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Transport fatal accidents and FN-curves: 1967-2001

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Transport fatal accidents and FN-curves: 1967-2001

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This paper responds to a research brief to provide transport fatal accident data and empirically based FN-curves. The aims are first to compare the frequencies and severities of fatal railway accidents with those of road and air transport, and secondly to present FN-curves showing the severities and frequencies of fatal main line train accidents, separately identifying those which are preventable by Automatic Train Protection (ATP). The paper presents FN-graphs for both these purposes. The paper also considers the use of criteria for FN-curves. The construction of empirical FN-curves requires a large amount of fatal accident data. The paper therefore assembles and presents data for 1967-2001 on all British transport fatal accidents with 10 or more fatalities on all modes; all British fatal main line train derailments, collisions and overruns; and all main line train accidents with 20 or more fatalities in the fifteen countries of the present European Union.

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CONTENTS

1. INTRODUCTION

This paper responds to a research brief from the Health and Safety Executive to provide fatal accident data and empirically based FN-curves for two purposes. These are:

(1) to compare the frequencies and severities of fatal railway accidents with those of road and air transport; and

(2) to show the frequencies and severities of fatal main line train accidents, separately identifying those that are preventable by Automatic Train Protection (ATP).

Following this introduction, the paper is in four sections.

Section 2 reviews the properties of FN-curves, considers how they are constructed, and discusses tolerability criteria for FN-curves.

Section 3 derives and compares empirical FN-curves for road, rail and air transport. The comparisons are based on accident data for the 33 years 1969-2001 for road transport and the 35 years 1967-2001 for rail and air transport. The paper discusses data sources, presents the accident data, and calculates and presents the FN-curves. There are no obvious criteria to judge the tolerability of these curves.

Section 4 considers FN-curves for fatal train derailments, collisions and overruns on the national railway system of Great Britain, again based on empirical accident data for 1967-2001. The number of British high-fatality accidents (with 20 or more fatalities) in this period was small, so the detail at the high-fatality end of the accident size distribution is fleshed out by splicing other European Union data to the British data on high-fatality railway accidents for the same period.

The FN-curves for train accidents in 1967-2001, for train accidents in 2001, for ATP preventable accidents in 2001, and for post TPWS/TPWS+ ATP-preventable accidents are all assumed to be parallel to each other on the FN-graph. The broad justification for these assumptions is that the shape of an FN-curve determines the mean number of fatalities per accident, and this mean appears to be have been roughly constant for train accidents over the long term, and is also not significantly different between ATP-preventable and non-ATP-preventable accidents. However, the frequency of fatal train accidents has fallen over the long term, and is different for different types of accident. The overall frequency of fatal accidents is represented on an FN-graph by the intercept of the FN-curve with vertical axis. Therefore the different FN-curves for train accidents are parallel on the FN-graph with different intercepts.

Section 4 concludes with a comparison of the FN-curve for train accidents derived in this paper with the published FN-curve for Railway Safety's Safety Risk Model.

Section 5 presents estimated FN-curves for 2001 for fatal road accidents, all fatal rail accidents, and ATP-preventable accidents after the installation of TPWS and TPWS+. The FN-graph also shows a selection of FN-criteria. These criteria include the so-called 'Canvey line', based on tolerability judgements made after the HSE's the studies of Canvey Island in l978-1981, the more recent criterion point mentioned in HSE's *Reducing risks, protecting people*, which is one order of magnitude more stringent, and the criterion line adopted in the Netherlands for hazardous installations, which is still more stringent. All these criteria were developed primarily for the purpose of judging the tolerability of the risk from single hazardous sites such as chemical works. No FN-criteria have been proposed for whole industries or transport systems at the national level. Because the only extant criteria refer to single industrial sites rather than whole national industries or systems, no conclusions can be drawn from the relative positions of the FN-curves and the criterion lines or points.

The construction of empirical FN-curves requires a large amount of fatal accident data. For the sake of transparency and for future reference, much of the detailed data used in the paper are presented in appendix tables. These tables include transport accidents with 10 or more fatalities on all modes in 1967-2001 (except for roads in 1967-1968); all fatal train derailments, collisions and overruns on the British main line railway system in 1967-2001, and all main line train accidents with 20 or more fatalities in the fifteen countries of the present European Union in 1967-2001.

2. PROPERTIES OF FN-CURVES

2.1 What are FN-curves?

FN-curves are a graphical presentation of information about the frequency of fatal accidents in a system and the distribution of the numbers of fatalities in such accidents. They plot the frequency $F(N)$ of accidents with N or more fatalities, where N ranges upward from 1 to the maximum possible number of fatalities in the system. Values of F for high values of N are often of particular political interest, because these are the frequencies of high-fatality accidents. Because the values of both F and N sometimes range across several orders of magnitude, FN-graphs are usually drawn with logarithmic scales.

The difference between the frequency of accidents with N or more fatalities, $F(N)$, and that with N+1 or more, $F(N+1)$, is the frequency of accidents with exactly N fatalities, usually represented by $f(N)$, with lower-case f. Because $f(N)$ must be non-negative, it follows that $F(N) \geq F(N+1)$ for all N, so that FN-curves never rise from left to right, but are always falling or flat. The lower an FN-curve is located on the FN-graph, the safer is the system it represents, because lower FN-curves represent lower frequencies of fatal accidents than higher curves.

The value $F(1)$ is the frequency of accidents with 1 or more fatalities, or in other words the overall frequency of fatal accidents. This is the left-hand point on FN-curves, where the curve meets the vertical axis (usually located at $N = 1$ with logarithmic scales). Parallel FN-curves with different intercepts on the vertical axis represent the same distribution of fatalities in accidents, but with different overall accident frequencies $F(1)$.

As noted above, it is possible to deduce the frequency of accidents with exactly N fatalities, $f(N)$, from the $F(N)$'s, and conversely, it is possible to calculate the $F(N)$'s from the $f(N)$'s by summing the $f(N)$'s upward from N. Indeed, $F(N)$-curves are usually constructed from information on the $f(N)$'s. We can write $f(N)$ as $F(1)p(N)$ where $p(N)$ is the probability that an accident has exactly N fatalities. It is straightforward to use these $p(N)$'s to calculate standard statistical quantities such as the mean and standard deviation of the number of fatalities per fatal accident. Thus every FN-curve has implicit for the system it represents the overall accident frequency $F(1)$, the probability distribution of fatalities in accidents $p(N)$, the mean and standard deviation of number of fatalities per accident, and the mean number of fatalities per year.

2.2 Construction of FN-curves

There are two general methods for constructing FN-curves, as there are for constructing frequency distributions. The first is to calculate the FN-curve directly from empirical frequency data on past accidents; the second is to develop and use a probability model to estimate the frequencies. There is a spectrum between these extremes, and most practical methods involve a mixture of empirical data and modelling. The method used in this paper is primarily the analysis of empirical data, though some assumptions and modelling results are used at critical points, as we shall see.

The data requirements for the empirical estimation of FN-curves or frequency distributions are demanding. The usual basic data collected in regular statistical publications, such as numbers of fatalities and numbers of fatal accidents, are insufficient. One needs to know exactly how many fatalities there were in every accident in a specified period of time. Furthermore, because we may require detail at the low-frequency high-consequence end of the fatality distribution, we may need to consider long periods of time in order to assemble enough data for sensible analysis.

This paper builds on previous work by the author which assembled much of the required data, both across the transport modes (Evans, 1994, 1995) and within railways for train accidents on the national railway system (Evans, 2000, 2002a). The data and further details on sources are given below.

2.3 Risk tolerability criteria and FN-curves

FN-curves themselves are simply a means of presenting descriptive information about fatal accident frequencies and fatality distributions. In this respect they are similar to histograms, and indeed present the same information as histograms in a different way. Most of this paper treats the data and FN-curves descriptively.

Nevertheless, once one has produced an FN-curve, what is one to do with it? In particular, is it possible to invoke criteria by which to decide whether the risks in the system represented by the FN-curve are tolerable or not? Such criteria are sometimes called 'societal risk criteria', but this is not a helpful label, and we do not use it in this paper.

The most obvious and tempting type of criterion is a line on the FN-graph. If a system's FN-curve lies wholly below the criterion line, the system is regarded as tolerable, but if any part of the FN-curve crosses the criterion line, the system is regarded as intolerable. Safety measures to lower the FN-curve may then be required.

