accidents suggests that the data are fairly complete for 1990-2009, and they are assumed complete in the analysis that follows. The NIBs also improved the accuracy of the information about accidents already identified. Nexis also identified a high proportion of the accidents found in 1980-1989 – 137 of 149 (92%) – but, as

[1] The search terms most commonly used were (rail* OR train) AND (accident OR crash OR fire).

noted above, Nexis' coverage was then smaller and there was no scrutiny by the NIBs, so these data cannot be assumed to be complete, other than for the seven countries mentioned above.

To summarise, the data for 1990-2009 are assumed to be complete for all countries of EU+NO+CH. The data for 1980-1989 are also assumed complete for the seven countries specified above, but not for the remaining countries of the EU. However, because multiple-fatality accidents are more likely to be reported in the press than less severe accidents, in Section 6 the data for 1980-1989 on accidents with four or more fatalities are also assumed to be complete.

## 3 TRAIN-KILOMETRES

**Table 2: Train-kilometres (million): 1980-2009**

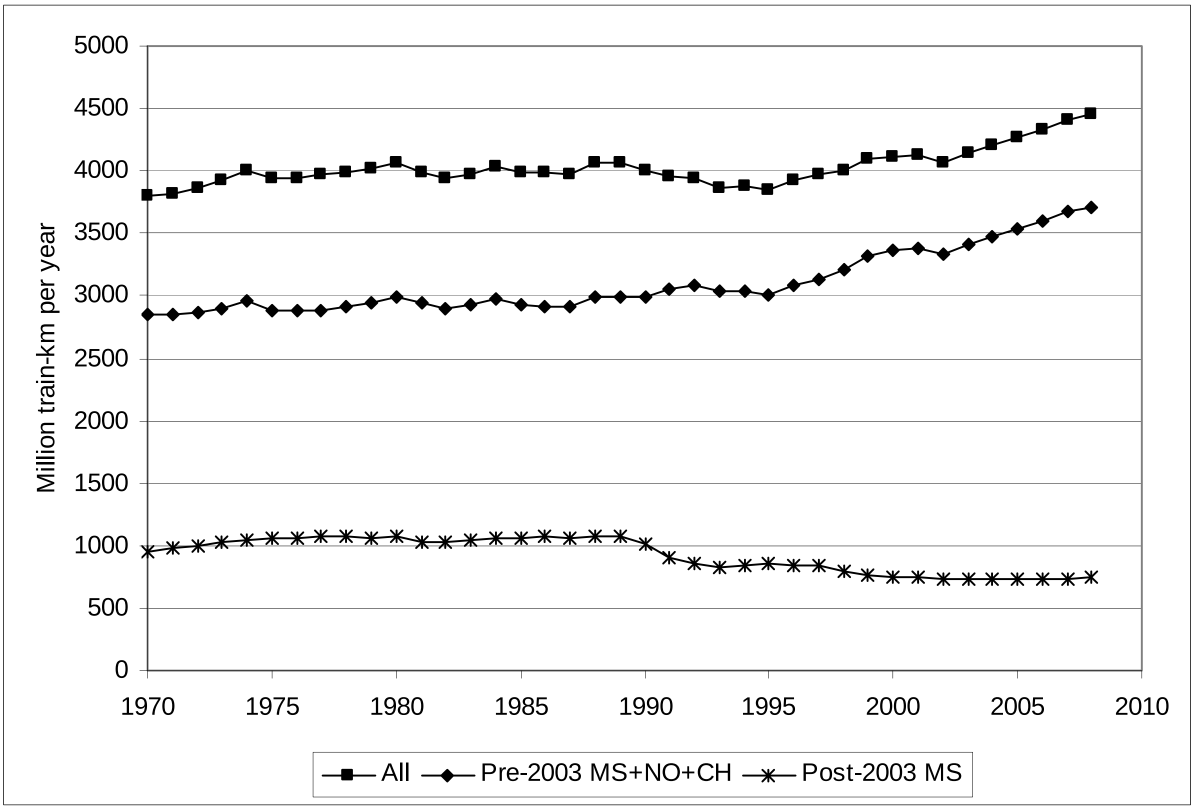
| | 1980-1984 | 1985-1989 | 1990-1994 | 1995-1999 | 2000-2004 | 2004-2009* | 1990-2009* | 2009* |
|---|---|---|---|---|---|---|---|---|
| Germany | 4524 | 4326 | 4327 | 4347 | 4755 | 5136 | 18565 | 1044 |
| France | 2487 | 2372 | 2401 | 2485 | 2664 | 2637 | 10187 | 541 |
| UK | 2029 | 2128 | 2160 | 2335 | 2606 | 2707 | 9808 | 548 |
| Italy | 1428 | 1472 | 1572 | 1700 | 1672 | 1846 | 6790 | 367 |
| Poland | 1889 | 1963 | 1569 | 1437 | 1247 | 1123 | 5376 | 224 |
| Spain | 718 | 781 | 844 | 872 | 977 | 1063 | 3756 | 214 |
| Czech Republic | 894 | 906 | 795 | 731 | 715 | 816 | 3057 | 175 |
| Switzerland | 540 | 596 | 649 | 646 | 725 | 882 | 2902 | 185 |
| Austria | 494 | 518 | 653 | 670 | 711 | 773 | 2807 | 158 |
| Netherlands | 563 | 579 | 598 | 611 | 629 | 681 | 2519 | 139 |
| Sweden | 510 | 522 | 482 | 519 | 567 | 670 | 2238 | 138 |
| Romania | 822 | 822 | 625 | 580 | 483 | 478 | 2166 | 96 |
| Hungary | 570 | 555 | 497 | 502 | 500 | 544 | 2043 | 109 |
| Belgium | 471 | 464 | 462 | 461 | 498 | 505 | 1926 | 99 |
| Denmark | 248 | 251 | 279 | 298 | 323 | 400 | 1300 | 82 |
| Slovak Republic | 366 | 372 | 327 | 303 | 271 | 252 | 1153 | 49 |
| Finland | 221 | 206 | 203 | 214 | 234 | 258 | 909 | 53 |
| Bulgaria | 294 | 314 | 247 | 221 | 181 | 177 | 826 | 35 |
| Portugal | 181 | 193 | 203 | 220 | 193 | 203 | 819 | 42 |
| Norway | 170 | 161 | 175 | 184 | 201 | 234 | 794 | 47 |
| Latvia | 141 | 145 | 122 | 100 | 87 | 93 | 402 | 20 |
| Slovenia | 95 | 95 | 92 | 91 | 95 | 98 | 376 | 20 |
| Greece | 79 | 81 | 80 | 89 | 83 | 99 | 351 | 21 |
| Lithuania | 120 | 120 | 111 | 81 | 71 | 76 | 339 | 16 |
| Ireland | 63 | 69 | 70 | 73 | 79 | 84 | 306 | 16 |
| Estonia | 45 | 45 | 44 | 41 | 44 | 41 | 170 | 7 |
| Luxembourg | 20 | 22 | 33 | 35 | 37 | 36 | 141 | 7 |
| EU+CH+NO | 19982 | 20078 | 19620 | 19846 | 20648 | 21912 | 82026 | 4452 |

*Train-kilometre data for 2009 are not available at the time of writing, so the 2009 data are taken to be a repeat of 2008.

