Research in Transportation Economics 43 (2013) 137–147

Contents lists available at SciVerse ScienceDirect

Research in Transportation Economics

journal homepage: www.elsevier.com/locate/retrec

The economics of railway safety

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ARTICLE INFO

Article history:
Available online 16 January 2013

Keywords:
Railways
Safety
Accidents
Cost benefit analysis
Train protection
Level crossings
Privatisation
Deregulation

JELCodes:
D61
L92
R41

ABSTRACT

This paper reviews the statistics and economics of railway safety in Great Britain, the European Union and the United States, together with some results for Finland and Japan. In these countries railway safety has improved over recent decades. That finding applies both to train accidents and to personal accidents such as persons struck by trains. Fatal train collisions and derailments command most attention even though they are infrequent and account for only a small minority of railway fatalities. Great Britain, the EU and the USA formally espouse conventional cost benefit analysis for the appraisal of railway safety measures, using the same valuations for the prevention of casualties as are used in road safety appraisal. However there are often strong institutional, legal and political pressures towards adopting railway safety measures with safety benefit: cost ratios well below 1. The best-documented examples of this are automatic train protection systems, which are discussed in the paper. Apart from trespassers, the largest group of railway fatalities occur at level crossings, which the paper also discusses. Level crossing safety measures would seem to be an appropriate subject for cost benefit analysis, but there are few case-studies in the literature. Over the last few decades, the railways in many countries have been privatised or deregulated with the aim of improving their economic performance. Such changes have the potential to affect safety. The paper reviews evidence of the effects on safety of railway restructuring in Great Britain, Japan and the United State, and finds no evidence that safety deteriorated.

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1. Introduction

This paper reviews the statistics and economics of railway safety. The principal countries considered are Great Britain (GB), the European Union (EU) collectively, and the United states of America (USA). Some results are also given for Finland and Japan. These are the countries for which most information and analysis are available.

Abbreviations: ALCRM, All Level Crossing Risk Model; ATP, Automatic Train Protection; BCR, Benefit cost ratio; BR, British Rail or British Railways; CBA, Cost benefit analysis; CSI, Common Safety Indicator [EU]; ERA, European Railway Agency; EU, European Union; FHWA, Federal Highway Administration [US]; FRA, Federal Railroad Administration [US]; GB, Great Britain; HEATCO, Harmonised European approaches for transport costing and project assessment; HSE, Health and Safety Executive [GB]; HSWA, Health and Safety at Work Act 1974 [GB]; ITF, International Transport Forum; JNR/JR, Japanese National Railway/Japanese Railways; LC, Level crossing; NTSB, National Transportation Safety Board [US]; ORR, Office of Rail Regulation [GB]; PTC, Positive train control; RI, Railway Inspectorate [GB]; RSIA08, Rail Safety Improvement Act 2008 [US]; RSSB, Rail Safety and Standards Board [GB]; SE, Standard error; SFAIRP, So far as is reasonably practicable; SMS, Safety Management System; SPAD, Signal passed at danger; TPWS, Train Protection and Warning System; UIC, International Union of Railways; VPF, Value of preventing a fatality; VPI, Value of preventing an injury; WTP, Willingness to pay.

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http://dx.doi.org/10.1016/j.retrec.2012.12.003

Section 2 looks at the railway risk profile in the 2000s, as measured by fatalities and fatality rates, and the medium term trends in the major classes of accident over periods of up to about three decades. Section 3 looks at the appraisal of railway safety measures and the use of cost benefit analysis. Section 4 considers the appraisal of an important and well-documented safety measure, automatic train protection. Section 5 considers level crossings, which are a major source of railway risk in almost all countries. Section 6 considers evidence of the effect on safety of rail privatisation and deregulation. Section 7 presents conclusions.

2. Railway risks and trends

This section reviews the safety risks on the railways and the medium term trends in these risks. The emphasis is on fatalities and fatal accidents, so as to avoid problems arising from different and changing definitions of non-fatal injuries, and from the underreporting and variable reporting of these. The main countries considered are GB, the EU and the United States (USA), with references also to Finland and Japan. Great Britain is included both on its own and as part of the EU, but it represents only about 12% of EU railway activity, as measured by train-kilometres.

2.1. The risk profile of railways

The common image of a railway accident is of a multi-fatality train collision or derailment, but most railway casualties are more mundane. Table 1 gives data on railway fatalities per train-kilometre in the USA for 2000–2009, the EU for 2006–2009, and GB for 2000–2009, together with some general data about the three systems.