FN-criterion lines have been used in various contexts in several countries for about three decades. They were reviewed for the HSE by Ball and Floyd (1998) under the title *Societal Risks*. The HSE itself has been cautious about recommending them, rightly in my view. Nevertheless, the HSE's publication *Reducing risk, protecting people* (R2P2) (HSE, 2001, paragraph 136) does cautiously recommend at least an FN-criterion point, if not a line, for single major hazardous industrial sites.

The R2P2 criterion point is that accidents causing 50 or more fatalities should not have a frequency greater in 1 in 5,000 per year. This point is one order of magnitude more stringent than an earlier criterion point derived by the HSE from their analysis of the Canvey Island industrial complex in the late 1970s and early 1980s. The 'Canvey point' is that the frequency of accidents causing 500 or more fatalities should not have a frequency greater than 1 in 5,000 per year. This point is shown in R2P2's predecessor *The tolerability of risk from nuclear power stations* (HSE, 1992, Figure D1), where it is extended to the whole fatality range by drawing the line through it with a slope of −1. As indicated in point (3) below, the slope of −1 has special significance in FN-criterion lines, though this appears to have arisen from a misunderstanding. Both the 'R2P2 point' and the 'Canvey line' are shown in Figure 4 in section 5, together with a criterion line from the Netherlands.

The present writer (in Evans and Verlander, 1997) has considered FN-criterion lines in some depth and considers them seriously flawed. The objections to them are:

(1) FN-criterion lines were conceived as an analogy to individual risk tolerability criteria. The justification for individual risk criteria is essentially equity: it is unfair to impose too high risks on particular individuals, whatever the benefits may be. However, there is no corresponding equity argument for accidents as distinct from individuals, and therefore the analogy is false.

(2) Even if limits to the tolerable frequencies of accidents of different sizes were desirable, they would need to be based on clear and preferably empirically derived criteria. There are at present no such criteria.

(3) Even if such criteria could be derived, FN-criterion lines are a technically incorrect method of implementing them. This is because they do not meet the requirements for consistency in decision making under uncertainty. As noted above, FN-curves represent the probability

distribution of fatalities in accidents, so that judgements about the tolerability of FN-curves are judgements about probability distributions. The literature on decision making under uncertainty (for example, Lindley 1985) shows that in order to achieve consistency, the form of the criterion quantity for such decisions must be the (statistically) expected value of some function, say $g(N)$, of the uncertain variable, in this case the number of fatalities N. In other words, the function used to judge tolerability must be of the form $F(1)\Sigma g(N)p(N)$. The choice of $g(N)$ is entirely for the decision maker. For example, if $g(N)$ were set equal simply to N, the criterion quantity would be $F(1)\Sigma Np(N)$, which is the (statistically) expected number of fatalities per year. Such a criterion would be 'accident size neutral', because it would make no difference whether a given expected number of fatalities per year arose from a high frequency of small accidents or a lower frequency of larger accidents. On the other hand, if the decision maker wished to give relatively more weight to fatalities in large accidents, $g(N)$ could be set to some function such as N^x, where x is a power greater than 1. Some people appear to believe that FN-criterion lines with a slope of $-x$ (with logarithmic scales) are simply a graphical means of representing the expected value criterion above, and that FN-criterion lines with a slope of -1 represent the 'accident size neutral' criterion. This belief is incorrect, except in extremely restricted circumstances. Nevertheless, this appears to be why many criterion lines were chosen to have a slope of -1.

3. FATAL ROAD, RAIL AND AVIATION ACCIDENTS

3.1 Accident data for 1967-2001

This section derives and presents empirical FN-curves for road, rail and aviation accidents. The data for rail and aviation accidents cover the 35 years from 1967 to 2001; the data for road accidents cover the 33 years from 1969 to 2001. The year 1967 is the starting year that the writer has usually come to adopt for long-term rail accident analysis, and it is natural to adopt the same year for aviation. The year 1969 is the first year for which full information on the distribution of fatalities in road accidents is available. The data cover all the fatal accidents on each mode from all causes. There is no obvious basis for comparing subsets of accidents.

Appendix Table 7 gives the distributions of numbers of fatalities in all fatal accidents on all three modes for the periods given. Tables 1 and 2 in section 3.2 give a summary of this information. Appendix Tables 8 and 9 give individual details of all transport accidents with 10 or more fatalities. The starting points for assembling this information were the writer's previous reviews of major accidents (Evans 1994 and 1995), to which later information has been added from official sources to complete the data to the end of 2001.

The primary source for road accident data is *Road Accidents Great Britain* (DfT, annual), which includes a table (currently Table 21) on the distribution of fatalities in accidents. This is supplemented by accounts of major accidents from Evans (1995), and by newspaper reports of road accidents for recent periods.

The primary sources for rail data are the Railway Inspectorate annual reports (HSE, annual). Except for recent years, the reports do not explicitly list multiple-fatality accidents, though it is reasonable to presume that such accidents are all mentioned somewhere in the text of each report. Therefore, the only way of identifying and counting multiple fatality accidents is by a complete close reading of the reports. This is an error-prone exercise, because the reports were not written for that purpose, and it is possible that corrections to the extracted data will be needed in future, although these would not materially affect the conclusions of this paper. Once multiple-fatality accidents have been identified, the number of single-fatality accidents can be deduced by subtracting fatalities in multiple-fatality accidents from total numbers of railway fatalities. For much of the period covered, it is not possible to distinguish British Rail (BR) from non-BR single-fatality rail accidents.

The sources of information for recent aviation accidents are the *Aviation Safety Reviews* by the Civil Aviation Authority (CAA 2000, 2002), which explicitly list all fatal aviation accidents anywhere in the world to UK-registered aircraft. The data include general aviation (private flying), which account for the great majority of fatal accidents, but not balloons, gliders, gyroplanes and microlights. They exclude accidents in airport terminals.

It would be desirable to include merchant shipping as well as the other modes, but data are not available. However, the data on major accidents in Tables 8 and 9 include merchant shipping accidents.

3.2 Results

Table 1 gives a summary of the main results for road, rail and aviation accidents for the 33/35-year periods. Table 2 gives the proportions of accidents and fatalities occurring in each of four broad fatality ranges.

Table 1
Summary of British fatal road, rail and air accidents: 1967-2001

	Road 1969-2001	Rail 1967-2001	Aviation 1967-2001
Years of data	33	35	35
Fatal accidents	163,336	2,411	644
Fatalities	178,278	2,856	2,259
Fatal accidents per year	4,949.6	68.9	18.4
Fatalities per year	5,402.4	81.5	64.5
Fatalities per fatal accident	1.09	1.18	3.51
Accidents with ≥10 fatalities	12	10	20
Fatalities in worst accident	32	49	146

Note: British here means, for road and rail, accidents in Great Britain. For aviation it means accidents anywhere in the world to UK-registered aircraft.

Table 2
Proportions of accidents and fatalities by accident size band

	Road 1969-2001	All rail 1967-2001	Aviation 1967-2001
Proportion of accidents with fatalities in given range			
1 fatality	92.9%	94.7%	51.2%
2-9 fatalities	7.1%	4.9%	45.7%
10-49 fatalities	0.0%	0.4%	1.6%
≥50 fatalities	0.0%	0.0%	1.6%
Proportion of fatalities in accidents of given size			
1 fatality	85.1%	80.0%	14.6%
2-9 fatalities	14.8%	11.4%	35.8%
10-49 fatalities	0.1%	8.6%	10.4%
≥50 fatalities	0.0%	0.0%	39.3%

Table 1 shows that over the long term there were an average of 4,950 fatal road accidents with 5,400 fatalities per year, 69 fatal railway accidents with 82 fatalities per year (excluding trespassers), and 18 fatal aviation accidents with 65 fatalities per year. It should be noted that the frequencies of fatal accidents on road and rail have fallen over the long term, so that the 33/35-year average frequencies are higher than recent frequencies. We return to this in section 3.4.

Table 2 shows that the great majority of both road and rail fatalities occurred in single fatality accidents. The distribution is different for aviation, in which the largest numbers of fatalities occurred in accidents in the 2-9 fatality range (mostly general aviation) and 50+ fatality range (public transport accidents). At the time of writing, there has been no large public transport accident to a UK-registered aircraft since Kegworth with 47 fatalities in 1989, so the recent underlying distribution may have changed. However, there have been serious aircraft accidents in other developed countries in recent years, and it would require an international analysis to form a more definite view on this.