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, the Common Safety Indicators provide train-kilometres, but only for 2006 to 2008. 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 ending with the 2008 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. At the time of writing, no data have been published for 2009, so the 2009 data are taken to be a repeat of 2008.

Table 2 gives train-kilometres in five year periods for each country from 1980 to 2009. 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 3 (in section 4.1) shows annual train-kilometres in the EU+NO+CH as a whole from 1980 to 2009. Figure 1 plots annual train-kilometres from 1970 to 2008 for EU+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 2008, train-kilometres rose by 24% in the pre-2003 MS, fell by 25% in the post-2003 MS, and rose by 11% overall.

**Figure 1: Train-kilometres per year: 1970-2008**




## 4 FATAL TRAIN COLLISIONS AND DERAILMENTS

### 4.1 Accident rates and trends for EU+NO+CH as a whole

Table 3 gives train-kilometres, observed fatal train collisions and derailments, and fatalities in these for the EU+NO+CH for each year 1980 to 2009. The table also gives data for serious level crossing accidents, which are discussed in section 5 below. 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, following the discussion in section 2, they are not assumed to be complete.

**Table 3: Train-kilometres, observed fatal accidents and fatalities: EU+NO+CH: 1980-2009**

| | Train-kilometres | Fatal train collisions and derailments | Fatalities in collisions and derailments | Serious level crossing accidents | Fatalities in serious level crossing accidents |
|---|---|---|---|---|---|
| 1980 | 4,060 | (13) | (168) | (3) | (52) |
| 1981 | 3,985 | (14) | (77) | (2) | (28) |
| 1982 | 3,938 | (17) | (59) | (6) | (75) |
| 1983 | 3,968 | (16) | (41) | (2) | (12) |
| 1984 | 4,031 | (16) | (99) | (1) | (17) |
| 1985 | 3,988 | (12) | (166) | (7) | (47) |
| 1986 | 3,982 | (5) | (26) | (2) | (17) |
| 1987 | 3,972 | (16) | (55) | (2) | (10) |
| 1988 | 4,067 | (22) | (179) | (3) | (23) |
| 1989 | 4,069 | (18) | (71) | (1) | (4) |
| 1990 | 4,001 | 19 | 77 | 2 | 10 |
| 1991 | 3,952 | 19 | 51 | 3 | 19 |
| 1992 | 3,936 | 19 | 71 | 3 | 27 |
| 1993 | 3,858 | 14 | 43 | 8 | 42 |
| 1994 | 3,873 | 10 | 64 | 7 | 33 |
| 1995 | 3,855 | 13 | 46 | 6 | 23 |
| 1996 | 3,918 | 10 | 20 | 7 | 44 |
| 1997 | 3,970 | 13 | 67 | 3 | 18 |
| 1998 | 4,008 | 5 | 114 | 5 | 13 |
| 1999 | 4,095 | 4 | 36 | 10 | 36 |
| 2000 | 4,112 | 17 | 57 | 10 | 28 |
| 2001 | 4,120 | 3 | 20 | 6 | 29 |
| 2002 | 4,065 | 14 | 42 | 4 | 19 |
| 2003 | 4,141 | 13 | 40 | 6 | 55 |
| 2004 | 4,210 | 6 | 9 | 6 | 23 |
| 2005 | 4,264 | 7 | 28 | 4 | 12 |
| 2006 | 4,335 | 8 | 22 | 4 | 11 |
| 2007 | 4,409 | 5 | 9 | 4 | 18 |
| 2008 | 4,452 | 9 | 21 | 7 | 29 |
| 2009 | 4,452 | 5 | 36 | 5 | 33 |
| 1980-1989 | 40,060 | (149) | (941) | (29) | (285) |
| 1990-1999 | 39,466 | 126 | 589 | 54 | 265 |
| 2000-2009 | 42,560 | 87 | 284 | 56 | 257 |

Figures in brackets are not assumed to be complete.

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

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

where

$k_t$ = train-kilometres in year $t$.

$\alpha$ is a scale parameter.

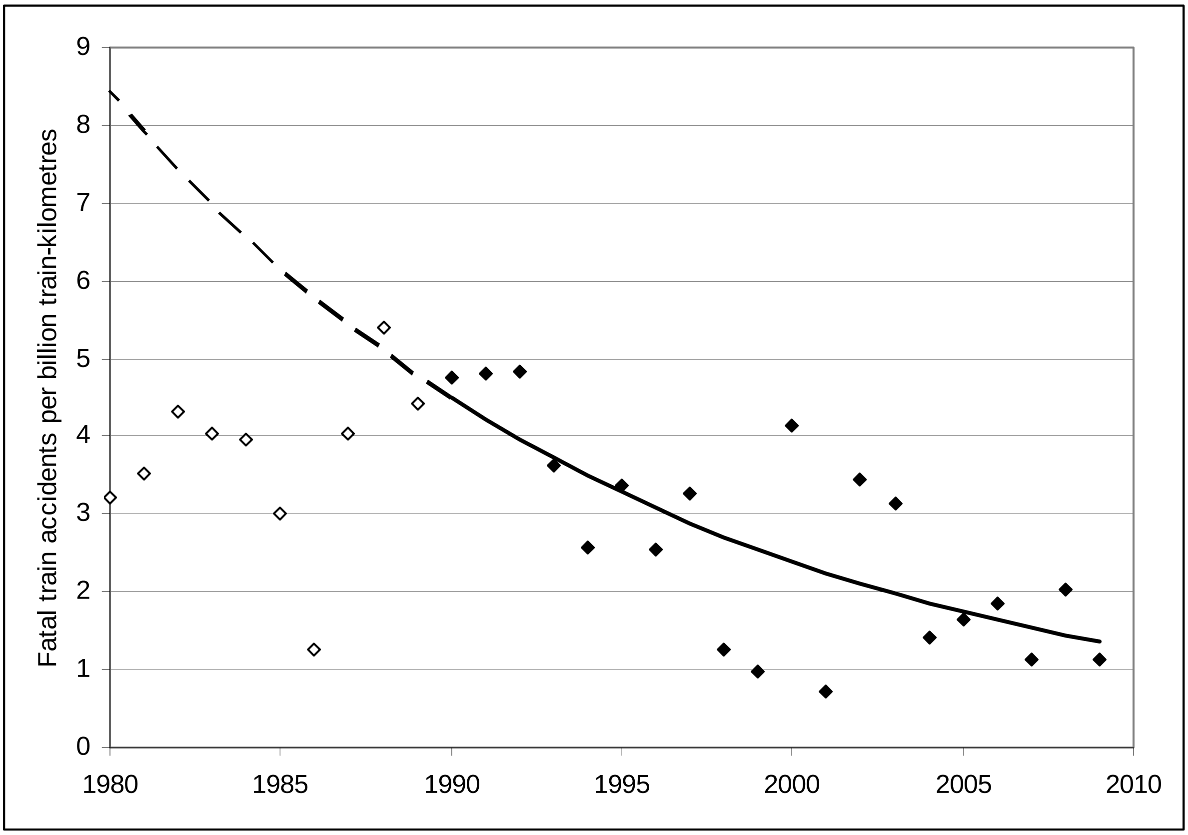
$\beta$ is a parameter measuring the long-term annual rate of change in accidents per train-kilometre.