The top panel of Table 1 gives route-kilometres, the average number of level crossings, and train-kilometres per year for each system, from which are calculated average train-kilometres per day per route kilometre, which is a measure of the density of train movements on the system, and level crossings per route-kilometre. There are substantial differences between the systems, which partly account for their different risk profiles. The most striking safety-related difference is that the USA has about three times as many level crossings per route-kilometre as GB and about twice as many as the EU. The effect is that even though the fatality rate per crossing per year in the USA is low and close to that in GB, level crossings are responsible for a much greater proportion of railway fatalities in the USA than in GB. Another difference, not shown Table 1 but shown elsewhere (OECD/International Transport Forum, 2010, Table 2.2) is that railway operations are mainly of freight trains in the USA but of passenger trains in Europe and Great Britain. In 2002–2006, 88% of train-kilometres in the USA were of freight trains, but in Great Britain 89% were of passenger trains.

Table 1
Railway fatalities in the United States, the European Union and Great Britain: 2000–2009.

	United States	European Union	Great Britain
	2000–2009	2006–2009	2000–2009
System data			
Average railway route-kilometres	194,002	212,607	16,108
Average number of level crossings	239,126	129,221	7457
Train-kilometres per year (10^9)	1.2065	4.1495	0.5248
Train-kilometres per day per route-kilometre	17.0	53.5	89.3
Level crossings (LCs) per route-kilometre	1.23	0.61	0.46
Fatalities per 10^9 train-km by person type			
Railway passengers	5.8	16.9	17.1
Staff	22.0	8.6	9.0
Public non-trespassers	300.0	112.1	25.9
All accidental non-trespassers	327.8	137.5	52.0
Trespassers	397.6	215.6	85.8
All accidental including trespassers	725.4	353.1	137.8
Suicides		598.2	398.1
All including trespassers and suicides		935.3	535.9
Fatalities per 10^9 train-km for selected accident types			
In train collisions and derailments, not at level crossings	10.6	6.1	4.4
At level crossings	291.1	103.2	20.2
Fatalities at level crossings per year per 1000 crossings	1.47	3.31	1.42
Selected ratios			
Fatalities to passengers and staff as percent of all non-trespassers	8.5%	18.5%	50.2%
Fatalities in train collisions and derailments as percent of all non-trespassers	3.2%	4.5%	8.4%
Fatalities at level crossings as percent of all non-trespassers	88.8%	75.0%	38.8%
Fatalities to trespassers as multiple of all non-trespassers	1.21	1.57	1.65
Suicides as multiple of all non-trespassers		4.23	7.65

Sources: calculated by author from data in Federal Railroad Administration (FRA, 2011 and earlier); European Railway Agency (ERA, 2011); Rail Safety and Standards Board (2011 and earlier); International Union of Railways (2010 and earlier). The FRA classify some fatalities at level crossings caused by misuse of the crossing as trespassers, but in order to maintain comparability all fatalities to road users at LCs are here classified as public non-trespassers.

The second panel of Table 1 shows fatalities per 10^9 train-kilometres classified by person type: railway passengers, staff, public non-trespassers, trespassers, and suicides. The first three groups are people legitimately on the railway; trespassers are not. The fatalities that receive most attention are those to passengers and staff. The USA, EU and GB all had about 25 fatalities to passengers and staff per 10^9 train-kilometres, but in the USA the majority of these were staff whereas in the EU and GB the majority were passengers. This presumably reflects the high proportion of freight operation in the USA and of passenger operation in the EU and GB. Some of the passengers and staff fatalities occurred in train collisions and derailments, but the majority were in accidents to persons, such as staff working on the track or passengers struck by trains.

The numbers of passenger and staff fatalities were small compared with fatalities to the non-trespassing public, which are dominated by those to level crossing users. In the USA 89% of all non-trespasser fatalities were at level crossings (but see the footnote under Table 1) and in the EU 75% were. Only in GB is the proportion of level crossing fatalities low at 39%; as noted above, that reflects partly the relatively low density of crossings in GB, and partly a lower fatality rate per crossing than in the EU. Turning to trespassers and suicides, Table 1 shows that in each of the USA, EU and GB the numbers of accidental fatalities to trespassers per train-kilometre exceeded those to non-trespassers, and in the EU and GB the numbers of suicides were several times greater still. All these are tragic events, but they receive relatively little attention in the context of railway safety.

