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# Speed and rolling stock of trains in fatal accidents on Britain's mainline railways

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# Speed and rolling stock of trains in fatal accidents on Britain's mainline railways

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This paper extends the author's previous statistical analyses of fatal train accidents on the national railway system of Great Britain to include data on speeds and further data on the rolling stock of the trains involved in the accidents. The objective is to explore whether such information is useful in improving projections of fatalities. It is found that the mean number of fatalities in accidents involving loaded or empty passenger trains does indeed rise with impact speed, with different estimated relationships for multiple unit and locomotive hauled passenger stock. However, the actual numbers of fatalities in individual accidents are very variable. An unexpected finding is that there has been only a slight upward trend over time in the mean speeds of trains in accidents, and this is not statistically significant from zero; therefore there is little reason to expect increased mean fatalities on this account. A direct estimate of the trend in mean fatalities per accident over time shows that this has been almost flat; for that reason the author's preferred projection is now to assume that mean fatalities per accident will remain constant at the overall mean in the data, currently 4.0. This gives projections about 10% higher than the author's most recent post-Ladbroke Grove projections.

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# 1. INTRODUCTION

In recent years, the author has assembled and analysed statistical data on fatal train collisions, derailments and buffer overruns on running lines of the national railway system of Great Britain since 1967. The data now cover the 34 years 1967 to 2000. The data have been used to estimate trends and frequencies of accidents and fatalities, to project these into the future, and to estimate the reductions in mean numbers of accidents and fatalities that might be expected from specified safety measures. The general methodology is described in Evans (2000a); the end-of-1999 estimates are in Evans (2000b), and the end-of-2000 estimates are in Evans (2001).

This paper describes an extension of the work to add and analyse data on the speeds of the trains involved in the accidents and further data on the rolling stock. The objectives are to investigate what relationships exist between the mean number of fatalities in accidents, the types of rolling stock, and the speeds of the trains, and to consider whether and how such relationships might affect projections of fatalities and the benefits of safety measures. The work is carried out for HM Railway Inspectorate (HMRI), and the objectives are intended to assist HMRI fulfil recommendation 43 of the Southall Accident Inquiry Report (Uff, 2000), which was that

> "HMRI should keep under long-term review the effect of speed on numbers of casualties in rail accidents" (page 218).

The paper continues as follows. Section 2 presents the data on fatal accidents, rolling stock and impact speeds and fatalities. Section 3 presents the results of statistical analyses. Section 4 considers the implications of the results for projections of fatalities. Section 5 summarises the conclusions. Appendix 1 and Table A1 contain the detailed accident data, including the new data on train speeds and rolling stock; Appendix 2 and Table A2 give statistical information on the results of regressions of fatalities on train speeds for accidents involving loaded or empty passenger trains.

# 2. DATA ON FATAL ACCIDENTS AND IMPACT SPEEDS

## 2.1 Fatal accidents

Appendix Table A1 lists the 77 fatal train collisions, derailments and buffer overruns on running lines of BR or Railtrack from 1967 to 2000. The information is based on accident reports or other official information, and the dataset is accepted by the industry and by the Health and Safety Executive (HSE) as being complete, so far as is known.

The list of accidents and most of the information in Table A1 have been published and discussed elsewhere, such as in Evans (2000b). Previous discussion is not repeated here, except to note that the consequences of accidents are measured by the numbers of fatalities, and that all the data and discussion in the paper refer to 'actual' fatalities rather than 'equivalent fatalities', which is the Railway Group's term for a weighted combination of injuries and fatalities. So long as the current weights for injuries are retained, an accepted guideline for converting 'actual' to 'equivalent' fatalities in train accidents is to multiply by about 1.5. The information in Table A1 on whether accidents were ATP-preventable is not used in this paper, but is included for completeness.

## 2.2 Impact speed data

The penultimate column of Table A1 is new. That column presents the data assembled for the present work on the speeds of the trains involved in the accidents. In the case of train collisions, the speed recorded for each accident is the 'closing speed', that is the sum of the speeds if the two trains involved were moving towards each other, the difference in the speeds if they were moving in the same direction, or the speed of the moving train if one was stationary. In the case of buffer stop overruns, the speed is that at which the train hit the buffers. In the case of derailments, the speed is that at which the train derailed.

The primary sources of information on impact speeds are HMRI accident reports. Most of these give impact speeds, either in the form of a point estimate or in the form of a range. Where the information is given as a range, the author has recorded the centre of the range. The coverage of the discussion of speeds varies considerably from report to report; there are occasionally conflicts of evidence concerning the speeds, in which case this author has adopted the conclusion of the inspecting officer. Speeds are almost always recorded in miles per hour; the author has converted these to kilometres per hour, and then rounded the result to the nearest whole number of kilometres per hour. Thus, for example, the trains in the Ladbroke Grove accident are recorded as having a closing speed "in the region of 130 mph" (HSE, 2000, paragraph 2.1); converting this figure and rounding gives 209 km/hour, as shown in Table A1. The author has kept a record of references to the page or paragraph numbers in the HMRI reports which provide the speed data, so that the information can be traced, but these references are not included in Table A1.

However, not all fatal train accidents have HMRI reports, and not all HMRI reports give information on impact speeds. In these cases, the author has made use of whatever alternative sources of information are available, such as copies of internal rail inquiry reports, where these exist. In four cases AEA Technology Rail (formerly BR Research) have been able to provide a figure from their internal sources.

In the end, the author has been able to obtain impact speed data for all of the 59 accidents involving loaded or empty passenger trains, and for 15 of the 18 not involving passenger trains. This makes a total of 74 out of the 77 accidents in 1967-2000. The accidents for which information is missing (or in one case not applicable) are identified in Table A1. Given what is known about the missing accidents, it is clear that their inclusion would not materially affect the conclusions of this paper.

### 2.3 Train and rolling stock data

The author's previous analyses of accident consequences have distinguished between accidents involving passenger trains and those not involving passenger trains; passenger train accidents have been subdivided between those involving Mark 1 rolling stock, and those involving post-Mark 1 stock, which is generally more crashworthy.

The present analysis takes the analysis of passenger rolling stock a step further by distinguishing between accident involving multiple unit trains, and those involving only locomotive-hauled trains. Other things being equal, one might expect fewer fatalities in locomotive-hauled trains because there are no passengers in the front vehicles.

Accidents involving both a multiple unit and a locomotive-hauled passenger train (including Ladbroke Grove) have been classified as 'multiple unit', because the presence of the multiple unit is likely to be the more influential in determining the mean number of fatalities. High speed diesel trains, which have a locomotive at each end, are classified as locomotive-hauled. The derailment at Polmont in 1984 is classified as 'multiple unit', because the train was being driven from the leading passenger vehicle like a multiple unit, though it had a locomotive at the rear.

In the process of re-reading the HMRI reports, the author uncovered an error that he himself made some years ago concerning the classification of rolling stock. The error is that he recorded the rolling stock in the single-fatality accident at Chinley in 1986 as 'post-Mark 1', when in fact it was 'Mark 1'. The error has been present in previous versions of Table A1, but is corrected in the present version.

# 3. RESULTS

## 3.1 Distribution of numbers of fatalities in accidents

Table 1 presents the distributions and mean numbers of fatalities in all the 77 accidents. The table shows accidents involving passenger and not involving passenger stock separately, and subdivides those involving passenger stock in two different ways: first by whether a multiple unit or only locomotive-hauled stock was involved, and secondly by whether Mark 1 stock (including two accidents with pre-Mark 1 stock) or post-Mark 1 stock was involved. (The fact that the 37 accidents involving multiple units have the same total number of fatalities - 210 - as the 42 accidents involving Mark 1 stock is just a numerical coincidence.) Figure 1 shows a histogram of the fatalities in passenger and non-passenger train accidents.