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.

The principal results in this section are based on fitting model (1) to the annual data in Table 3 for 1990-2009, 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 1990-2009, 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 –6.3% per year, with a standard error of 1.2%, so it is statistically significantly different from zero. This trend is close to what the writer has separately found for Great Britain (–6.4% per year in 1967-2009; Evans 2010a) and for Japan (–6.1% per year in 1971-2006; Evans 2010b). The central estimate of the European accident rate in 2009 is 1.35 fatal train collisions and derailments per billion train-kilometres, which is a reduction of 70% on the corresponding rate of 4.50 in 1990. Combining these rates with the train-kilometres implies that the estimated mean numbers of train collisions and derailments were 6.0 in 2009 and 18.0 in 1990. Table 3 shows that the actual numbers of accidents in those years were 5 and 19 respectively.

The open data points on the left-hand side of Figure 2 are the recorded accidents per billion train-kilometres for 1980-1989, and the dashed line is the extrapolation backwards of the trend fitted to the 1990-2009 data. It can be seen that with the exception of 1988, all the 1980-1989 data points are below the extrapolated trend. This strongly supports the discussion in section 2 that the data for 1980-1989 are incomplete. The expected total number of accidents in 1980-1989 implied by the back extrapolated trend is 259; the recorded number is 149. This suggests that the number of missed accidents is of the order of 100. Further evidence in support of this order of magnitude is presented in section 6.1

**Figure 2: Fatal train accidents per billion train-kilometres: EU+NO+CH: 1980-2009**



### 4.2 Accident rates and trends by country

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 is enough data to carry out an analysis at the national level.

Table 4 gives the numbers of recorded fatal train collisions and derailments for each country of EU+NO+CH in five-year periods from 1980 to 2009. Five-year periods are adopted to avoid the presence of too many zeros. As noted in sections 2 and 4.1, for many countries the data for 1980-1989 are 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 4, the figures not used are shown in brackets; all other figures are used.

**Table 4: Fatal train collisions and derailments by country: 1980-2009**

| | 1980-1984 | 1985-1989 | 1990-1994 | 1995-1999 | 2000-2004 | 2004-2009 | 1990-2009 | 1980-2009 |
|---|---|---|---|---|---|---|---|---|
| EU+CH+NO | (76) | (73) | 81 | 45 | 53 | 34 | 213 | (362) |
| Germany (DE) | 7 | 11 | 9 | 9 | 4 | 0 | 22 | 40 |
| France (FR) | 4 | 7 | 8 | 0 | 3 | 1 | 12 | 23 |
| UK (UK) | 13 | 9 | 6 | 5 | 3 | 1 | 15 | 37 |
| Italy (IT) | (3) | (5) | 7 | 6 | 9 | 9 | 31 | (39) |
| Poland (PL) | (5) | (6) | 9 | 1 | 1 | 2 | 13 | (24) |
| Spain (ES) | (16) | (6) | 7 | 4 | 5 | 2 | 18 | (40) |
| Czech Republic (CZ) | (3) | (2) | 1 | 4 | 4 | 5 | 14 | (19) |
| Switzerland (CH) | (2) | (2) | 3 | 1 | 4 | 1 | 9 | (13) |
| Austria (AT) | (3) | (4) | 6 | 4 | 4 | 1 | 15 | (22) |
| Netherlands (NL) | 3 | 1 | 1 | 0 | 1 | 1 | 3 | 7 |
| Sweden (SE) | 5 | 2 | 1 | 0 | 0 | 0 | 1 | 8 |
| Romania (RO) | (0) | (0) | 1 | 3 | 1 | 2 | 7 | (7) |
| Hungary (HU) | (2) | (0) | 3 | 0 | 1 | 2 | 6 | (8) |
| Belgium (BE) | (1) | (2) | 1 | 1 | 3 | 1 | 6 | (9) |
| Denmark (DK) | (1) | (1) | 3 | 1 | 2 | 0 | 6 | (8) |
| Slovak Republic (SK) | (0) | (0) | 3 | 2 | 1 | 0 | 6 | (6) |
| Finland (FI) | (0) | (0) | 0 | 2 | 0 | 0 | 2 | (2) |
| Bulgaria (BG) | (0) | (9) | 2 | 0 | 1 | 0 | 3 | (12) |
| Portugal (PT) | (2) | (4) | 5 | 1 | 4 | 2 | 12 | (18) |
| Norway (NO) | 0 | 0 | 3 | 0 | 1 | 0 | 4 | 4 |
| Latvia (LV) | (0) | (0) | 0 | 0 | 0 | 2 | 2 | (2) |
| Slovenia (SI) | (1) | (0) | 0 | 0 | 0 | 0 | 0 | (1) |
| Greece (EL) | (3) | (2) | 1 | 0 | 0 | 2 | 3 | (8) |
| Lithuania (LT) | (0) | (0) | 0 | 0 | 1 | 0 | 1 | (1) |
| Ireland (IE) | 2 | 0 | 1 | 0 | 0 | 0 | 1 | 3 |
| Estonia (EE) | (0) | (0) | 0 | 0 | 0 | 0 | 0 | (0) |
| Luxembourg (LU) | (0) | (0) | 0 | 1 | 0 | 0 | 1 | (1) |

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.

A further qualification is that some countries have had so few accidents that their rates and trends cannot be estimated at all from these data. The minimum requirement is that a country should have at least two five-year periods with non-zero numbers of accidents. It will be seen from Table 4 that six countries do not meet this condition: Finland, 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 we adopt the same model (1) 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 102, made up of 42 from the seven countries each with six 5-year periods, and 60 from the remaining 15 countries each with four 5-year periods (counting “Others” as a single country for this purpose). Train-kilometres are given in Table 2.

To test whether the countries collectively have statistically significantly different accident rates and trends we fit different variants of model (1), 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. This implies that a separate version of model (1) should be fitted for each country.