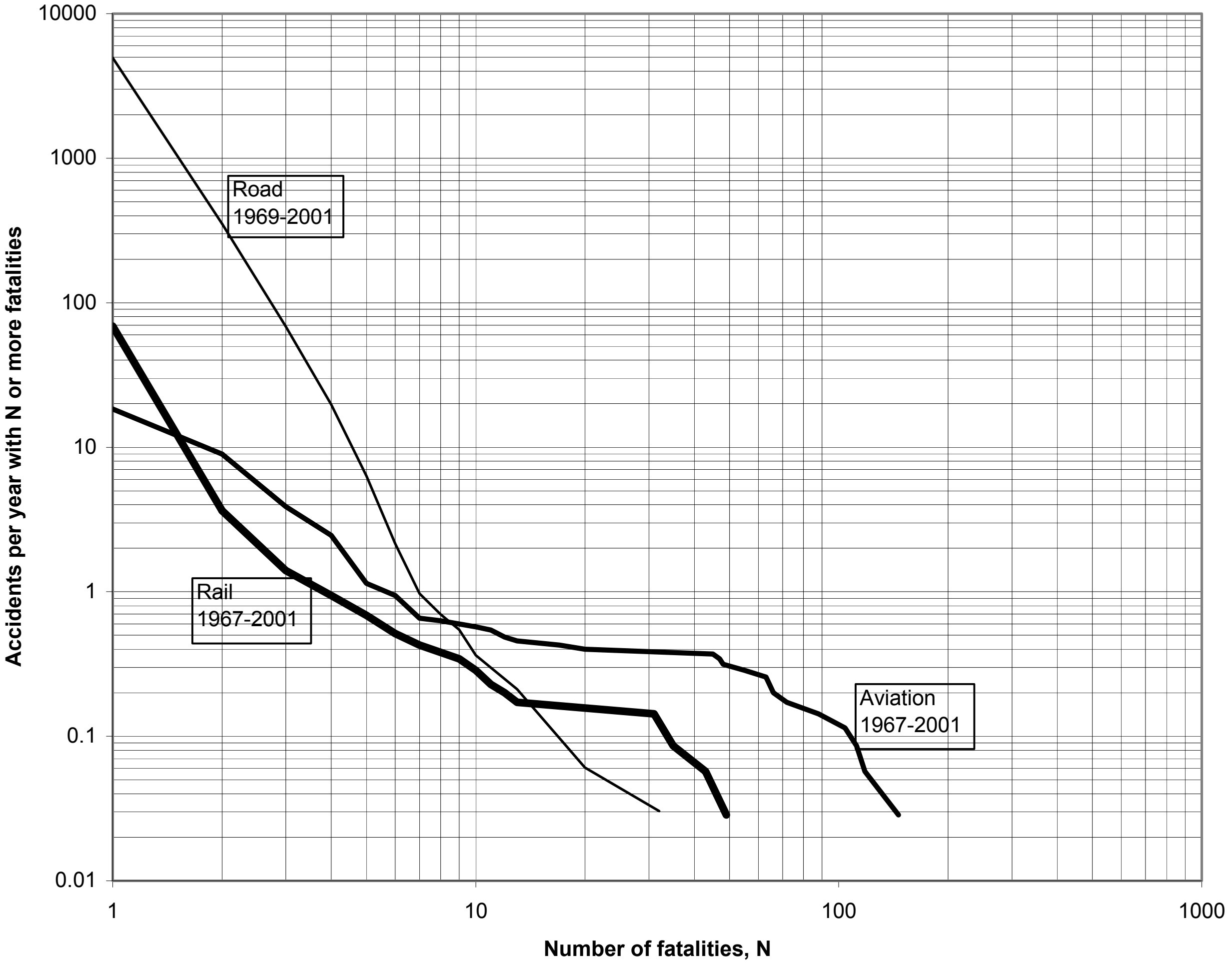
Table 1 shows that there have been 12 accidents with 10 or more fatalities on the roads in the long term data, 10 in rail, and 20 in aviation. The details of these accidents are given in Tables 8 and 9. The worst road accident was a coach overturning at Dibbles Bridge in the Yorkshire Dales in 1975 with 32 fatalities; the worst rail accident was the derailment at Hither Green in 1967 with 49 fatalities; the worst accident to a British aircraft was a flight into a mountain on the Canary Islands in 1980 with 146 fatalities. The overall worst British transport accident in the period was the capsizing of the *Herald of Free Enterprise* at Zeebrugge in 1987 with 193 fatalities. The worst transport 'event' affecting Britain was the bombing of Pan Am flight 103 over Lockerbie in 1988, which caused 270 fatalities, but that is excluded from this analysis because it was not to a British aircraft. Even if it had been to a British aircraft, it would raise the question of whether an intended act of that kind should be included with unintended accidents.

3.3 FN-curves for long-term data

Given the data in Table 7, it is straightforward to calculate the FN-curve for each transport mode for the 33/35-year period. Each of the figures in the table must first be divided by the number of years on which they are based to convert them to frequencies, which are the (lower case) $f(N)$'s. The $F(N)$'s are then calculated from the $f(N)$'s.

Figure 1 shows the resulting FN-curves. It will first be noted that the left-hand end of the curves are the frequencies of all fatal accidents, that is the frequencies in Table 1 above: 4,950 for roads, 69 for rail, and 18 for aviation. Next, it will be seen that each curve crosses each of the other two once. This reflects the facts that road accidents are the most frequent but least severe; aviation are the least frequent but most severe, and rail are in the middle on both counts. What is not very obvious from the graph is the important fact that roads have an average number of fatalities per year that is two orders of magnitude greater than those of the other two modes. This is because of the foreshortening effect of the logarithmic frequency scale.

Figure 1: FN-curves for road, rail and air transport 1967-2001



3.4 Road and rail FN-curves for 2001

A limitation on the usefulness of the FN-curves in Figure 1 is that they represent long-term averages, and therefore they are not up to date. Fatal accident frequencies on road and rail have both fallen substantially over the long term. For roads, the number of fatal accidents was 3,176 in 2001, compared with the average per year of 4,950 in 1969-2001. For rail, the number of fatal accidents in 2000/01 was 32 (excluding trespassers), compared with the average per year of 69 in 1967-2001. It follows that at least the left-hand points of the road and rail FN-curves would be lower than they are in Figure 1 if they could be drawn for 2001 alone. However, it is not possible to construct FN-curves for a single year directly from empirical data, because a single year does not provide enough detail about the distribution of fatalities in accidents, particularly at the high-fatality end of the distribution. Therefore some assumptions and modelling are necessary to construct FN-curves for 2001.

The obvious way of estimating FN-curves for 2001 is to combine the 2001 fatal accident frequencies with the long-term fatality distributions. The 2001 FN-curves would then be parallel to but lower than the long-term FN-curves. In the notation of section 2.1, we would base $F(1)$ on the 2001 frequency data but the $p(N)$'s on the long-term data. This assumes that while the frequency of fatal accidents falls, the distribution of the number of fatalities in accidents remains unchanged. Such an assumption requires justification, and there is some empirical evidence that it is reasonable for road and rail (though it might not be for aviation).

The evidence for road is that while fatal accident frequencies and rates have fallen over the long term, the average number of fatalities per fatal accident has remained remarkably constant at about 1.09. This does not prove that the shape of the FN-curve has remained constant, but it is consistent with such an assumption. For rail the evidence is that the fall in the frequency of all fatal accidents, which are dominated numerically by single-fatality movement accidents, is similar to the estimated fall in the frequency of main line train accidents alone, which we consider in section 4. Therefore the falls in the frequencies of different kinds of fatal railway accidents appear to be rather similar, and it is plausible that the general shape of the FN-curve has remained much the same.

For road accidents we implement these assumptions by constructing an FN-curve for 2001 which is parallel to but lower than that in Figure 1, with a left-hand end point of 3,176 fatal accidents per year. For rail the construction is more complicated in order to maintain consistency with the work on main line train accidents discussed in section 4. We first remove the main line train accidents from the data, then lower the remaining FN-curve in the same way as for roads, and finally add back the fatal train accidents for 2001, as derived in section 4. The resulting road and rail FN-curves for 2001 are shown in Figure 4 below.