**Table 1**
**Distributions of numbers of fatalities in accidents: 1967-2000**

| Type of stock | Number of accidents with given number of fatalities | | | | | | | | | | | | | | | Total fata- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **9** | **10** | **13** | **31** | **35** | **49** | **All** | **lities** | **acc.** |
| **Passenger stock**: | | | | | | | | | | | | | | | | |
| **Multiple unit** | 15 | 7 | 2 | 4 | 3 | | 1 | 1 | | 1 | 1 | 1 | 1 | 37 | 210 | 5.68 |
| **Loco hauled** | 10 | 2 | 1 | 1 | 2 | 3 | 2 | | 1 | | | | | 22 | 73 | 3.32 |
| **Pre- & Mark 1** | 15 | 8 | 1 | 4 | 5 | 3 | 2 | 1 | 1 | | | 1 | 1 | 42 | 210 | 5.00 |
| **Post-Mark 1** | 10 | 1 | 2 | 1 | | | 1 | | | 1 | 1 | | | 17 | 73 | 4.29 |
| **All passenger** | 25 | 9 | 3 | 5 | 5 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 59 | 283 | 4.80 |
| **Non-passenger** | 12 | 5 | 1 | | | | | | | | | | | 18 | 25 | 1.39 |
| **All** | 37 | 14 | 4 | 5 | 5 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 77 | 308 | 4.00 |

A key point from Table 1 and Figure 1 is that the distribution of fatalities is very skew. Most fatal accidents have small numbers of fatalities, but three accidents in the past 34 years have had large numbers of fatalities: Hither Green in 1967 with 49 fatalities, Clapham Junction in 1988 with 35 fatalities, and Ladbroke Grove in 1999 with 31 fatalities[1].

[1]It may be noted that two other high-fatality railway accidents have occurred since 1967, both on the London Underground. These were the buffer overrun at Moorgate in 1975 with 43 fatalities, and the station fire at Kings Cross in 1987 with 31 fatalities. They are excluded from the present paper because they were not on the main line railway system; in addition, Kings Cross was not a train accident.

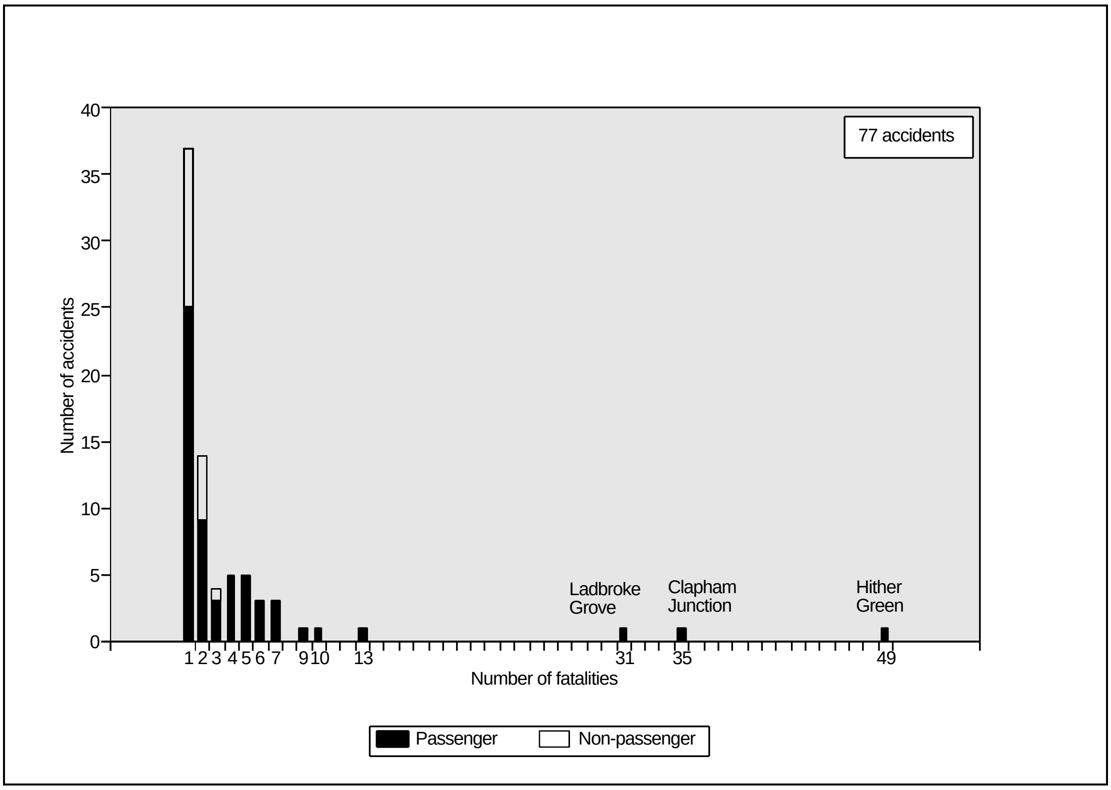


**Figure 1: Distribution of numbers of fatalities in train accidents: 1967-2000**

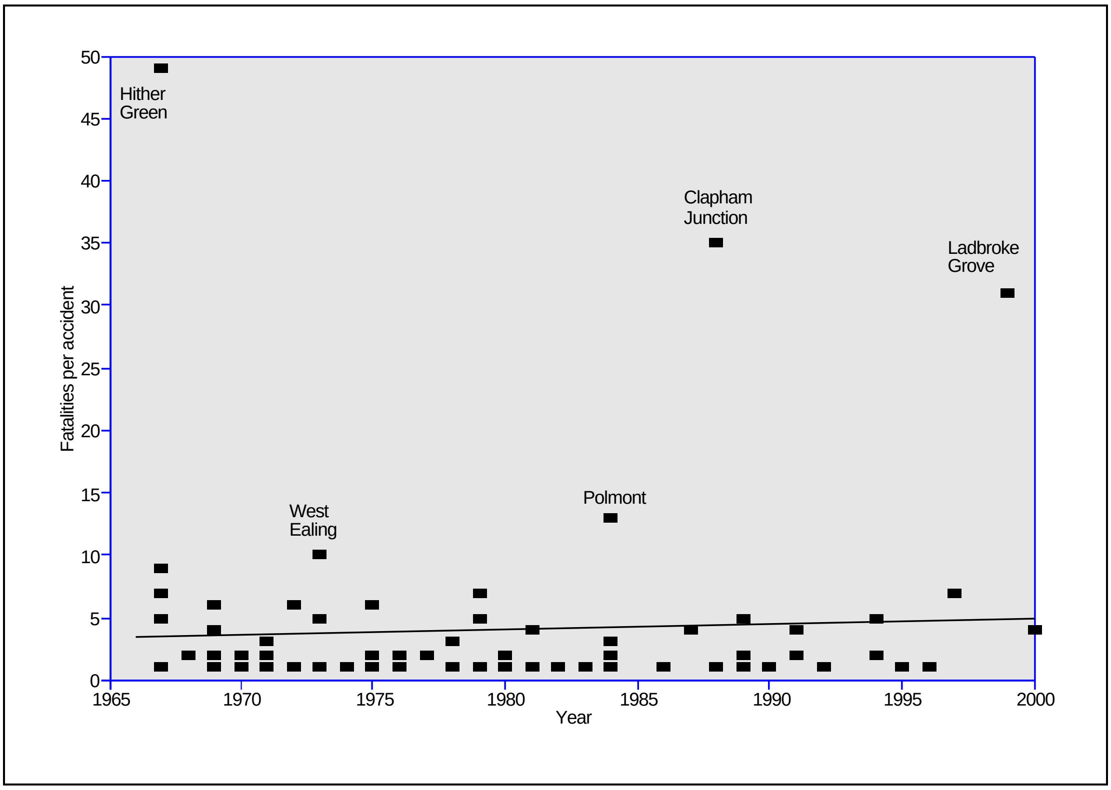


**Figure 2: Fatalities in fatal train accidents: 1967-2000**

## 3.2 Distribution of fatalities per accident over time

Figure 2 plots the number of fatalities in each accident by the year of the accident, together with the least-squares regression line of fatalities per accident on time. It can be seen that the regression line has a very slight upward slope, but this slope is far from statistically significantly different from zero: that is, the data are quite consistent with the hypothesis that the mean number of fatalities per accident has been constant over the long term. The equation of the fitted line is:

$$f = 3.47 + 0.040y$$

where $f$ is the mean number of fatalities per accident, and $y$ is the date measured in years since 1966 (for example, $y = 1$ for 1967; $y = 34$ for 2000). The standard error of the slope of the line of 0.040 is 0.092.

## 3.3 Impact speeds

As noted in section 2.2, information on impact speeds is available for all 59 accidents involving passenger stock, and for 15 out the 18 accidents involving only non-passenger trains.

The overall average impact speed in the 74 accidents was 75 km/hour; the average for passenger trains was 79 km/hour, and for non-passenger trains was 63 km/hour. The average speed of the passenger trains involving multiple units was 67 km/hour, and of those involving only locomotive hauled trains was 98 km/hour. The average speed of the passenger trains involving predominantly Mark 1 rolling stock was 70 km/hour, and of those involving predominantly post-Mark 1 rolling stock was 104 km/hour.

Figure 3 shows the distribution of impact speeds in the 74 accidents, distinguishing passenger from non-passenger stock. It shows that the distribution of impacts speeds is much less skew than that of fatalities. The speeds in the Ladbroke Grove and Hatfield accidents were 209 and 185 km/hour respectively, which makes those the two highest-speed accidents since 1967. The third highest was 157 km/hour in the collision at Colwich in 1986.

## 3.4 Trends in impact speeds over time

Figure 4 plots the impact speed of each of the 57 accidents involving loaded or empty passenger trains against the year in which the accident occurred, together with the least-squares regression line of speed on year. Accidents involving multiple units are distinguished from those involving locomotive hauled trains, and the seven highest-speed accidents are identified by their location.