**Table 5: Estimated mean fatal train accidents per billion train-kilometres in 2009 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 2009 (95% confidence limits in brackets) | Estimated annual rate of change in fatal accident rate over given period (95% confidence limits in brackets) |
|---|---|---|---|
| EU+NO+CH | 1990-2009 | 1.35 (1.00, 1.83) | –6.3% p.a. (–8.7%, –3.9%) |
| Germany | 1980-2009 | 0.62 (0.29, 1.30) | –5.3% p.a. (–9.1%, –1.6%) |
| France | 1980-2009 | 0.60 (0.22, 1.65) | –5.7% p.a. (–10.8%, –0.7%) |
| United Kingdom | 1980-2009 | 0.57 (0.23, 1.42) | –9.1% p.a. (–13.4%, –4.8%) |
| Italy | 1990-2009 | 5.17 (2.68, 9.97) | +1.4% p.a. (–4.9%, +7.7%) |
| Poland | 1990-2009 | 0.53 (0.10, 2.97) | –12.6% p.a. (–24.7%, –0.6%) |
| Spain | 1990-2009 | 2.13 (0.72, 6.29) | –7.9% p.a. (–16.5%, +0.6%) |
| Czech Republic | 1990-2009 | 8.02 (3.32, 19.4) | +6.7% p.a. (–3.0%, +16.3%) |
| Switzerland | 1990-2009 | 1.99 (0.51, 7.74) | –4.6% p.a. (–16.2%, +6.9%) |
| Austria | 1990-2009 | 1.97 (0.55, 6.98) | –9.4% p.a. (–19.1%, +0.2%) |
| Netherlands | 1980-2009 | 0.69 (0.11, 4.43) | –6.3% p.a. (–15.6%, +3.0%) |
| Sweden | 1980-2009 | 0.03 (0.00, 1.61) | –21.9% p.a. (–38.1%, –5.6%) |
| Romania | 1990-2009 | 4.36 (1.06, 17.9) | +3.1% p.a. (–10.1%, +16.3% |
| Hungary | 1990-2009 | 2.15 (0.40, 11.6) | –3.2% p.a. (–17.5%, +11.1%) |
| Belgium | 1990-2009 | 3.72 (0.84, 16.4) | +2.0% p.a. (–12.4%, +16.4%) |
| Denmark | 1990-2009 | 1.04 (0.11, 9.64) | –13.7% p.a. (–29.8%, +2.5%) |
| Slovak Republic | 1990-2009 | 1.01 (0.08, 13.3) | –13.7% p.a. (–31.7%, +4.3%) |
| Bulgaria | 1990-2009 | 0.76 (0.02, 29.1) | –12.9% p.a. (–38.2%, +12.4%) |
| Portugal | 1990-2009 | 9.94 (2.85, 34.6) | –3.8% p.a. (–14.2%, +6.5%) |
| Norway | 1980-2009 | 2.96 (0.44, 19.8) | –1.3% p.a. (–12.6%, +9.9%) |
| Greece | 1990-2009 | 15.12 (2.30, 99.4) | +7.1% p.a. (–14.4%, +28.6%) |
| Ireland | 1980-2009 | 0.17 (0.00, 40.6) | –19.0% p.a. (–41.6%, +3.7%) |
| Others combined* | 1990-2009 | 4.07 (1.01, 16.4) | +5.3% p.a. (–9.3%, +19.9%) |

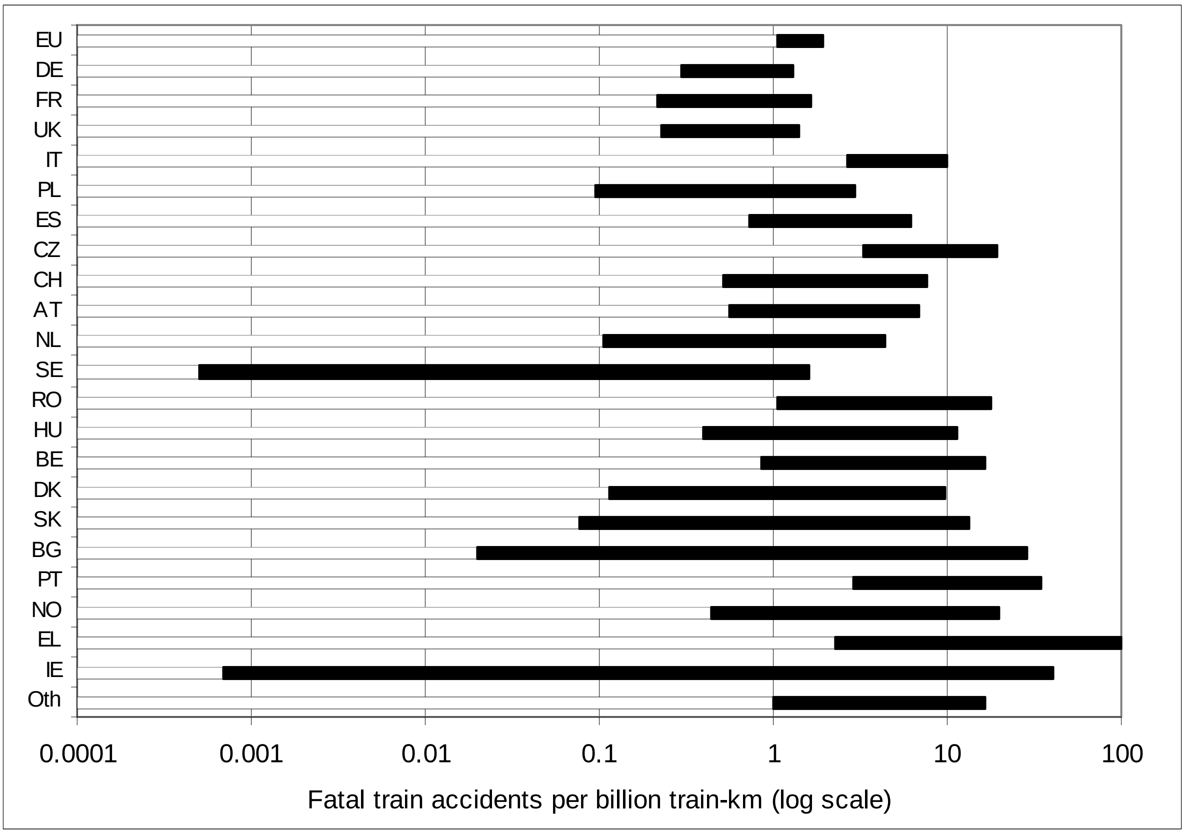
*Finland, Latvia, Slovenia, Lithuania, Estonia and Luxembourg

From the results of these models, Table 5 gives the estimated mean number of fatal accidents per billion train-kilometres in 2009 and the estimated annual rate of change for each country, each with its 95% confidence limits. The values for EU+NO+CH as a whole are taken from the analysis in section 4.1. Figure 3 plots the 95% confidence intervals for the mean accident rates in 2009 for each country on a logarithmic scale. Because of the form of the model, the central estimate is at the centre of these bars.

Some of the confidence intervals for the estimates of the mean fatal accidents in 2009 are very wide, stretching over several orders of magnitude, because of little data. The two countries with the widest confidence intervals and also the lowest central estimate of the mean accident rate are Sweden and Ireland. At the end of 2009 Sweden had suffered no fatal train collisions or derailments since 1990, and Ireland none since 1991. In the upper part of the table it is interesting that the three largest systems – those of Germany, France and the UK – all have almost the same estimated mean fatal accident rate in 2009 of 0.6 fatal accidents per billion train-kilometres, and that this is well below the Europe-wide figure of 1.35.

Most countries have central estimates of accident rates declining over time. Some have rates that are statistically significantly below zero, indicated by negative upper confidence limits for the trends in Table 5. 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 trend are negative.

**Figure 3: 95% confidence intervals for mean fatal train accident rates per billion train-km: 2009**




### 4.3 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 6 gives the numbers of accidents by broad cause and by decade for 1980-2009 for the seven countries for which the 1980s data are considered complete. Table 7 gives similar information by 5-year period for 1990-2009 for the remaining countries.