4 MAIN LINE DERAILMENTS, COLLISIONS AND OVERRUNS

4.1 British fatal accidents 1967-2001

The writer has previously done much analysis of fatal train derailments, collisions and overruns on the national railway system of Great Britain since 1967. These analyses have contributed to many of the debates on railway safety measures in the past decade, including the Joint Inquiry into Train Protection. The principal account of the statistical methodology is in Evans (2000), and the results up to the end of 2001 are in an unpublished Centre for Transport Studies working paper (Evans 2002a).

Appendix Table 10 presents the list of fatal accidents up to the end of 2001, and includes for completeness some information that is not actually used in this paper, such as the train impact speed. These accidents are referred to below as 'train accidents' for simplicity, but it should be noted that the accidents in the table are only a subset of what HMRI define as train accidents. In particular, accidents initiated by collisions between train and road vehicles (including Great Heck) are generally excluded, and so are train fires. (However, both of these classes of accident, and all others, are included in the analysis in Section 3.).

The number of fatal train accidents in Table 10 is 78, with 311 fatalities. This gives an overall frequency of 2.23 fatal accidents per year, with 4.0 fatalities per accident. The trend over time in the frequency of accidents is downward, and Evans' latest analysis of these data (Evans 2002a) estimates the overall frequency of such accidents in 2001 at 1.07 per year before TPWS is assumed to have had any effect, of which 0.54 were ATP-preventable and 0.53 were non-ATP preventable.

Although there is a downward trend over time in the frequency of fatal train accidents, Evans (2002a) concluded that there is no statistically significant trend in the average number of fatalities per fatal accident, even though there is great variation in the number of fatalities between individual accidents. Therefore Evans concluded that the current average number of fatalities per accident is the same as the long-term number, namely 4.0.

4.2 Comparison of fatalities in ATP- and non-ATP-preventable accidents

The data in Table 10 classify accidents by whether they were ATP-preventable or not. Of the 78 accidents, 32 were ATP-preventable and 46 were non-ATP-preventable. Table 3 shows the distribution of fatalities separately for the ATP-preventable and non-ATP-preventable accidents. The table shows that the observed average number of fatalities per fatal accident is very similar for two classes of accident: 3.9 for the ATP-preventable and 4.1 for the non-ATP-preventable accidents. The difference between these averages is far from statistically significant, and therefore it is reasonable to assume that the distribution of fatalities is the same for ATP-preventable as for non-ATP-preventable accidents.

Table 3
Fatalities in ATP- and non-ATP-preventable train accidents: 1967-2001

Type of accident	Number of accidents with given number of fatalities: 1	2	3	4	5	6	7	9	10	13	31	35	49	All	Total fatalities	Fatalities/ acc.
ATP-preventable?																
Yes	11	5	4	2	4	3	2				1			32	124	3.88
No	25	11		3	1		1	1	1	1		1	1	46	187	4.07
All	36	16	4	5	5	3	3	1	1	1	1	1	1	78	311	3.99

4.3 Major European accidents 1967-2001

From the point of view of estimating FN-curves (though not from other points of view), a weakness of the British data on main line train accidents is that the number of high-fatality accidents is small. There were just three accidents with more than 20 fatalities in 1967-2001. This means that the shape of the train accident FN-curve can be estimated only coarsely at the upper end of the fatality distribution from British accident data. In this section, we use the phrase 'high-fatality' accident to mean an accident with 20 or more fatalities.

In this situation, it is natural to ask whether more empirical data can be found to flesh out the detail at the upper end of the fatality distribution. A possibility is to look to European as well as British data on high-consequence train accidents. There is no comprehensive source of European train accident data, but Semmens (1994) has produced a useful account of all train accidents with 20 or more fatalities worldwide since 1900, based on press reports.

Evans (2000b) extracted the accidents from Semmens' book for the current fifteen countries of the European Union since 1967 and extended the period to 2001. There were 24 accidents with 20 or more fatalities in 1967-2001 in the fifteen current countries of the EU, including the three in Great Britain. These high-fatality European accidents are listed in Table 11. These accidents together caused a total of 1,080 fatalities, of which 115 occurred in the three British high-fatality accidents.

The average number of fatalities per high-fatality accident in the three British accidents is 38, which is not very different from the average of 45 in the 24 European accidents. This is despite the fact that the European data contain two accidents with just over 100 fatalities; these accidents in the European data are counterbalanced by several accidents in the 20-29 fatality range, of which there were none in Great Britain.

The frequency of high-fatality British accidents is broadly in line with that of Europe. Britain accounts for 3 out of 24, or one eighth, of the European accidents, which is roughly in line with the scale of railway activity.

Table 4
Adopted distribution of fatalities in train accidents

Number of Fatalities	Proportion of fatal train accidents with fatalities equal to or greater than given number
1	100.0%
2	53.8%
3	33.3%
4	28.2%
5	21.8%
6	15.4%
7	11.5%
9	7.7%
10	6.4%
13	5.1%
22	3.8%
24	3.5%
25	3.4%
28	3.0%
29	2.7%
31	2.6%
33	2.4%
34	2.2%
35	2.1%
41	1.8%
43	1.4%
46	1.3%
47	1.1%
49	1.0%
59	0.8%
76	0.6%
94	0.5%
101	0.3%
108	0.2%
>108	0%

Table 5
Proportions of train accidents and fatalities by accident size band

	Accidents	Fatalities
1 fatality	46.2%	10.9%
2-9 fatalities	47.4%	41.4%
10-49 fatalities	5.6%	31.2%
≥50 fatalities	0.8%	16.5%

4.4 Adopted distribution of fatalities in main line train accidents

Given the greater detail on high-fatality accidents in the European data, for the purpose of constructing an FN-curve for train accidents, it is sensible to replace the data on the high-fatality British accidents by a scaled version of the European data, which of course include the British data. The scaling should be such as to retain the same frequency of high-fatality accidents as in the British data. This requires scaling the European data downwards by a factor of 8, so that the frequency of high consequence accidents remains at 3 in 35 years.

Table 4 shows the results of doing this. The proportions of accidents at the low consequence end of the fatality distribution are based directly on the British data in the bottom line of Table 3. The proportions of accidents in the ranges at or above 20 fatalities are based on a scaled version of the European data. Thus, for example, the proportion of accidents with 101 or more fatalities is shown in Table 4 as 0.3%. This is based on the fact that 2 out of 24 of the high fatality accidents in the European data had ≥101 fatalities and 3 out of 78 accidents in the British data were high-fatality. The product of 2/24 and 3/78 is 0.3%.

We adopt the spliced British/European fatality distribution in Table 4 to describe the shape of the FN-curve for train accidents. Figure 2 below shows the shape of these curves. Table 5 shows the proportions of accidents and fatalities in each of the four broad fatality ranges.

An effect of adopting the spliced distribution is to raise the estimated mean number of fatalities per train accident slightly from 4.0 in the British data alone (Table 3) to 4.2 in the spliced data. This is a consequence of the fact that, as noted above, the mean number of fatalities per high-fatality accident is slightly higher in the European data than in the British data. It is interesting to note that the mean number of fatalities per accident in the distribution in Table 4 is still only about 4, notwithstanding that the empirical data on which it is based include two accidents with more than 100 fatalities.

4.5 Main line train accident frequencies

In section 4.1 we noted that the observed frequency of main line train accidents from all causes was 2.23 accidents per year over the whole period 1967-2001, but that the trend was downwards. The frequency in 2001was estimated in Evans (2000a) to be 1.07 per year, of which 0.54 were ATP-preventable in the absence of TPWS. This implies about one fatal ATP-preventable accident every two years in the absence of TPWS.

TPWS and TPWS+ are expected to reduce the frequencies of ATP-preventable accidents substantially. The view adopted in the NERA (2003) review of economic aspects of the work of the ERTMS Programme Team was that TPWS could be expected to reduce the frequency of ATP-preventable accidents by 75%, and that TPWS+ could take this to 80%, leaving a residual frequency of 20% of 0.54 or 0.11 fatal ATP-preventable accidents per year. This is the source of the statement in the NERA review that with TPWS and TPWS+ installed we can expect one ATP-preventable fatal accident every 10 years.

Table 6 summarises all these frequencies.