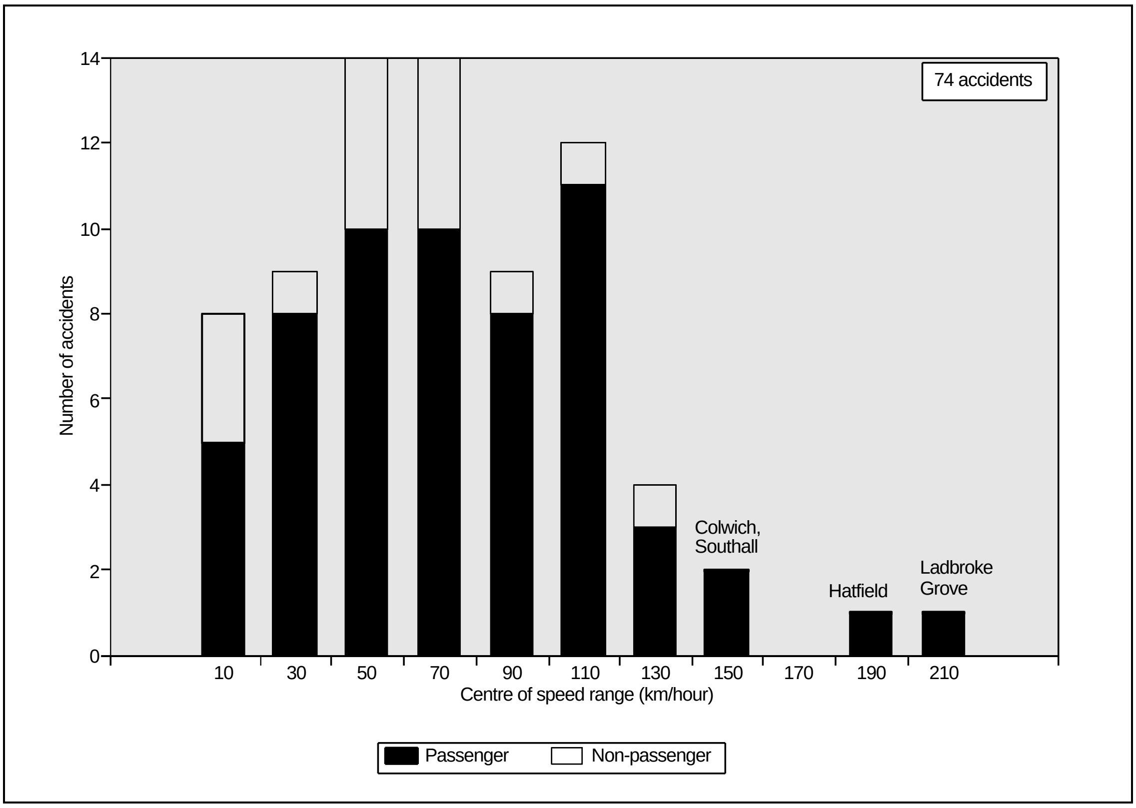


**Figure 3: Distribution of speeds in fatal train accidents: 1967-2000**

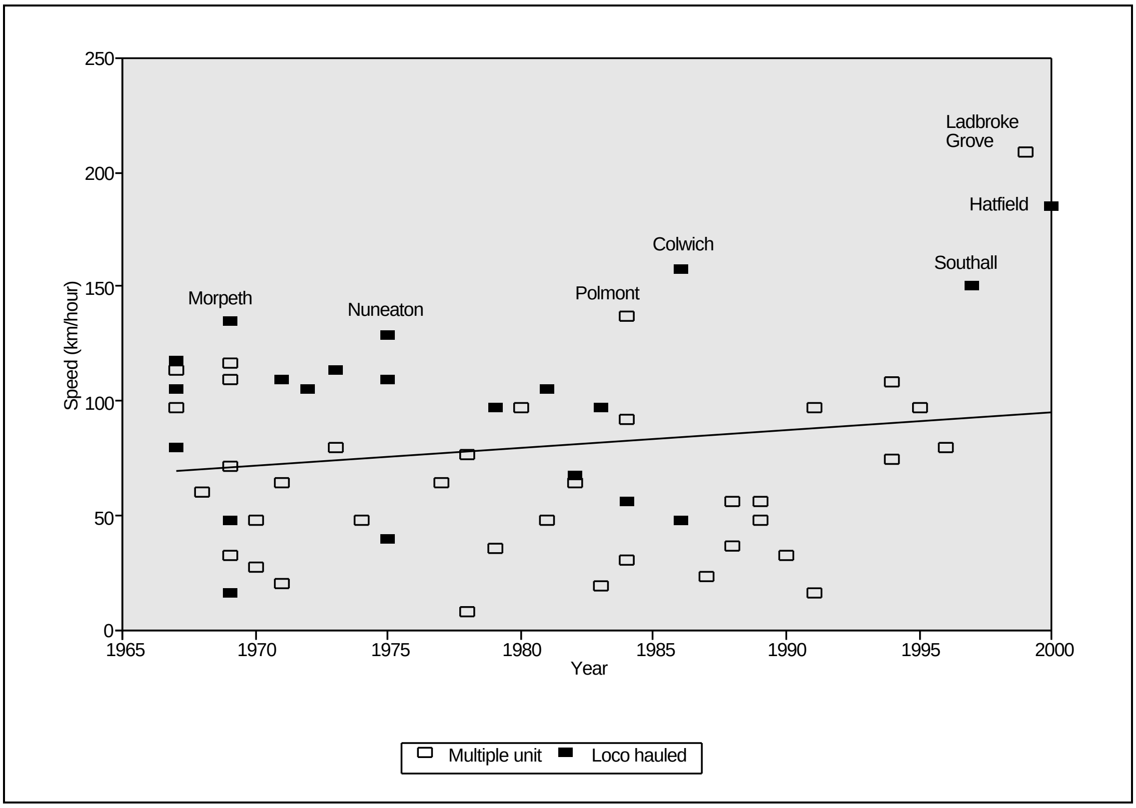


**Figure 4: Speeds in fatal train accidents: 1967-2000**

Figure 4 shows the unexpected finding that, notwithstanding the high speeds in the accidents at Ladbroke Grove and Hatfield, the mean impact speed in accidents has only a modest upward slope, and this is not statistically significantly different from zero. That implies that the data are consistent with the hypothesis that the mean impact speed has remained unchanged over the long-term. The equation of the line is:

$$s = 68.6 + 0.765y$$

where $s$ is the mean impact speed in kilometres/hour, and $y$ is the date measured in years since 1966. The standard error of the slope is 0.587 km/hour per year. The slope implies a mean increase in impact speeds of 7.65 km/hour per decade.

The mean impact speed in the 15 non-passenger accidents likewise shows no significant trend over time. The central estimate of the slope of the regression line of mean speed on year is very slightly negative.

The absence of a significant trend in mean impact speed is unexpected because it is widely accepted that the performance of trains, measured in terms both of speed and acceleration, appears to have improved over the long term, though the author is not aware of a quantification of this trend (and it is also not clear exactly what should be measured in the present context). However, whatever might have been the improvement in train performance, it is not significantly reflected in the impact speeds in accidents. Therefore, one must presume that the effects of increased train performance have been counterbalanced by other factors, particularly long-term improvements in braking.

It follows that, even if there is a relationship between mean impact speeds and fatalities, there would not be more than weak statistical grounds for projecting an increase in the future mean numbers of fatalities per accident for that reason.

### 3.5 Fatalities and impact speeds: passenger trains

Figure 5 plots the numbers of fatalities against impact speeds for each of the 59 accidents involving passenger rolling stock. The three high-fatality accidents clearly stand out, though the figure shows that two of them - Clapham Junction and Hither Green - were not at conspicuously high speeds. Indeed, the impact speed at Clapham Junction (56 km/hour) was well below the average.

The general impression given by Figure 5 is that the number of fatalities and the impact speed in accidents are slightly correlated in the expected direction: there seems to be a slight tendency for the mean number of fatalities to rise with impact speed. This is supported by the statistical analysis discussed below and in Appendix 2. However, it is also clear that the relationship is not at all close: even given the impact speed of an accident, the number of fatalities is still extremely variable.