**Table 6: Number of fatal train collisions and derailments by broad cause: DE, FR, UK, NL, SE, NO and IE: 1980-2009**

| Broad cause | 1980-1989 | 1990-1999 | 2000-2009 | Total |
|---|---|---|---|---|
| Signal passed at danger | 18 | 15 | 4 | 37 |
| Overspeeding | 8 | 4 | 1 | 13 |
| Signalling or dispatching error | 10 | 3 | 3 | 16 |
| Other operational error | 8 | 4 | 0 | 12 |
| Rolling stock failure | 5 | 3 | 0 | 8 |
| Infrastructure, track or points failure | 7 | 5 | 4 | 16 |
| External to railway | 1 | 2 | 2 | 5 |
| Total excluding unknown | 57 | 36 | 14 | 107 |
| | | | | |
| Unknown | 7 | 7 | 1 | 15 |
| Total including unknown | 64 | 43 | 15 | 122 |

**Table 7: Number of fatal train collisions and derailments by broad cause: Rest of EU and CH: 1990-2009**

| Broad cause | 1990-1994 | 1995-1999 | 2000-2004 | 2005-2009 | Total |
|---|---|---|---|---|---|
| Signal passed at danger | 12 | 8 | 11 | 9 | 40 |
| Overspeeding | 4 | 5 | 2 | 4 | 15 |
| Signalling or dispatching error | 7 | 2 | 5 | 4 | 18 |
| Other operational error | 3 | 1 | 2 | 1 | 7 |
| Rolling stock failure | 1 | 0 | 3 | 4 | 8 |
| Infrastructure, track or points failure | 1 | 3 | 4 | 5 | 13 |
| External to railway | 2 | 1 | 4 | 0 | 7 |
| Total excluding unknown | 30 | 20 | 31 | 27 | 108 |
| | | | | | |
| Unknown | 22 | 11 | 10 | 4 | 47 |
| Total including unknown | 52 | 31 | 41 | 31 | 155 |

The accident causes in Tables 6 and 7 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 $\chi^2$ 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 writer has also found no evidence that the distribution of accident causes differs between the better and worse performing 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 6 and 7 is signals passed at danger, accounting for 77 accidents of the 215 with known causes (36%). The second most common cause is signalling or dispatching errors, accounting for 34 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.

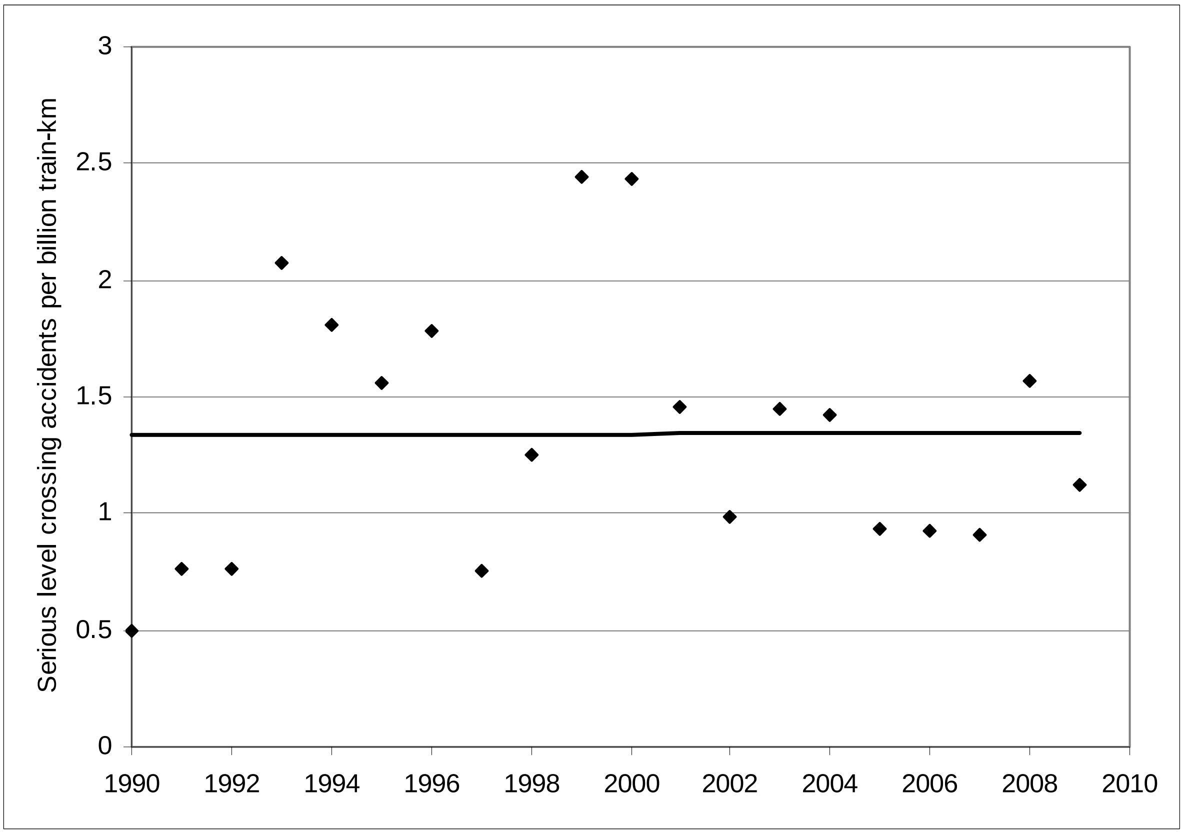
## 5 SERIOUS LEVEL CROSSING ACCIDENTS

Accidents at level crossings are significant. Fatal level crossing accidents are more numerous and account for more fatalities than fatal train collisions and derailments. The CSIs for 2006 to 2008 record 1,306 fatalities in level crossing accidents. Most level crossing fatalities occur in single-fatality accidents, so there must be three or four hundred fatal level-crossing accidents per year, but there is apparently no published series. It would not have been possible to assemble data on all fatal level crossing accidents in the present project, partly because many are not especially newsworthy and not recorded in the press, and partly because the volume of accidents would have been 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 "serious" level crossing accidents.

The right-hand-columns of Table 3 above give the recorded numbers of serious level crossing accidents and the fatalities in these for each year from 1980 to 2009. 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 serious level crossing accidents recorded in Table 3 for 2006-2008 is 58, which is only 4.4% of the CSI total mentioned above. This indicates that the serious level crossing accidents in Table 3 are only a small fraction of all level crossing accidents, even smaller than 4.4% because the serious accidents in Table 3 should include all the high-fatality level crossing accidents.

**Figure 4: Serious level crossing accidents per billion train-km: EU+NO+CH: 1990-2009**




The same form of model (1) has been fitted to the 1990-2009 serious level crossing accidents per billion train-kilometres in Table 3 as was fitted to the fatal collisions and derailments in section 4.1. The fitted trend is shown in Figure 4, together with the 20 data points. The curve is almost flat. The central estimate of the rate of change in the accident rate is +0.03% per year, with a standard error of 1.64% per year. Therefore the slope is far from 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 no reduction in the rate of serious level crossing accident rate in the last 20 years. It is not possible to say whether the absence of improvement also applies to the much larger number of less serious fatal level crossing accidents, because there are no comprehensive data, but it is plausible that they have shown no improvement either.

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 110 fatal level crossing accidents in 1990-2009 in Table 3, 83 have known causes, and of these 83, 82 were errors or violations by road users. The one accident down to the railway was caused by failed warning lights. 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 are broadly similar to countermeasures for road accidents, particularly education and enforcement. The engineering and maintenance of level crossings is regarded largely as the responsibility of the railways, though sometimes shared with the highway authority.