Table 6
Frequencies of fatal main line train accidents

	Fatal accidents per year
Observed average frequency from all causes 1967-2001	2.23
Estimated underlying frequency from all causes 2001	1.07
Estimated frequency of ATP-preventable accidents 2001	0.54
Estimated frequency of ATP-preventable accidents at 2001 traffic levels with TPWS/TPWS+ installed	0.11

4.6 FN-curves for main line train accidents

Section 4.1 noted that there has been no significant trend over time in the mean number of fatalities per fatal train accident. Section 4.2 noted that there is no significant difference between the mean number of fatalities per fatal accident in ATP-preventable and non-ATP-preventable accidents.

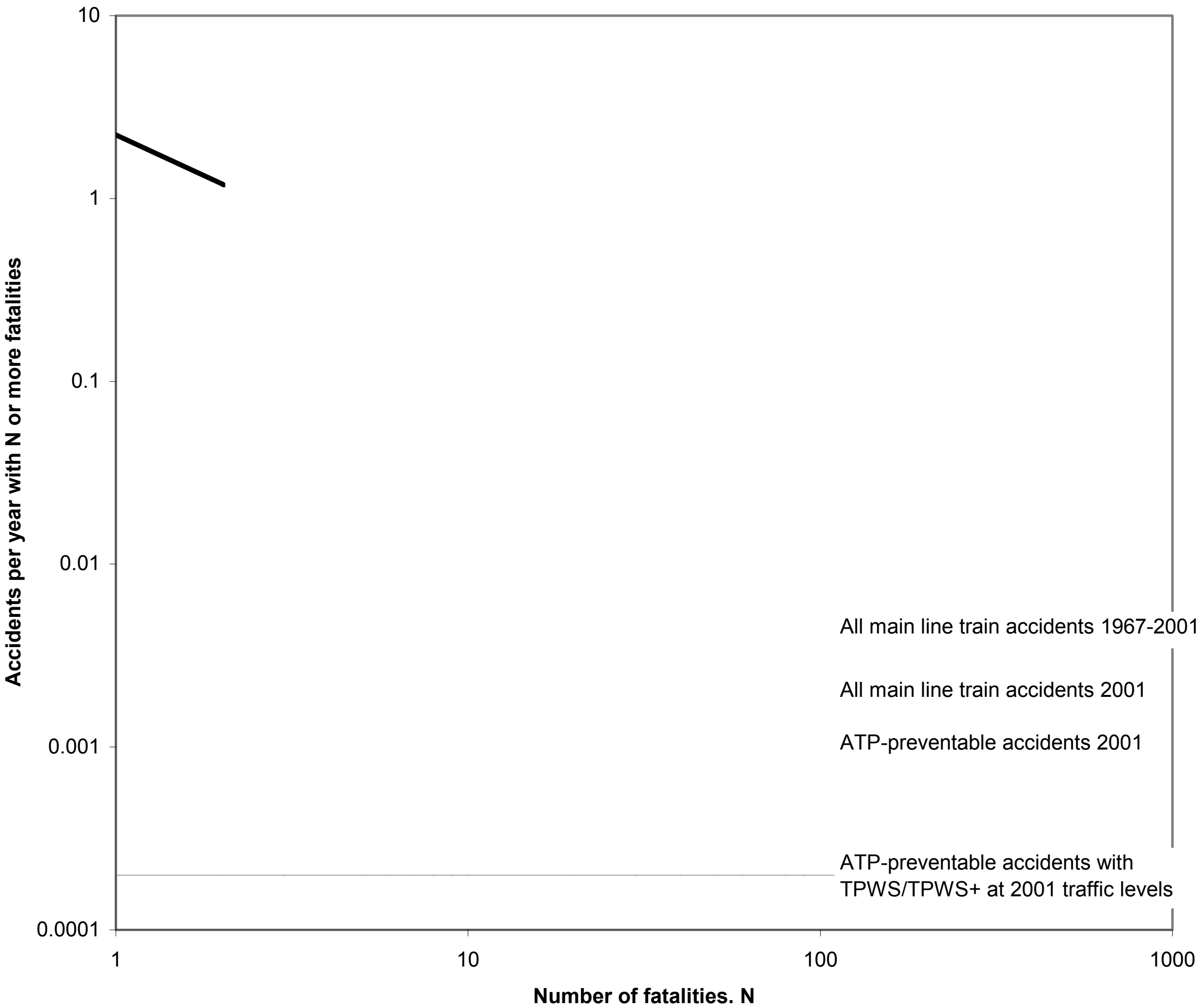
Given these findings, it is reasonable to presume that the distribution of fatalities in train accidents was the same in 2001 as the average for 1967-2001, and the same for ATP-preventable accidents as for all train accidents. In other words, it is reasonable to assume that the shape of the FN-curve is the same for each of these distributions, and is given by the shape of the distribution in Table 4. Only the overall accident frequency differs between one set of train accidents and another. These differences are represented on the FN-graph by different vertical locations of parallel FN-curves.

Although it is expected that TPWS and TPWS+ will reduce mean ATP-preventable fatalities by about 80%, it is not clear whether this will be achieved through a frequency reduction of 80% with the same fatality distribution, or in some other way. The ERTMS and NERA reports assumed that it would be achieved through an accident frequency reduction. If that were so, and the distribution of fatalities in ATP-preventable accidents remained unchanged, the post-TPWS ATP-preventable FN-curve would again be parallel to the other train accident FN-curves, but again be lower, with an intercept on the vertical axis of 0.11 fatal accidents per year.

Figure 2 shows all four parallel FN-curves, with intercepts on the vertical axis as given in Table 6.

It should be noted that the vertical locations of the FN-curves in Figure 2 are much lower than those for all accidents in Figure 1. Figure 2 is concerned with fatal accident frequencies that are at most just over 2 per year, whereas Figure 1 was concerned with accident frequencies that in the case of road accidents run into thousands per year.

Figure 2: FN-curves for main line train accidents



4.7 The Safety Risk Model

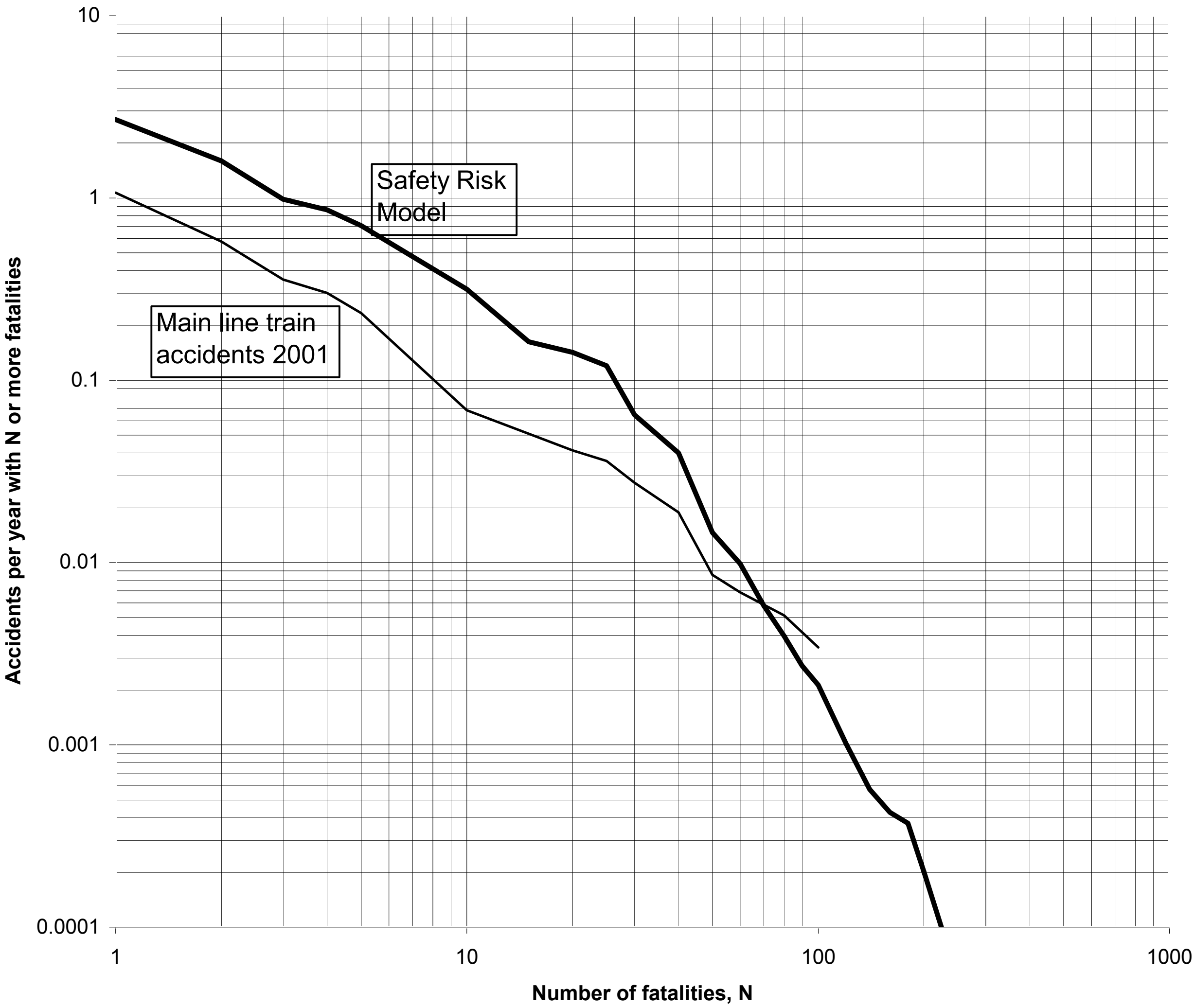
Railway Safety's Safety Risk Model (SRM) also provides in the *Risk Profile Bulletin* (*RPB*) (Railway safety 2001, page 29) an FN-curve for multiple fatality railway accidents, derived not from past accident data but from modelling the precursors and consequences of fatal accident sequences. Railway Safety has kindly provided to the writer the data from which the SRM FN-curve was drawn, so that it can be compared with the empirically based curves derived in this paper. The left-hand point of the SRM FN-curve is 2.7 fatal accidents per year; the mean number of fatalities per accident is 4.9, the mean number of fatalities per year is 13.3.