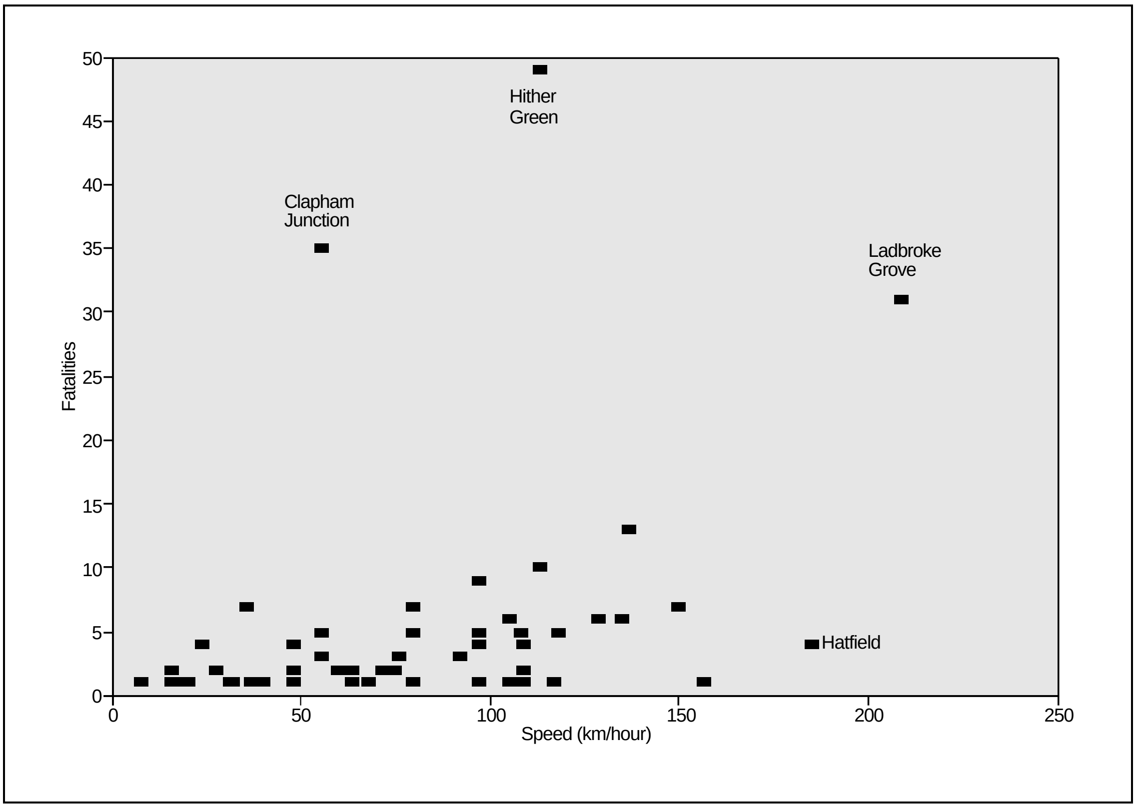


**Figure 5: Fatalities and speeds in fatal passenger train accidents: 1967-2000**

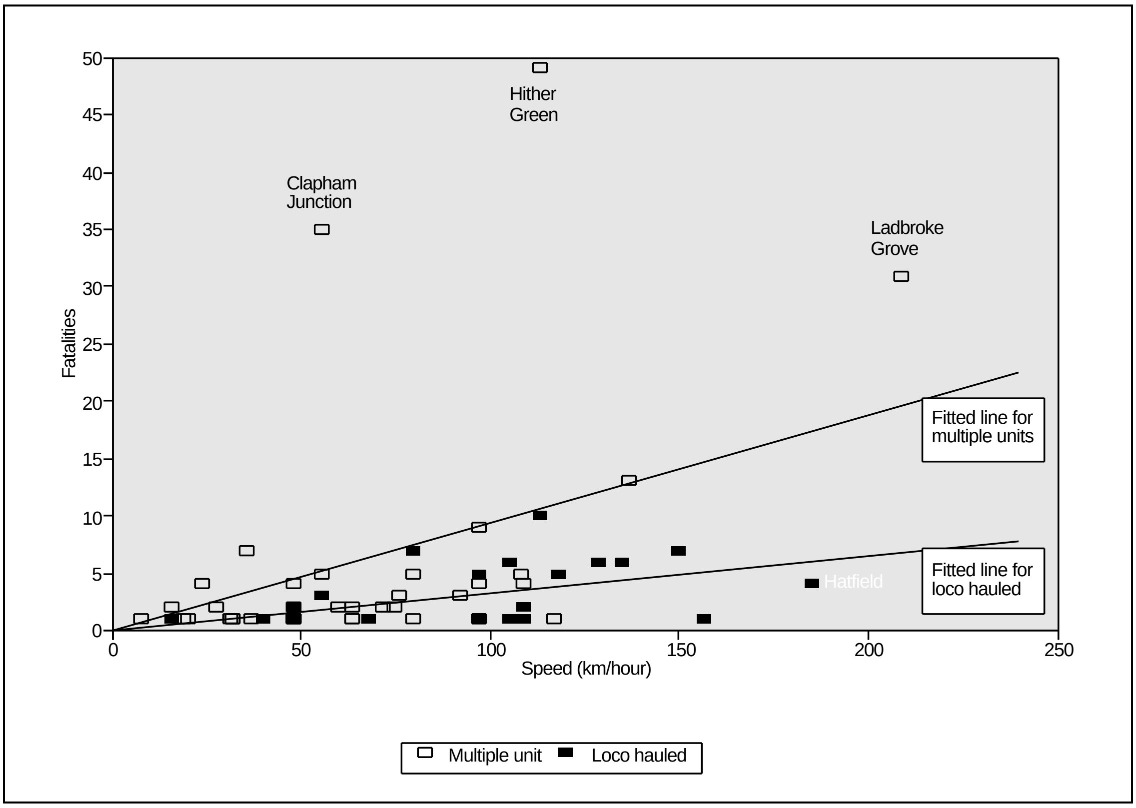


**Figure 6: Fatalities and speeds by type of passenger train: 1967-2000**

The author has fitted a number of statistical models to the data in Figure 5. The dependent variable is the number of fatalities in accidents, and the explanatory variables are the impact speed and the type of rolling stock (multiple unit or locomotive hauled and Mark 1 or post-Mark 1). The models have been fitted by the usual technique of 'least squares'. The results are discussed in more detail in Appendix 2. It should be said that the standard statistical tests using 'least squares' models depend on the assumption that the dependent variable has a bell-shaped normal distribution, but it was noted in section 3.1 that the distribution of fatalities in passenger train accidents is in fact very skew. It might be possible to employ more elaborate statistical techniques to allow for this to some extent, but it seems unlikely that different techniques would alter the qualitative conclusions, even if they altered the quantitative conclusions to some degree.

The qualitative conclusions from the statistical analysis are the following:

- There is clear evidence that the mean number of fatalities in fatal accidents rises with impact speed.

- There is evidence that at any given speed, the mean number of fatalities per accident is higher in accidents involving multiple units than in accidents involving only locomotive hauled passenger stock.

- Nevertheless, the relationships between fatalities and impact speed are not close. That is, even given impact speed in an accident and the type of stock, the actual number of fatalities is very variable.

- The mean number of fatalities in accidents with post-Mark 1 stock is not statistically significantly lower than that with Mark 1 stock, even at the same impact speed.

A simple quantitative expression for the linear relationship between mean fatalities, $f$, and impact speed, $s$, measured in km/hour, for all fatal passenger train accidents taken together is:

$$f = 0.062s$$

The corresponding linear relationship for multiple units is:

$$f = 0.093s$$

and the relationship for locomotive hauled stock is:

$$f = 0.033s$$

These lines are derived in Appendix 2. The lines for multiple units and locomotive hauled stock are shown in Figure 6, together with the data points from Figure 5, now subdivided between the two classes of stock. It is clear that the numbers of fatalities in individual accidents are still widely dispersed about the lines. It is also clear that, given the dispersion, a wide range of different lines would fit the data almost equally well (or equally poorly).

As noted in Appendix 2, one of the reasons why the multiple-unit/ locomotive-hauled distinction is an effective statistical discriminator is that all three of the highest fatality accidents in the past 34 years - Hither Green, Clapham Junction and Ladbroke Grove - have involved multiple units. The highest-fatality accident involving only locomotive-hauled stock was the derailment at West Ealing in 1973 with 10 fatalities. Without the three highest-fatality accidents, the multiple unit/

locomotive-hauled distinction would be of less importance than the Mark 1/ Post-Mark 1 distinction, and both would be statistically significant after allowing for impact speed.

A further possible categorisation of fatal accidents is by whether they were collisions or derailments. The author has explored this categorisation along the lines of the analyses in Appendix 2. It does not provide significantly better fits of mean fatalities on speeds than the results discussed above.

It is possible that more detailed data for each accident, including other factors besides speed and type of rolling stock, such as passenger loading, would provide a better-fitting statistical model of fatalities than the present one. However, there are so many chance factors in the occurrence of accidents that it seems unlikely that anything approaching a close fit could be achieved.

### 3.6 Fatalities and impact speeds: non-passenger trains

Figure 7 plots the numbers of fatalities against impact speeds for each of the 15 accidents involving only non-passenger trains. It should be noted that the scale on the vertical (fatality) axis is quite different from that in the corresponding Figure 5 for passenger trains, because, as shown in Table 1, the highest number of fatalities in any non-passenger accident in the data is 3, compared with 49 for passenger accidents. The speed range is also shorter.

Figure 7 suggests that there is no systematic relationship between mean fatalities and impact speed in non-passenger accidents. Statistical analysis confirms this: the slope of the regression line of number of fatalities on speed is close to zero, and far from significantly different from zero. Therefore it is reasonable to presume that the mean number of fatalities in non-passenger accidents is the overall average of 1.39, irrespective of the speed.