## 6 ACCIDENT CONSEQUENCES

### 6.1 Fatal train collisions and derailments (FCDs)

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 8 shows the distribution of fatalities in accidents for 1980-1989 and 1990-2009. Table 8 shows that there were 12 collisions and derailments with 30 or more fatalities between 1980 and 2009. Table 9 identifies these, and also includes the two level crossing accidents with 30 or more fatalities referred to in section 6.2. The most serious accident in the whole period had 101 fatalities.

**Table 8: Observed numbers of train collisions and derailments with given number of fatalities: EU+NO+CH: 1980-2009**

| Number of fatalities | 1980-1989 | 1990-2009 | 1980-2009 |
|---|---|---|---|
| 1 | 40 | 91 | 131 |
| 2 | 23 | 42 | 65 |
| 3 | 20 | 20 | 40 |
| 4 | 11 | 12 | 23 |
| 5 | 11 | 10 | 21 |
| 6 | 8 | 10 | 18 |
| 7 | 4 | 3 | 7 |
| 8 | 5 | 5 | 10 |
| 9 | 5 | 2 | 7 |
| 10 | 3 | 3 | 6 |
| 11 | 3 | 1 | 4 |
| 12 | 1 | 2 | 3 |
| 13 | 2 | | 2 |
| 14 | 1 | | 1 |
| 16 | 1 | 2 | 3 |
| 17 | | 2 | 2 |
| 18 | 1 | 1 | 2 |
| 19 | 1 | 3 | 4 |
| 25 | 1 | | 1 |
| ≥30 | 8 | 4 | 12 |
| Total 1 to 3 | 83 | 153 | 236 |
| Total 4 or more | 66 | 60 | 126 |
| Total accidents | 149 | 213 | 362 |
| Total fatalities | 941 | 873 | 1814 |

**Table 9: Accidents with 30 or more fatalities: EU+NO+CH: 1980-2009**

| Date | Cou-ntry | Location | Type of accident | Brief description | Fatal-ities |
|---|---|---|---|---|---|
| 19/08/1980 | PL | Otłoczyn | FCD | Passenger/freight train collision | 67 |
| 21/11/1980 | IT | Lamezia Terme | FCD | Three train collision | 30 |
| 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 |

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

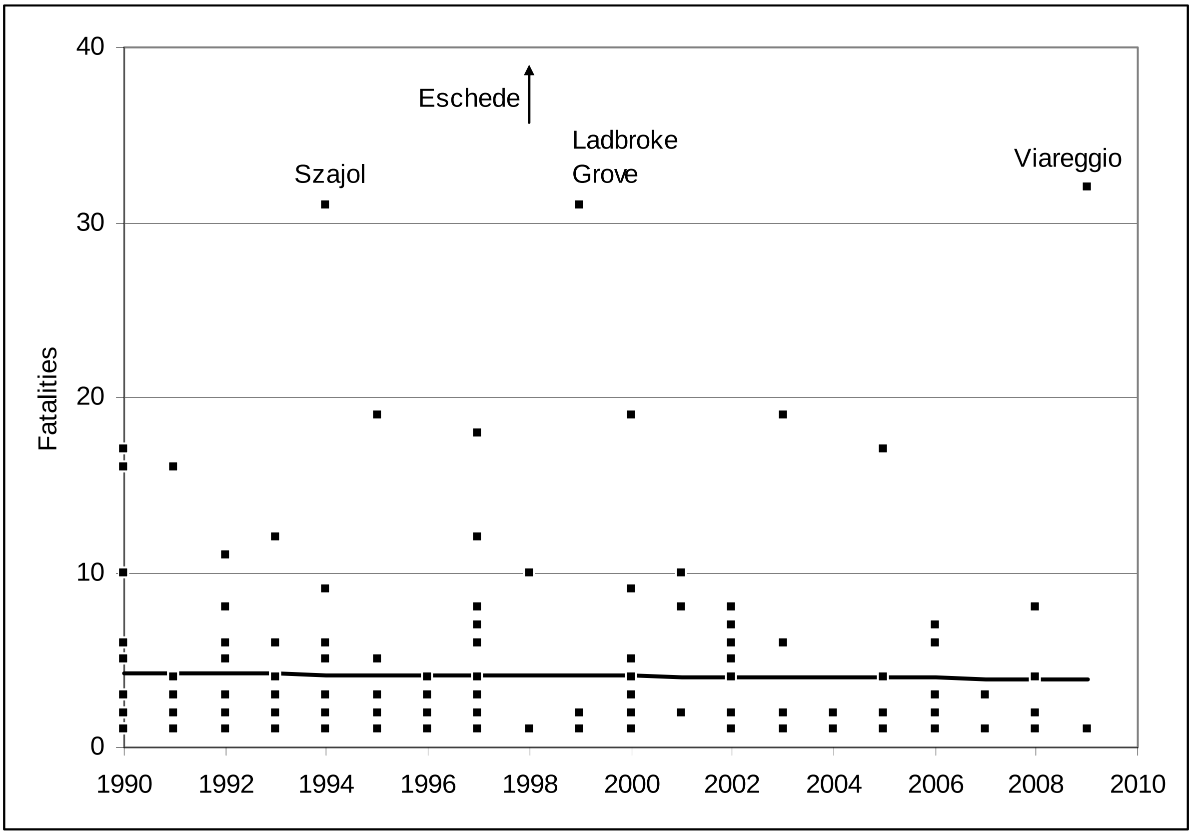
As noted previously, the accidents in the 1980s are almost certainly under-recorded. Furthermore, given the data sources it is to be expected that the under-recording is selective. It is unlikely that the data sources would miss any serious multiple-fatality accident, because these are so newsworthy; 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 6.32 in 1980-1989 and 4.10 in 1990-2009. 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 sizeable 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 8. If we assume (a) that the data for 1990-2009 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 1990-2009, the estimated number of 1-fatality to 3-fatality accidents in the 1980s would be 66*153/60 = 168. The observed number is 83, which gives a shortfall of 85. This is somewhat smaller than the estimate of the shortfall of 110 made by back extrapolation of the trend in section 4.1, but it is of the same order of magnitude. Thus we have two separate estimates that the number of missed accidents in the 1980s is of the order of 100.

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, we confine the analysis to the data for 1990-2009. Figure 5 plots the number of fatalities in each of the 213 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 4.10. The shape of the data in Figure 5 and the mean of 4.10 fatalities per accident are both close to those found by the writer in a similar analysis for Great Britain (Evans 2010a).

The combination of the estimated mean number of accidents per year in 2009 of 6.02 (section 4.1) with 4.10 fatalities per accident implies an estimated mean of 24.6 fatalities per year in Europe in train collisions and derailments in 2009. Table 3 shows that the actual number was 36. The actual number is high because, as shown in Table 9 and Figure 5, there was a severe accident in 2009 with 32 fatalities.

**Figure 5: Fatalities in train collisions and derailments: EU+NO+CH: 1990-2009**




### 6.2 High-consequence accidents and *FN*-curves

As noted in section 2, the data sought included 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 10 gives the distribution of fatalities in each type of accident with four or more fatalities in 1980-2009. 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.