The SRM FN-curve covers all train accidents with the potential for multiple fatalities. The exact categories of accidents are listed in the Table A1 of the *RPB*; they include all train derailments, collisions, and overruns; collisions between trains and road vehicles (mostly at level crossings); and train fires. A few non-train accidents also have the potential for multiple fatalities, such as station fires, but for simplicity these are excluded from the SRM FN-curve. It is accepted that the method by which the SRM FN-curve is estimated gives an underestimate of the fatal accident frequency at the low-fatality end of the distribution, and hence of the overall fatal accident frequency. However, Railway Safety believes that the curve is an accurate representation of the SRM for frequencies of accidents with 5 or more fatalities.

The most suitable comparator from this paper for the SRM FN-curve is the FN-curve for all main train accidents in 2001. Figure 3 shows this comparison. For much of its length the SRM FN-curve is above the empirical curve. This is no surprise, partly because of the wider coverage of the SRM curve, and partly because, as discussed in NERA (2003), estimates from the SRM tend to be higher than those obtained directly from accident data. However, what is perhaps more surprising is that the two curves come fairly close together at the high fatality end of the range (50-100 fatalities). The SRM FN curve continues above the 100-fatality level to include the possibility of accidents larger than any that have occurred in Western Europe in the last 35 (indeed 50) years, but by then the frequencies are so low that these make little contribution to the overall risk.

Railway Safety has informed the writer that Issue 2 of the *RPB*, with its FN-curve, is soon to be replaced with a new issue.

Figure 3: FN-Curves for Safety Risk Model and data on train accidents



5. OVERALL COMPARISONS AND FN-CRITERIA

Figure 4 presents some of the FN-curves previously described, together with FN-criteria. The figure shows three FN-curves (the bold curves), two criterion lines (the thinner lines) and a criterion point. In order to accommodate the wide range of accident frequencies displayed, the vertical axis ranges through nine orders of magnitude.

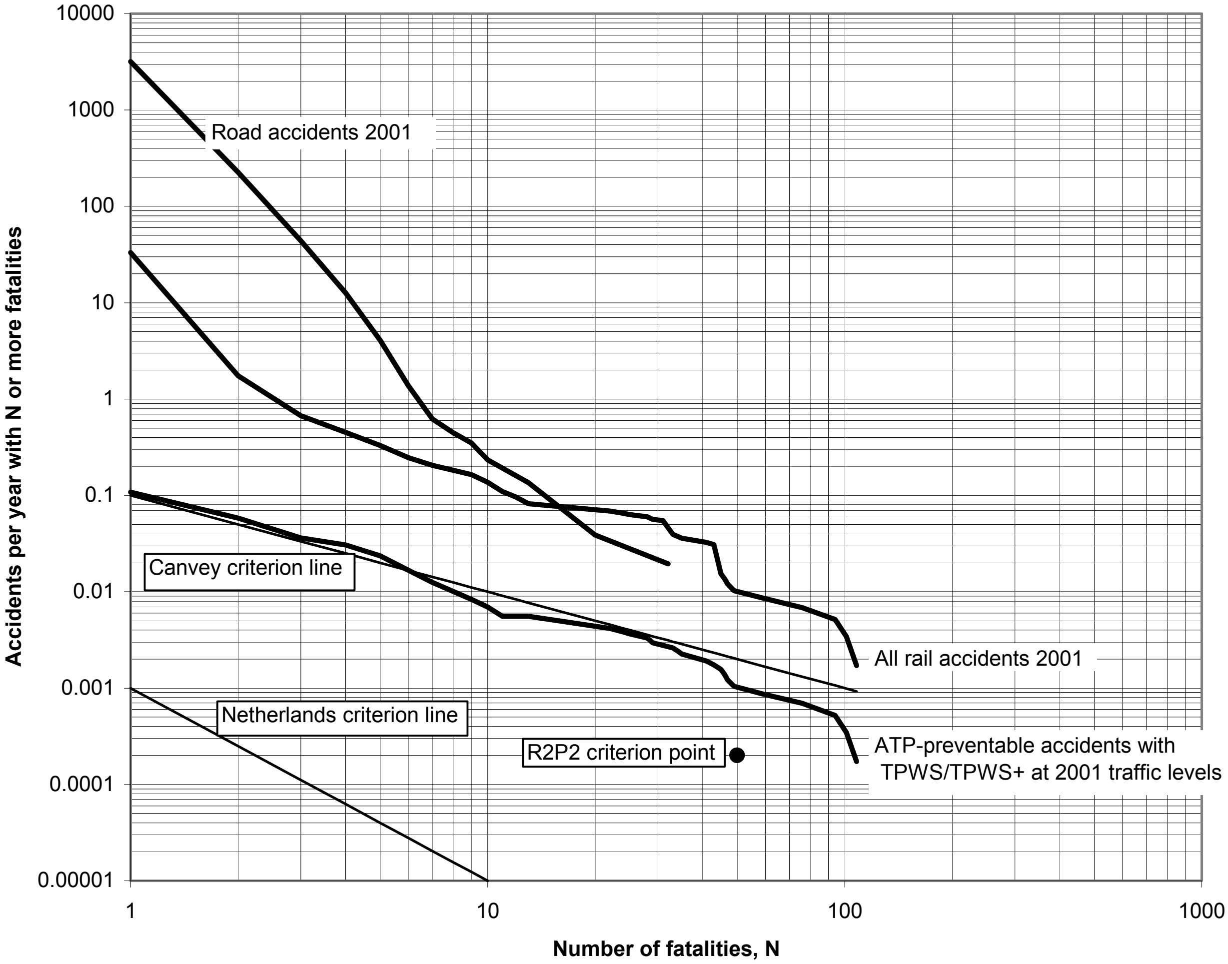
The top two FN-curves are for road and all railway accidents for 2001, estimated as discussed in section 3.4. The lowest FN-curve is for ATP-preventable main line train accidents after the installation of TPWS and TPWS+, assuming 2001 traffic levels. This is a reproduction of the lowest of the four curves in Figure 2. (The reason it appears to be flatter is that the vertical scale is different in Figure 4 from that in Figure 2.)