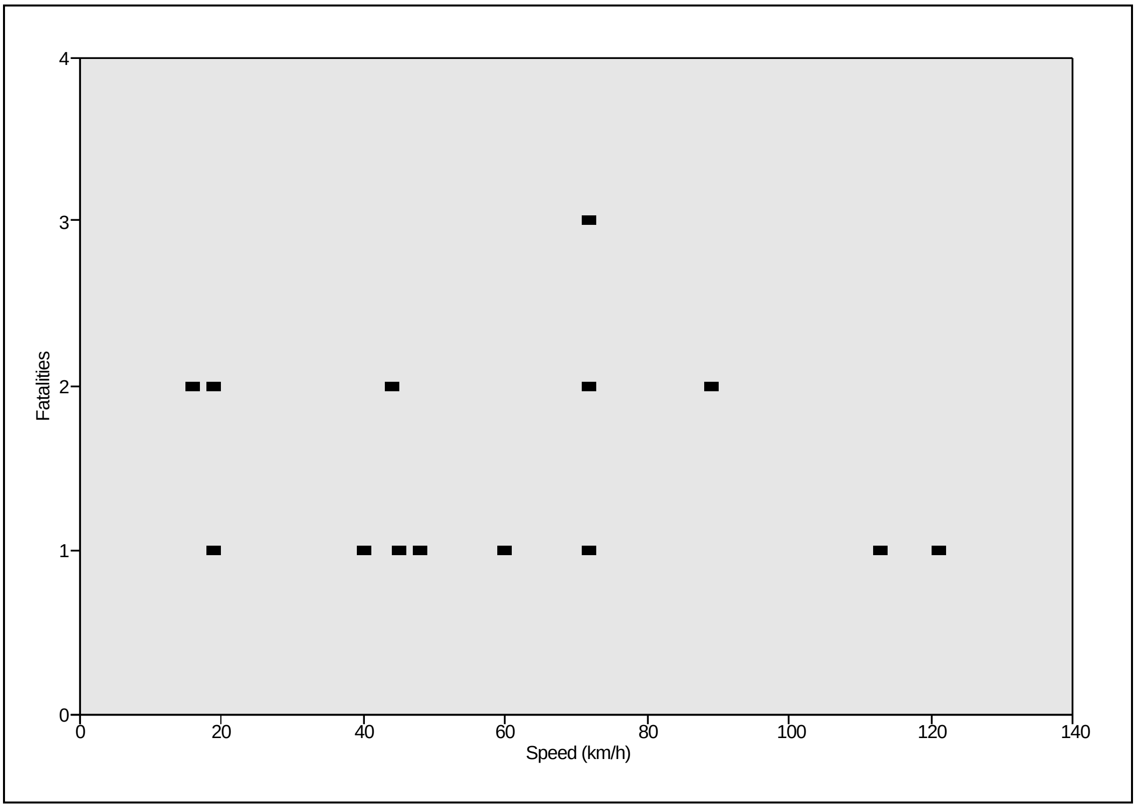


**Figure 7: Fatalities and speeds in non-passenger train accidents: 1967-2000**

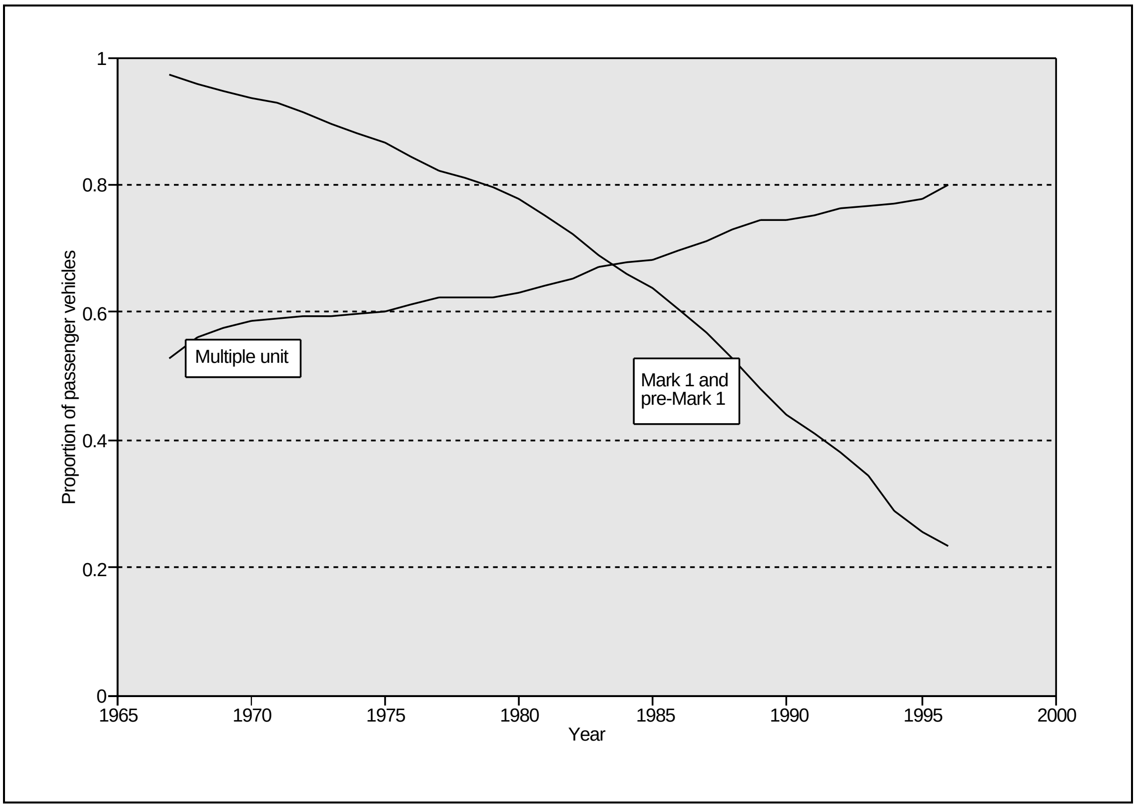


**Figure 8: Composition of passenger vehicle fleet: 1967-1996**

# 4. PROJECTIONS OF FATALITIES PER ACCIDENT

## 4.1 Past projections based on Mark 1 and post-Mark 1 stock

In his previous work on train accident risk (Evans 2000a), the author projected the mean number of fatalities in future accidents by making separate estimates of the mean number of fatalities per accident for Mark 1, post-Mark 1, and non-passenger accidents; he then presumed that these means would also apply in the future. He did not previously consider impact speeds.

Until the Ladbroke Grove accident, the mean number of fatalities per accident with post-Mark 1 stock was about half that with Mark 1 stock, and the difference was statistically significant. Moreover, engineering analyses, particularly by Lewis (1997), supported the conclusion that post-Mark 1 rolling stock is more crashworthy. The HSE's unequivocal view in their guidance to the Railway Safety Regulations 1999 was that:

> "[Mark 1] rolling stock does not have the crashworthiness of trains built to modern standards, and is likely to suffer far more damage in a collision." (HSE, 1999, paragraph 45.)

The next step in the author's projections was the observation that the proportion of Mark 1 stock in the passenger fleet had steadily declined from 97.2% in 1967 (including a little pre-Mark 1 stock) to 23.4% in 1996 (Evans, 1997), and was set to decline to zero by 2003 under the Railway Safety Regulations 1999 (HSE, 1999). The downward-sloping curve in Figure 8 charts the decline in the proportion of Mark 1 vehicles from 1967 to 1996. Thus it was reasonable to expect that the mean number of fatalities in passenger stock accidents would gradually decline from about the Mark 1 level in 1966 to the post-Mark 1 level by 2003, even though it was recognised that the number of fatalities in individual accidents could be very variable.

The Ladbroke Grove accident was by far the most serious accident to have occurred with modern rolling stock, and it raised the mean number of fatalities per accident in post-Mark 1 by about 70%, to a level that was not very much less than that of Mark 1 stock, and not statistically significantly different from it. Table 1, and the top panel of Appendix Table A2, show that this is still the position. Thus one must conclude that, although post-Mark 1 stock may be more crashworthy than earlier stock, other trends may be overlaid on the trend towards a more crashworthy fleet, so that the mean number of fatalities per accident cannot necessarily be expected to fall. In the light of the preceding findings of this paper, the obvious possibilities are trends in impact speeds and trends in the proportion of multiple units in the fleet.

## 4.2 Effect of impact speed

Section 3.5 of this paper shows that mean fatalities rise with the impact speed in accidents, and that they may be reasonably assumed proportional to speed, with different constants of proportionality for different kinds of rolling stock.

It would follow that an increase in mean fatalities per fatal accident could be expected *if* there were an upward trend in the speeds of trains in accidents. However, the results of section 3.2 show that the upward trend in speeds in accidents is only slight, and not statistically significantly different from zero, even though the two most recent accidents (Ladbroke Grove and Hatfield) were the highest-speed accidents in the data. The evidence on speeds thus provides only weak evidence to expect an increase in mean fatalities per accident.

### 4.3 Multiple unit and locomotive hauled stock

Section 3.5 shows that the constant of proportionality of mean fatalities on speed appears to be higher for multiple units than for locomotive-hauled stock: in other words, at any given impact speed the mean number of fatalities is higher for multiple units than for locomotive-hauled stock.