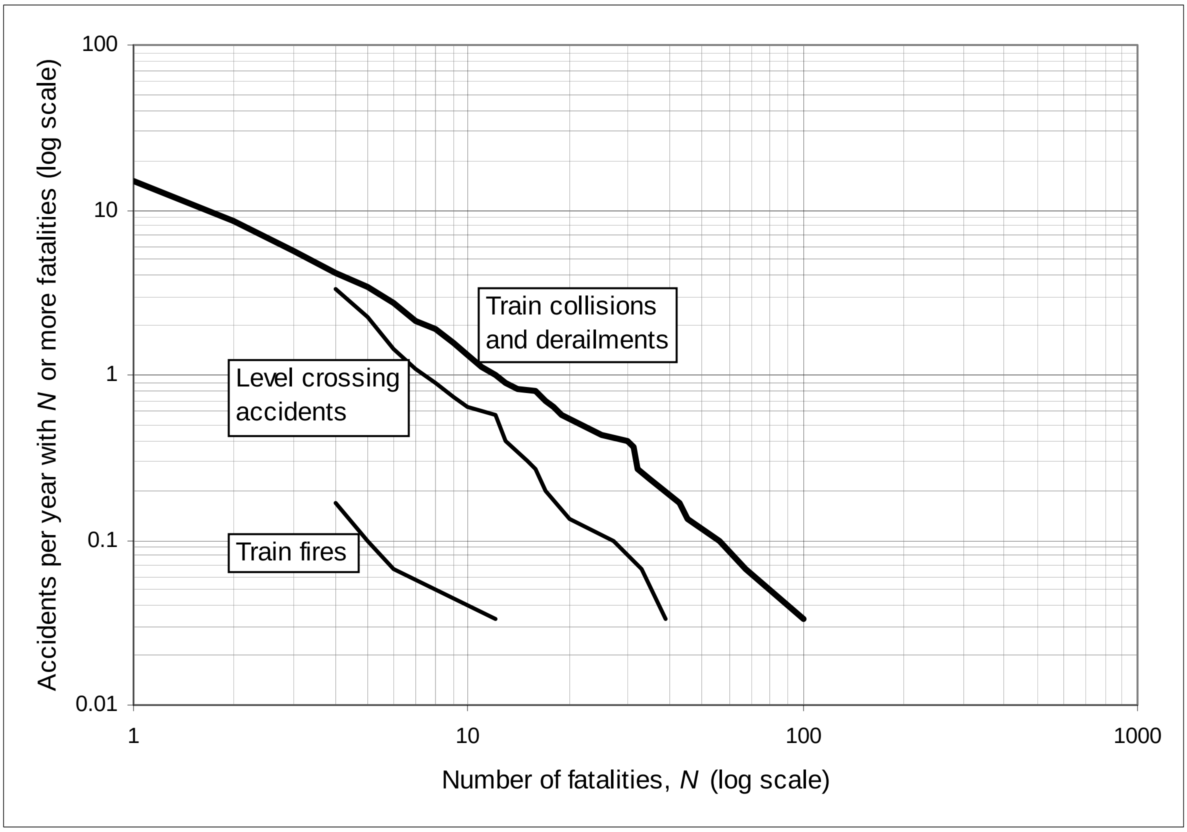
A common form of illustration of accident size distributions are *FN*-curves. These plot the frequency *F* of accidents with *N* or more fatalities against *N*. *FN*-graphs usually have logarithmic scales. Figure 6 plots the empirical *FN*-curves for 1980-2009 from the data in Table 10 for train collisions 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 6.1.

The *FN*-curves in Figure 6 are based on accident frequencies averaged over the 30-year period 1980-2009. Notional *FN*-curves for 2009 could be estimated by combining the shapes in Figure 6 with the estimated accident frequencies in 2009. This would have the effect of lowering the *FN*-curve for train collisions and derailments to about 40% 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 not fall at all, because, as shown in Figure 4, the frequency of serious level crossing accidents has not fallen. That would bring the 2009 *FN*-curves closer together. It demonstrates that level crossings, as well as train collisions and derailments, are an important source of serious accidents.

**Table 10: Numbers of accidents with four or more fatalities: EU+NO+CH: 1980-2009**

| Number of fatalities | Train collisions and derailments | Level crossing accidents | Train fires | Persons struck by rolling stock | Total |
|---|---|---|---|---|---|
| **4** | 23 | 33 | 2 | 4 | 62 |
| **5** | 21 | 25 | 1 | 1 | 48 |
| **6** | 18 | 10 | | 2 | 30 |
| **7** | 7 | 6 | | 1 | 14 |
| **8** | 10 | 5 | | | 15 |
| **9** | 7 | 3 | 1 | | 11 |
| **10** | 6 | 1 | | | 7 |
| **11** | 4 | 1 | | | 5 |
| **12** | 3 | 5 | 1 | | 9 |
| **13** | 2 | 3 | | | 5 |
| **14** | 1 | | | | 1 |
| **15** | | 1 | | | 1 |
| **16** | 3 | 2 | | | 5 |
| **17** | 2 | 2 | | | 4 |
| **18** | 2 | | | | 2 |
| **19** | 4 | | | | 4 |
| **20** | | 1 | | | 1 |
| **25** | 1 | | | | 1 |
| **27** | | 1 | | | 1 |
| **≥30** | 12 | 2 | | | 14 |
| **Total ≥4** | 126 | 101 | 5 | 8 | 240 |

**Figure 6: Empirical FN-curves for train accidents: EU+NO+CH: 1980-2009**



## 7 CONCLUSIONS

In the past the principal obstacle to a comprehensive analysis of fatal train collisions and derailments at the European level has been the absence of data. This paper uses a new set of data for the European Union, together with Norway and Switzerland, assembled partly under the auspices of the European Railway Agency and partly on the author's own account. The data are based on a mixture of press reports, scrutiny by the National Investigation Bodies, and other sources. The evidence is that the data are complete, or almost complete, for 1990-2009, but that there is a shortfall of about 100 fatal train collisions and derailments in 1980-1989. However, the 1980s' data are assumed complete for seven countries and for accidents with four or more fatalities. Exposure to accidents is measured by train-kilometres, which are based on UIC and ERA sources, scrutinised and moderated where necessary by the author.

The estimated overall European trend in fatal train collisions and derailments per train-kilometre is –6.3% per year from 1990 to 2009, with a 95% confidence interval of –8.7% to –3.9%. The estimated accident rate in 2009 is 1.35 fatal collisions or derailments per billion train-kilometres with a 95% confidence interval of 1.00 to 1.83. There are assumed to have been 4.452 billion train-kilometres in 2009, so the estimated mean number of fatal accidents in 2009 is 6.0. The overall number of fatalities per fatal accident in 1990-2009 is 4.10, with no apparent long term change over time. The combination of 6.0 fatal accidents in 2009 with 4.10 fatalities per accident gives an estimate mean of 24.6 fatalities per year in train collisions and derailments in 2009.

There are statistically significant differences in both 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 countries with the lowest central estimates of the accident rate in 2009 are Sweden and Ireland although both have very wide confidence limits. The central estimates of the accident rates in 2009 of the three largest systems – Germany, France, and the UK – are all about the same, 0.6 accidents per billion train-kilometres. This figure is well below the overall European figure of 1.35.

Although the fatal train collision and derailment rates have fallen substantially over the long term, the distribution of broad accident causes appears to have remained unchanged. In other words, the safety improvement appears to have been across the board, and not focused on any specific cause. The most frequent cause is signals passed at danger; accounting for 36% of the total; the second most frequent cause is signalling or dispatching error, accounting for 16%.