The higher of the two criterion lines is the 'Canvey line' mentioned in section 2.3, which cuts the vertical axis at 0.1 fatal accidents per year, and has a slope of –1. By coincidence the Canvey line is close to the post-TPWS ATP-preventable FN-curve for *N* up to about 40 fatalities. The lower criterion line is that adopted for hazardous sites by the Netherlands Planning Department from 1989 (see Ball and Floyd 1998). It is much more stringent than criteria proposed by the HSE: it cuts the vertical axis at 0.001, and has a slope of –2. Finally, the 'R2P2 criterion point' is that proposed for hazardous industrial sites by the HSE in *Reducing risks, protecting people*, also discussed in section 2.3. It is one order of magnitude more stringent than the Canvey line. R2P2 did not recommend a criterion line as distinct from a point, but the obvious extension of the R2P2 point would be a line parallel to the Canvey line, and one order of magnitude below it.

It should be stressed that all the criteria shown in Figure 4 were proposed for single hazardous industrial sites such as chemical or nuclear plants, not industries at the national scale or national transport systems. No FN-criteria have ever been proposed for such systems.

The author of this paper does not believe that any conclusions can be drawn from the relative positions of the FN-curves and criteria in Figure 4. This is partly because of the general objections to FN-criteria outlined in section 2.3, and partly because none of the FN-criteria that have been proposed and are shown in Figure 4 are relevant to national transport systems.

Figure 4: Transport FN-curves for 2001 and FN-criteria



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APPENDIX: ACCIDENT DATA

Table 7
Distributions of numbers of fatalities in road, rail and air accidents: 1967-2001

	Number of accidents with given number of fatalities		
Number of Fatalities	**Road 1969-2001**	**Rail 1967-2001**	**Aviation 1967-2001**
All	163,336	2,411	644
1	151,722	2,284	330
2	9,350	78	178
3	1,612	16	50
4	443	9	46
5	138	6	7
6	39	3	10
7	9	3	1
8	5		2
9	6	2	
10	5	2	1
11		1	2
12		1	1
13	5	1	1
17			1
20	1		1
31		2	
32	1		
35		1	
43		1	
45			1
47			1
48			1
49		1	
55			1
63			2
66			1
72			1
88			1
104			1
112			1
118			1
146			1

Table 8
British transport accidents with 10 or more fatalities: 1969-2001

Date	Mode	Location	Nature of accident	Fatalities
28. 2.01	Rail	Great Heck	Car/train/train collision	10
5.10.99	Rail	Ladbroke Grove	Train collision, fire	31
5. 7.95	Road	A40 near Raglan	Coach-lorry collision	10
24. 5.95	Air	Near Leeds Airport	Crash after take-off	12
23. 5.95	Road	M4 near Bristol	Coach left road, overturned, fire	13
18.11.93	Road	M40 near Warwick	Minibus hit lorry in shoulder, fire	13
10.11.93	Road	M2 near Faversham	Coach left road, overturned	10
14. 3.92	Air	North Sea	Helicopter crash in sea	11
13. 3.91	Road	M4 near Hungerford	Multiple collisions in fog, fire	10
20. 8.89	Water	River Thames, London	*Marchioness* in collision	51
8. 1.89	Air	M1 Kegworth	Aircraft engine failure, crash	47
12.12.88	Rail	Clapham Junction	Train collision	35
18.11.87	Rail	Kings Cross, London	Underground station fire	31
28.10.87	Road	M61 near Preston	Tanker hit traffic queue, fire	13
6. 3.87	Water	Zeebrugge, Belgium	*Herald of Free Enterprise* capsized	193
6.11.86	Air	North Sea	Helicopter crash in sea	45
23. 6.86	Road	M4 near Maidenhead	Van crossed central barrier, hit car	13
21.10.85	Road	M6 near Preston	Coach hit traffic queue, fire	13
22. 8.85	Air	Manchester Airport	Aircraft fire on ground	55
19. 8.84	Air	Marchington, Staffs	Aircraft engine failure, crash	11
30. 7.84	Rail	Polmont, Scotland	Train hit cow, derailment	13
3. 6.84	Water	North of Bermuda	Tall ship *Marques* capsized	19
8.12.83	Air	Near Stornaway	Aircraft crash in sea	10
16. 7.83	Air	Isles of Scilly	Helicopter crash in sea	20
13. 8.81	Air	North Sea	Helicopter crash in sea	13
9. 9.80	Water	North Pacific	*Derbyshire* foundered	44
24. 4.80	Air	Tenerife, Canary Is	Aircraft crash into mountain	146
6.11.79	Water	English Channel	*Pool Fisher* foundered	13
31. 7.79	Air	Sumburgh, Shetland	Aircraft crash on take-off	17
6. 7.78	Rail	Taunton	Sleeping car fire	12
10. 9.76	Air	Zagreb, Yugoslavia	Mid-air collision	63
16. 6.75	Road	A74 near Moffat	Lorry crossed central reserve, hit coach	10
27. 5.75	Road	Dibbles Bridge, Yorks	Coach ran away on hill, overturned	32
28. 2.75	Rail	Moorgate, London	Underground train hit tunnel end	43
25. 1.75	Water	Off Cornwall	*Lovat* foundered	11
19.12.73	Rail	West Ealing	Locomotive defect; derailment	10
10. 4.73	Air	Near Basle, Switzerland	Aircraft crash on approach	104
18. 6.72	Air	London Heathrow	Aircraft crash on take-off	118
11. 5.72	Water	River Plate	*Royston Grange* in collision	74
2.10.71	Air	Near Ghent, Belgium	Structural failure of aircraft	63
17. 8.71	Road	Helmsley, Yorkshire	Coach-car collision	10
3. 7.70	Air	Near Barcelona, Spain	Aircraft crash into mountain	112
9. 4.70	Water	Genoa, Italy	*London Valour* foundered	20
6. 2.70	Water	Off River Tees	*Lairdsfield* foundered	10
14. 8.69	Road	Stanhope, Co Durham	Coach ran away on hill, hit house	20

Note: Road and rail accidents are for Great Britain. Aviation and shipping accidents are to British-registered craft anywhere in the world. Source: Evans (1994), updated.

Table 9
British rail, air and water accidents with 10 or more fatalities: 1967-1968

Date	Mode	Location	Nature of accident	Fatalities
9. 8.68	Air	Near Munich, Germany	Crash on to autobahn	44
6. 1.68	Rail	Hixon Level Crossing	Train/road transporter collision	11
5.11.67	Rail	Hither Green	Passenger train derailment	49
12.10.67	Air	Sea near Rhodes	Explosion on board aircraft	66
13. 9.67	Water		*Denny Rose* missing	42
4. 6.67	Air	Stockport	Crash on airport approach	72
3. 6.67	Air	Near Perpignan, France	Crash into mountain	88

Note: Road and rail accidents are for Great Britain. Aviation and shipping accidents are to British-registered craft anywhere in the world. Source: Evans (1994), updated.

Table 10
Fatal collisions, derailments and overruns: national railway system: 1967-2001