Furthermore, the proportion of multiple units in the fleet has been rising. The upward curve in Figure 8 charts the proportion of multiple unit passenger vehicles, which rose from 52.8% of the fleet in 1967 to 80.1% in 1996. The source of these data is the same as the data on the proportion of Mark 1 vehicles in the fleet, namely the end-of-year stock data in successive British Railways Board (BRB) annual reports from 1966 until 1996, analysed in detail in Evans (1997). The BRB reports ceased to have useful information of this nature after 1996, but it appears that the proportion of multiple units in the fleet has continued to rise.

The increase in the proportion of multiple units would be expected to lead to a rise in mean fatalities per accident, other things being equal. That is possibly one of the factors counteracting the improvements in crashworthiness.

### 4.4 Direct estimation of the trend in fatalities per accident

An alternative to considering trends in speeds and in the composition of the passenger rolling stock fleet, is to estimate trends in fatalities per accident over time directly. That was done in section 3.2 and Figure 2 of this paper. That analysis includes accidents involving non-passenger stock as well as passenger stock.

It was found that the trend in fatalities per accident was almost flat over the long term; the central estimate of the trend was slightly upwards, but it was far from statistically significant from zero. In view of its non-significance, the author would treat the trend as flat[2]. The flat trend can be thought of as the resultant of various favourable and unfavourable factors, including greater crashworthiness, changes in fleet composition, and the weak evidence on trends in speeds.

### 4.5 Discussion of projections

It would be possible to project mean fatalities per accident by extrapolating the trends in speeds and in the composition of the fleet, and combining these with the statistical estimates of the effects of these quantities on mean fatalities per accident derived section 3.5 and Appendix 2. However, the author now considers that would be over-elaborate for the projection of the overall mean, with too many assumptions and too large a standard error. The author prefers the extrapolation of the directly estimated trend of mean fatalities on time. As noted in section 4.4, that trend currently happens to be flat, so that extrapolating the trend reduces to the very simple projection that future mean fatalities per accident will remain constant at the current mean of 4.00 fatalities per accident,

[2]It may be noted that this treatment is different from the author's treatment of another trend that is almost flat and not statistically significantly different from zero, namely the trend in the frequency of accidents due to signals passed at danger protecting conflicting movements (C-SPADs in Table A1), for which the end-of-1999 estimated trend was +1.4% per year, with a standard error of 2.7% per year (Evans, 2000b; quoted also in Davies, 2000). The author did not treat that trend as zero. The reason for the differing treatments is that the C-SPAD trend was one of a family of four such accident frequency trends, the others of which were not zero, and it is desirable to treat all the members of such families in a similar way.

including non-passenger accidents. That figure is given in the bottom right-hand corner of Table 1. The figure implies about 6 'equivalent fatalities' per accident, when injuries are included.

The reasons why the more complex projections would be over-elaborate is that they would rely too much on separate projections of the various factors presumed to influence fatalities per accident, and too much on the detailed statistical estimates in Appendix 2, some of which have large standard errors. The possibility of high-fatality accidents, and the presence of a small number of such accidents in the data, are reasons for basing projections on estimates taken over large rather than small sets of the data; larger sets of data are more likely to include high-fatality accidents at roughly the correct frequency, whereas small sets may either not include a high-fatality accident at all or be dominated by a high-fatality accident, thus giving projections that are either too low or too high respectively.

The author's previous long-term estimates of the mean number of fatalities per accident were 3.62 made at the end of 1999, and 2.26 made before the Ladbroke Grove accident, both based on a combination of the post-Mark 1 passenger stock and the non-passenger averages[3]. Using the current overall mean of 4.00 thus increases the projections of fatalities in train accidents by a further 10% compared with the end-of-1999 estimate, which was itself about 70% higher that the pre-Ladbroke Grove projection.

Whatever figures are used for projecting the mean number of fatalities, the actual outcome in any particular period is almost certain to be different, possibly very different, because of the widely varying outcomes of individual accidents, as well as variations in the frequencies of accidents. It is to be expected that most fatal accidents will have fewer fatalities than the mean, but there is always the possibility of a high-fatality accident.

[3]Both of these figures are slightly higher than those published at the time, because they incorporate a correction for the classification error mentioned at the end of section 2.3.

# 5. CONCLUSIONS

The principal conclusions of this paper are the following.

(a) Data on impact speeds have been assembled for all 59 fatal accidents involving loaded or empty passenger trains that occurred on running lines of the national railway system in the 34 years 1967-2000, and for 15 out of the 18 non-passenger train accidents (section 2.2).

(b) Accidents involving passenger rolling stock have been classified according to whether multiple units or only locomotive hauled stock was involved, as well as by the previous classification of Mark 1 or post-Mark 1 stock (section 2.3).

(c) The distribution of fatalities in train accidents is very skew. Most fatal accidents have a small number of fatalities, but there have been three high-fatality accidents on the national railways since 1967, including Ladbroke Grove (section 3.1).

(d) Taking all accidents together, the long-term trend in mean fatalities per accident has been almost flat (section 3.2).

(e) The average impact speed of the trains in all accidents for which information is available is 75 km/hour. The distribution of speeds is more bell-shaped than that of fatalities. The two recent accidents at Ladbroke Grove and Hatfield are those with the highest speeds (section 3.3).

(f) Notwithstanding the high speeds at Ladbroke Grove and Hatfield, there is only a slight upward trend over time in the mean impact speeds of passenger trains, which is not statistically significant from zero. The trend for non-passenger trains is also not significant (section 3.4).

(g) For passenger stock accidents there is a statistically significant relationship between the mean number of fatalities and impact speed: a simple description is that mean fatalities may be regarded as rising in proportion to speed, with constants of proportionality that are different for multiple units and locomotive hauled stock. The estimated constants of proportionality are 0.62, 0.93 and 0.33 mean fatalities for each 10 km/hour in impact speed for all passenger stock accidents taken together, for multiple units and for locomotive hauled stock respectively. However, the relationship between the number of fatalities and train speed is not at all close, because the actual number of fatalities in accidents is very variable (section 3.5 and Appendix 2).

(h) For accidents involving only non-passenger trains there is no significant relationship between the mean number of fatalities and train speed (paragraph 3.6).

(i) The author's preferred method of projecting mean fatalities per accident is now to extrapolate the directly estimated trend of mean fatalities per accident on time. As this trend is currently flat, this approach reduces to assuming that mean fatalities will remain constant at the overall average, currently 4.0 fatalities per accident, including non-passenger trains. This gives projections about 10% higher than the author's most recent post-Ladbroke Grove projections (section 4.5).

(j) The flat trend can be regarded as the resultant of a combination of favourable and unfavourable trends. A favourable trend is towards more crashworthy rolling stock; an unfavourable trend is towards more multiple units; in addition, the central estimate of the trend in speeds is slightly upwards, though this is not statistically significantly different from zero (sections 4.2-4.4).

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# APPENDIX 1

**Table A1:**
**Fatal collisions, derailments and overruns: national railway system: 1967-2000**

| 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.
†Figure provided by AEA Technology Rail; all others are from accident reports or other HMRI sources.

**Table A1 (continued):
Fatal collisions, derailments and overruns: national railway system: 1967-2000**

| 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 |
| 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 |
| 12. 6.67 | Headstone Lane | Dislodged brake block | No | Non-passenger | Not app | 1 |
| 5. 3.67 | Connington South | Derailment | No | Mark 1 LH | 118 | 5 |
| 28. 2.67 | Stechford | Train collision | No | Mark 1 MU | 97 | 9 |

# APPENDIX 2

## STATISTICAL MODELLING OF EFFECT OF SPEED ON MEAN FATALITIES IN PASSENGER TRAIN ACCIDENTS

Table A2 presents key statistical results from 'least squares' regressions of the number of fatalities on train speed for each accident involving loaded or empty passenger trains with a number of different assumed models. It should be said that the results in Table A2 are not exhaustive; other model variants are possible, but none investigated by the writer add further useful results.