In contrast to fatal train collisions and derailments, the rate per train-kilometre of serious accidents at level crossings remained unchanged in 1990-2009. Thus level crossing accidents represent an increasing proportion of serious accidents.

## ACKNOWLEDGEMENTS

The data for 1990-2007 were assembled in a contract for the European Railway Agency (ERA), which has made public the results. Lloyd's Register Rail were co-contractors. Many of the National Investigation Bodies scrutinised the data for completeness and accuracy. Five libraries have been helpful: the British Library, Imperial College, the National Railway Museum; the Science Museum; and University College. Former Imperial College and University College student Simon Blainey in his MSc dissertation first investigated the feasibility of using press reports to identify train accidents. The author's post is supported by The Lloyd's Register Educational Trust. The author is grateful to all, but is alone responsible for the contents of this paper.

## REFERENCES

Andersen, Terje (1999). Human Reliability and Railway Safety. !6th ESReDA seminar on Safety and Reliability in Transport.

Bäckman, Johan (2002) Railway Safety: Risks and Economics. (PhD dissertation). ISSN 1615-0216, Royal Institute of Technology, Stockholm.

European Railway Agency (2010). Railway safety performance in the European Union 2010. ERA, Valenciennes, France.

Evans, A W (2007). Rail safety and rail privatisation in Britain. Accident Analysis and Prevention **39**, 510-523.

Evans, A W (2010a). Fatal train accidents on Britain's main line railways: end of 2009 analysis. Unpublished working paper, Imperial College London.
http://www.cts.cv.ic.ac.uk/html/ResearchActivities/publicationDetails.asp?PublicationID=1330

Evans, A W (2010b). Rail safety and rail privatisation in Japan. Accident Analysis and Prevention **42**, 1296-1301.

Preuss, Erich (1995). Eisenbahnunfälle in Europa: Tatsachen, Berichte, Protokolle. (Railway accidents in Europe: facts, accounts, records.) Transpress, Berlin.

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)

Sando, Svein (2003) Jernbaneulykker i Norge: downloaded 26/09/2009

Semmens, Peter (1994). Railway Disasters of the World. Patrick Stephens Ltd, Sparkford, Somerset, UK

**LIST OF ABBREVIATIONS**

| | |
|---|---|
| AFP | Agence France Presse |
| AP | Associated Press |
| CSI | Common Safety Indicator |
| ERA | European Railway Agency |
| EU | European Union |
| EU+NO+CH | Countries of the EU, Norway and Switzerland |
| FCD | Fatal train collisions and derailments |
| LC | Level crossing |
| MS | Member state (of EU) |
| NIB | National accident Investigation Body |
| NSA | National Safety Authority |
| UIC | International Union of Railways |
| UPI | United Press International |

## APPENDIX 1: DATA SOURCES USED

**News Agency reports accessed via Nexis® UK**
Agence France Presse (AFP); ANSA English Media Service (Italy); Associated Press (AP); Athens News Agency; Baltic News Service; BBC summary of world broadcasts (UK); CTK Czech News Agency; Deutsche Presse Agentur; MTI Hungarian News Agency; PAP News Wire (Poland); Press Association (UK); Sofia News Agency; United Press International (UPI); TASS News Agency (Russia); Xinhua General News Service.

**Newspaper reports accessed via Nexis® UK**
Chemical Week; Les Echos (France); Frankfurter Allgemeine Zeitung (Germany); Globe and Mail (Canada); Guardian (UK); Independent (UK); Le Monde (France); New York Times (USA); Telegraph (Australia); Times (UK); Toronto Star (Canada); Washington Post (USA); Le Vif/L'Express (Belgium); World Loss Report.

**National Investigation Body (NIB) reports**

**National Sources, particularly for the 1980s**
Germany: Preuss (1995)
France: *La Vie du Rail* (weekly magazine)
UK: Evans (2007); also The Railways Archive (http://www.railwaysarchive.co.uk)
Netherlands: (http://www.zero-meridean.nl/overzicht_spoorweg_ongevallen.php), last accessed 11/06/2010.
Sweden: Bäckman (2002).
Norway: Sando (2003)
Ireland: (http://en.wikipedia.org/wiki/Railway_accidents_in_Ireland), last accessed 10/06/2010

**Other principal sources**
*Today's Railways/ Today's Railways Europe* (monthly magazine from 1994)
Times (UK) Digital Archive (to 1985)
Andersen (1999)
Semmens (1994)
Wikipedia

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

As noted in sections 4.1 and 4.2, the assumed basic model (1) is that the number of accidents in period $t$ is Poisson-distributed with mean $\lambda_t$ given by

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

where $k_t$ = train-kilometres in period $t$, $\alpha$ is a scale parameter determining the general accident level, and $\beta$ 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 2009, $\alpha$ is the mean accident rate in 2009. If $\beta = 0$, there is no long-term change in the mean accident rate.

As noted in section 4.2, if the fatal train collisions and derailments for each country are grouped into 5-year periods, the data for fitting the model consist of 102 accident counts comprising six 5-year counts for seven countries and 4 five-year counts for 20 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 102 accident counts, each with different assumptions about the values of the parameters $\alpha$ and $\beta$. The model variants are the following

(a) Each country is assumed to have the same mean $\alpha$ in 2009 and no trend ($\beta = 0$).

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

Table 11 gives statistical results from fitting each of these model variants. The number of degrees of freedom is the number of observations (102) 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 $\chi^2$ distribution with the given number of degrees of freedom. The mean of the $\chi^2$ 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 $\chi^2$ distribution with degrees of freedom equal to the difference in degrees of freedom between the two variants.

**Table 11: Statistical results for variants of model for means and trends in accident rates: Fatal train collisions and derailments by country: EU+NO+CH**

| Variant of model | Degrees of freedom | Scaled deviance |
|---|---|---|
| (a) Common mean $\alpha$; no trend ($\beta = 0$) | 101 | 238.4 |
| (b) Common mean $\alpha$; common trend $\beta$ | 100 | 223.3 |
| (c) Different means $\alpha_i$; no trend ($\beta = 0$) | 80 | 157.8 |
| (d) Different means $\alpha_i$; common trend $\beta$ | 79 | 113.6 |
| (e) Different means $\alpha_i$; different trends $\beta_i$ | 58 | 78.8 |

The important comparisons in Table 11 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 109.7, to be tested against $\chi^2$ with 21 degrees of freedom, whose upper 5% point is 32.7. 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 34.8, also to be tested against $\chi^2$ with 21 degrees of freedom. This reduction is also significant at 5%. Thus we accept model variant (e). The estimates of $\alpha_i$ and $\beta_i$ for each country and their 95% confidence limits are given in Table 5.

Finally, it may be noted that with a scaled deviance of 78.8 and 58 degrees of freedom in variant (e), the data are somewhat more dispersed than would be expected if they really did have a Poisson distribution. That might suggest using the Negative Binomial distribution in place of the Poisson. However, we have not pursued that, partly because of the simplicity of the Poisson, and partly because the Negative Binomial would require one more parameter for each country, leaving only one degree of freedom for many countries, and making the model over-parameterised.