Date	Location	Nature of accident	ATP*-preventable?	Rolling stock	Speed km/h	Fatal-ities
17.10.00	Hatfield	Derailment	No	Post-Mk1 LH*	185	4
5.10.99	Ladbroke Grove	Train collision, fire	Yes: C-SPAD*	Post-Mk 1 MU*	209	31
19. 9.97	Southall	Train collision	Yes: C-SPAD	Post-Mk 1 LH	150	7
8. 8.96	Watford Junction	Train collision	Yes: C-SPAD	Post-Mk 1 MU	80	1
8. 3.96	Rickerscote	Derailment, then collision	No	Non-passenger	121	1
31. 1.95	Ais Gill	Derailment, then collision	No	Post-Mk 1 MU	97	1
15.10.94	Cowden	Train collision	Yes: C-SPAD	Mark 1 MU	108	5
25. 6.94	Branchton	Derailment	No	Mark 1 MU	75	2
13.11.92	Morpeth	Train collision	No	Non-passenger	40	1
27. 7.91	Newton	Train collision	Yes: C-SPAD	Mark 1 MU	97	4
8. 1.91	Cannon Street	Buffer stop collision	Yes: Overrun	Mark 1 MU	16	2
4. 8.90	Stafford	Train collision	No	Post-Mk 1 MU	32	1
20. 4.89	Holton Heath	Train collision	No	Non-passenger	60	1
6. 3.89	Bellgrove Junction	Train collision	Yes: C-SPAD	Mark 1 MU	48	2
4. 3.89	Purley	Train collision	Yes: C-SPAD	Mark 1 MU	56	5
27. 2.89	Warrington	Train collision	No	Non-passenger	16	2
12.12.88	Clapham Junction	Train collision	No	Mark 1 MU	56	35
11.11.88	St Helens	Derailment	No	Post-Mk 1 MU	37	1
19.10.87	Glanrhyd Bridge	Collapsed bridge; train fell	No	Mark 1 MU	24	4
19. 9 86	Colwich	Train collision	Yes: C-SPAD	Post-Mk 1 LH	157	1
9. 3.86	Chinley	Train collision	No	Mark 1 LH	48	1
4.12.84	Eccles	Train collision, fire	Yes: P-SPAD	Post-Mk 1 LH	56	3
3.12.84	Longsight	Train collision	No	Mark 1 MU	31	1
11.10.84	Wembley Central	Train collision	Yes: C-SPAD	Post-Mk 1 MU	92	3
30. 7.84	Polmont	Derailment	No	Post-Mk 1 MU	137	13
3. 2.84	Wigan	Train collision	No	Non-passenger	19	2
9.12.83	Wrawby Junction	Train collision	No	Mark 1 MU	19	1
3. 2.83	Elgin	Derailment	No	Post-Mk 1 LH	97	1
9.12.82	Linslade	Derailment	No	Mark 1 LH	68	1
27. 5.82	Alvechurch	Train collision	No	Mark 1 MU	64	1
11.12.81	Seer Green	Train collision	No	Mark 1 MU	48	4
8.12.81	Ulleskelf	Derailment	No	Post-Mk 1 LH	105	1
7.11.80	Crewe	Train collision	No	Non-passenger	44	2
14. 3.80	Appledore	Derailment	Yes: Excess speed	Mark 1 MU	97	1
22.10.79	Invergowrie	Train collision	Yes: P-SPAD	Mark 1 LH	97	5
16. 4.79	Paisley Gilmour St	Train collision	Yes: C-SPAD	Mark 1 MU	36	7
25. 2.79	Fratton	Train collision	No	Mark 1 LH	97	1
22.12.78	Milford LC*	Train/car collision	Yes: C-SPAD	Mark 1 MU	8	1
19.12.78	Hassocks-Brighton	Train collision	Yes: P-SPAD	Mark 1 MU	76	3
5. 9.77	Farnley Junction	Train collision	No	Mark 1 MU	64	2
9.11.76	Newton-on-Ayr	Train collision	Yes: C-SPAD	Non-passenger	Unknown	1
3. 1.76	Worcester Tunnel Jc	Train collision	No	Non-passenger	72	2
26.10.75	Lunan Bay	Train collision	No	Post-Mk 1 LH	40	1
11. 9.75	Corby	Train collision	No	Non-passenger	Unknown	1
24. 8.75	Carstairs	Train collision	No	Non-passenger	89	2
6. 6.75	Nuneaton	Derailment	Yes: Excess speed	Mark 1 LH	129	6
23. 1.75	Watford Junction	Derailment, then collision	No	Post-Mk 1 LH	109	1

*ATP = Automatic train protection; C-SPAD = Signal passed at danger protecting a conflicting movement; P-SPAD = Signal passed at danger protecting preceding train on same line; MU = multiple unit; LH = locomotive-hauled; LC = Level crossing.

Continued…

Table 10 (continued)
Fatal collisions, derailments and overruns: national railway system: 1967-2001

Date	Location	Nature of accident	ATP-preventable?	Rolling stock	Speed km/h	Fatal-ities
23.10.74	Bridgwater	Train collision	Yes: P-SPAD	Non-passenger	72	1
11. 6.74	Pollokshields E Jc	Train collision	Yes: C-SPAD	Mark 1 MU	48	1
19.12.73	West Ealing	Derailment	No	Mark 1 LH	113	10
30. 8.73	Shields Junction	Train collision, fire	Yes: P-SPAD	Mark 1 MU	80	5
27. 4.73	Kidsgrove	Train collision	Yes: P-SPAD	Non-passenger	19	1
6. 9.72	Leicester	Train collision	No	Non-passenger	48	1
11. 6.72	Eltham Well Hall	Derailment	Yes: Excess speed	Mark 1 LH	105	6
16.12.71	Nottingham	Train collision	Yes: C-SPAD	Non-passenger	72	3
6.10.71	Beattock	Train collision	No	Non-passenger	72	1
2. 7.71	Tattenhall Jc	Derailment	No	Mark 1 LH	109	2
21. 5.71	Cheadle	Derailment, then collision	No	Non-passenger	45	1
15. 4.71	Finsbury Park	Train collision	No	Mark 1 MU	64	1
26. 2.71	Sheerness	Buffer stop collision	Yes: Overrun	Mark 1 MU	20	1
17. 7.70	Kirkstall	Train collision	No	Mark 1 MU	28	1
20. 5.70	Guide bridge	Derailment	No	Mark 1 MU	48	2
31.12.69	Roade Junction	Derailment, then collision	No	Post-Mk 1 MU	117	1
30.12.69	Streatham Hill	Train collision	No	Mark 1 MU	32	1
18. 5.69	Beattock	Train collision	No	Mark 1 LH	16	1
7. 5.69	Morpeth	Derailment	Yes: Excess speed	Mark 1 LH	135	6
8. 4.69	Monmore Green	Train collision, fire	Yes: C-SPAD	Post-Mk 1 MU	72	2
8. 3.69	Ashchurch	Derailment, then collision	Yes: Excess speed	Mark 1 LH	48	2
4. 1.69	Paddock Wd-Marden	Train collision	Yes: P-SPAD	Mark 1 MU	109	4
9. 9.68	Castlecary	Train collision	No	Mark 1 MU	60	2
11. 3.68	Peterborough North	Train collision	No	Non-passenger	Unknown	2
?. ?,68	Hatfield	Train collision	Yes: Excess speed	Non-passenger	Unknown	2
5.11.67	Hither Green	Derailment	No	Mark 1 MU	113	49
27. 9.67	Didcot	Derailment	Yes: Excess speed	Mark 1 LH	105	1
15. 8.67	Copy Pit	Train collision	Yes: P-SPAD	Non-passenger	113	1
31. 7.67	Thirsk	Derailment, then collision	No	Mark 1 LH	80	7
5. 3.67	Connington South	Derailment	No	Mark 1 LH	118	5
28. 2.67	Stechford	Train collision	No	Mark 1 MU	97	9

Table 11
European main line train accidents with 20 or more fatalities: 1967-2001

Date	Country	Location	Nature of accident	Fatalities
5.10.99	UK	Ladbroke Grove	Two passenger train collision, fire	31
3. 6.98	Germany	Eschede	Passenger train derailment	101
12.12.88	UK	Clapham Junction	Triple train collision	35
27. 6.88	France	Paris, Gare de Lyon	Runaway passenger train, collision	59
11. 9.85	Portugal	Nelas-Alcafache	Two passenger train collision, fire	45
31. 8.85	France	Argenton-sur-Creuse	Pass train derailment, then collision	43
3. 8.85	France	Flaujac	Two passenger train collision	35
21.11.80	Italy	Lamezia Terme	Triple train collision	28*
15. 4.78	Italy	Vado	Pass train derailment, then collision	47
27. 6.77	Germany	Lebus	Passenger/freight train collision, fire	29
28. 2.77	Spain	near Barcelona	Two passenger train collision	22
4. 5.76	Netherlands	near Schiedam	Two passenger train collision	24
8. 6.75	Germany	Warngau-Schaftlach	Two passenger train collision	41
30.10.72	Germany	Karl Marx Stadt	Two passenger train collision	25
21. 7.72	Spain	near Jerez	Two passenger train collision	76
17. 6.72	France	Vierzy Tunnel	Tunnel collapse; two trains hit debris	108
21. 1.71	Germany	Freiburg-im-Breisgau	Passenger train derailment	22
27. 5.71	Germany	Radevormwald	Two passenger train collision	46
9. 2.71	Germany	Aitrang	Pass train derailment, then collision	28
9. 8.70	Spain	Plencia	Passenger/freight train collision	33
1.10.68	Greece	Corinth	Two passenger train collision	34
15. 3.68	Spain	Nr SM de la Almeda	Pass/engineering train collision, fire	25
5.11.67	UK	Hither Green	Passenger train derailment	49
6. 7.67	Germany	Langenweddingen	Pass train/petrol tanker collision, fire	94

Source: Semmens (1994), updated by Evans.
*This figure is given as 28+ in Semmens, but is taken as 28 in the analysis.

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