The model variants in Table A2 are presented in three groups: (a) in which mean fatalities are assumed independent of impact speed, which is therefore ignored; (b) in which mean fatalities are presumed to be a general linear function of speed; and (c) in which mean fatalities are presumed to be proportional to speed. Group (c) is a specialisation of (b), in which the line is forced through the origin; this is simpler than (b), and plausible because it is reasonable to presume that zero impact speed implies zero fatalities.

Within each of the three groups, results for four different model variants are presented: (1) where all passenger stock is presumed to have the same parameters; (2) where multiple units are presumed to have different parameters from locomotive-hauled stock; (3) where Mark 1 stock is presumed to have different parameters from post-Mark 1 stock; and (4) where all four combinations of multiple unit/ locomotive hauled/ Mark 1/ post-Mark 1 stock are presumed to have different parameters.

For each model variant, Table A2 gives the number of degrees of freedom, which is the number of observations, 59, less the number of fitted parameters, the residual sum of squares of the data about the fitted mean or line, and for groups (a) and (c) the parameter estimates - means or slopes - with their standard errors. The parameter estimates are omitted for group (b) because they are not used in what follows, and this avoids unnecessary detail.

The residual sum of squares in Table A2 is the sum of the squares of the differences between the observed fatalities in each accident and the fatalities predicted for that accident by the model variant being considered. Clearly, the smaller is this sum, the better is the fit of the model variant to the data. The residual sum of squares divided by the degrees of freedom is the mean square deviation, or the residual variance. The square root of the residual variance is the residual standard deviation.

If the distribution of fatalities in accidents had a bell-shaped Normal distribution (which it does not - see Figure 1), the test of the statistical significance of one parameter added to the model (and the degrees of freedom thus reduced by 1) is that the reduction in the residual sum of squares would need to be at least about 4 times the residual mean square. (The figure of about 4 is the 5% point of the $F_{1,55}$ distribution.) In most variants of the model, the residual mean square is about 60 (that is, about 3300/55); therefore the required reduction in the sum of squares for a parameter to be significant is about $4 \times 60 = 240$; the corresponding required reduction for two simultaneous parameters to be significant (derived from the 5% point of the $F_{2,55}$ distribution) is about 380, and for four simultaneous parameters is about 600. We use these tests as a screening device for the models, even though fatalities are not Normally distributed.

**Table A2: Statistical results for variants of the model for the relationship between mean fatalities and speed**

| Variant of model | Degrees of Freedom | Residual sum of Squares | Estimated parameters (standard errors in brackets) | |
|---|---|---|---|---|
| **(a) Mean fatalities assumed independent of speed** | | | **Mean fatalities per accident** | |
| (a1) All passenger stock together | 58 | 4,128 | All: | 4.80 (1.10) |
| (a2) MU/LH distinguished | 57 | 4,051 | MU: | 5.68 (1.71) |
| | | | LH: | 3.32 (0.58) |
| (a3) Mk1/PMk1 distinguished | 57 | 4,122 | Mk1: | 5.00 (1.36) |
| | | | PMk1: | 4.29 (1.83) |
| (a4) All four combinations | 55 | 4,038 | MU Mk1: | 5.57 (2.01) |
| | | | MU PMk1: | 6.00 (3.38) |
| | | | LH Mk1: | 3.86 (0.78) |
| | | | LH PMk1: | 2.38 (0.78) |
| **(b) Mean fatalities assumed to be a general linear function of speed** | | | | |
| (b1) All passenger stock together | 57 | 3,676 | (Estimates of parameters omitted to avoid unnecessary detail) | |
| (b2) MU/LH distinguished | 55 | 3,181 | | |
| (b3) Mk1/PMk1 distinguished | 55 | 3,533 | | |
| (b4) All four combinations | 51 | 2,984 | | |
| **(c) Mean fatalities assumed proportional to speed** | | | **Increase in mean fatalities per accident for each 10 km/hour in speed** | |
| (c1) All passenger stock together | 58 | 3,678 | All: | 0.62 (0.12) |
| (c2) MU/LH distinguished | 57 | 3,238 | MU: | 0.93 (0.19) |
| | | | LH: | 0.33 (0.05) |
| (c3) Mk1/PMk1 distinguished | 57 | 3,628 | Mk1: | 0.71 (0.17) |
| | | | PMk1: | 0.51 (0.13) |
| (c4) All four combinations | 55 | 3,188 | MU Mk1: | 1.02 (0.29) |
| | | | MU PMk1: | 0.84 (0.21) |
| | | | LH Mk1: | 0.43 (0.07) |
| | | | LH PMk1: | 0.21 (0.06) |

Abbreviations: MU = Multiple unit; LH = Locomotive hauled; Mk1 = Mark 1; PMk1 = Post-Mark 1

The residual sums of squares for the model variants in group (b) are all significantly less than those of group (a) on the criteria above, and therefore group (b) is preferred to group (a). However, the increase in the residual sums of squares in moving from group (b) to group (c), that is forcing the lines through the origin, are sufficiently small that group (b) does not fit significantly better than group (c). Therefore group (c) is preferred to group (b), and thus also to group (a). The conclusion is that mean fatalities do indeed rise with the impact speed, and that this can be represented by presuming that mean fatalities are proportional to speed. The conclusion that mean fatalities rise with speed accords with what would be expected on both commonsense and engineering grounds.

Within group (c) it can be seen that the model variants in which multiple unit and locomotive hauled stock are distinguished fit statistically significantly better than those in which they are not (compare (c2) with (c1) or (c4) with (c3). On the other hand, distinguishing Mark 1 from post-Mark 1 stock does not significantly improve the fit (compare (c3) with (c1) or (c4) with (c2)). Therefore the preferred variant within group (c) is (c2), and this is therefore the overall statistically preferred model, although for some purposes model (c1), taking all the passenger stock together, might be useful. In these models mean fatalities are assumed to be proportional to speed, with different constants of proportionality for all stock, multiple units, and locomotive hauled stock.

The bottom-right hand panel of Table A2 shows that the estimated constant of proportionality in model (c1) is 0.62 mean fatalities per 10km/hour of impact speed, and those in model (c2) are 0.93 and 0.33 for multiple unit and locomotive hauled stock respectively. With three significant figures (to avoid rounding errors), the equations representing the relationships are:

$$f = 0.0616s$$

for all stock;

$$f = 0.0934s$$

for multiple units; and

$$f = 0.0326s$$

for locomotive-hauled stock, where $f$ is the mean number of fatalities per fatal accident, and $s$ is impact speed in km/hour.

These relationships imply that in the past the mean number of fatalities in accidents involving multiple units is estimated to have been about 2.9 (that is, 0.934/0.326) times greater than that in accidents involving only locomotive-hauled trains, when the accidents have the same impact speed. It should be noted that although the relationships are significantly different, the fit of the model to the data is still not at all close, and the individual data points are still scattered widely about their means. This is indicated by the fact that the residual sum of squares in model variant (c2) is still large. Therefore it may be inferred that although the multiple-unit/ locomotive-hauled distinction has been a factor influencing the number of fatalities, many other chance factors influence the outcome of particular accidents.

It should also be noted that one of the reasons why the multiple-unit/ locomotive-hauled distinction is an effective statistical discriminator is that all the high-fatality accidents in the past 34 years - Hither Green, Clapham Junction and Ladbroke Grove - have involved multiple units. The highest-fatality accident involving only locomotive hauled stock was the derailment at West Ealing in 1973 with 10 fatalities.

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