A problem with data on trespasser fatalities is that the reporting authorities often find it difficult to know whether specific deaths to persons on the track were accidents or suicides. Traditionally authorities reported fatalities as suicides only if a coroner had so determined. Open verdicts were treated as accidental and classified as trespassers. This led to overestimates of accidental trespasser fatalities and underestimates of suicides. In the last decade the RSSB in GB has used the so-called 'Ovenstone criteria' (RSSB, 2011, Appendix 4) to classify suspected suicides as suicides without a coroner's verdict. The effect has been to reduce the estimated number of trespassers and increase that of suicides. In the decade from 1991/2 to 2000/01 the Railway Inspectorate (RI) used the old reporting system to report a total of about 260 trespassers and suicides per year in GB, of which 49% were trespassers and 51% were suicides. In the 2000s the principal data come from the RSSB, who use the Ovenstone criteria. The RSSB data in Table 1 imply about the same total number of trespasser and suicide deaths per year in 2000–2009 as in the earlier decade, but only about 18% of these are trespassers. The RSSB data are likely to be closer to the truth than the pre-Ovenstone data, but the change in reporting means that there are no consistent long term data on trespassers in GB. In the USA, the railroads were not required to report suicides until mid-2011, but it is likely that the trespasser fatalities include some suicides. A study by George (2008) for the FRA covering 2002–2004 estimated that about 23% of reported trespassers were suicides. Savage (2007) presents an analysis of trespasser fatalities and injuries in the USA, covering both their nature and their trends.

As an indication of the absolute numbers of fatalities from which the fatality rates in Table 1 are derived, the average numbers of fatalities per year to passengers in the USA, EU and GB were 7, 28 and 9 respectively; the average numbers of fatalities per year to staff were 26, 14 and 5 respectively; the average numbers of fatalities per year to public non-trespassers were 362, 186 and 14 respectively; and the average numbers of fatalities per year to trespassers were 480, 358 and 45 respectively.

2.2. Train collisions and derailments

Among the types of accident, train collisions, collisions with obstacles, and derailments receive most attention, perhaps because they often lead to multiple fatalities and are almost always wholly the responsibility of the railways. The casualties in these accidents are mostly passengers and staff, but sometimes they include members of the public, notably in recent years at Graniteville in the USA in 2005 (National Transportation Safety Board (NTSB), 2005) and at Viareggio in Italy in 2009 (ERA, 2010), where freight trains carrying hazardous goods derailed with 8 and 32 fatalities to the public respectively. However, fatal train collisions and derailments are infrequent, and Table 1 shows that the fatalities in such accidents accounted for a small proportion of all non-trespasser fatalities: 4.2% in the USA, 4.5% in the EU, and 8.4% in GB. Section 2.3 shows that the frequency of such accidents is also generally falling, at least in GB, the EU, and Japan.

The causes of fatal train collisions and derailments are varied. There is usually an immediate cause, but there are also often contributory causes, and there are almost always antecedents related to organisational or management failures. Table 2 gives the immediate causes of the 224 identified fatal train collisions and derailments in the EU plus Norway and Switzerland in the 21 years 1990–2010. The most common cause is signals passed at danger (SPAD), where a driver for some reason misses a red signal. SPADs are never intentional and are very rare for any particular driver, but given the frequency with which red signals are encountered, they are fairly common in a large system, and a few of them lead to collisions. Overspeeding is also a driver's error: a train may be derailed because the driver overlooked a permanent or temporary speed limit. Signalling or dispatching errors occur when a signaller authorises a train movement when the line is not clear, or occasionally a signal failure leads to a green signal incorrectly being shown. There are many other operational errors that can lead to accidents, such as brakes not being properly connected or a loose load fouling another train. Accidents external to the railway are initiated from outside, such as a car falling from a bridge onto the tracks. Level crossing accidents are also commonly external in that sense, but they are not included in Table 2 because in this paper (and most others) they are categorised separately from collisions and derailments.

A common feature of many operational accidents is so-called 'human error': for example, a staff member may fail to perform a task correctly, such as stop at a red signal, slow down for a speed restriction, check that the line is clear before authorising a movement, etc. Human error has long been recognised as occurring rarely but persistently in such tasks. In consequence there has been a continuing effort to develop protection against such errors, so that either they cannot occur or their consequences are not serious. An early example of protection against signallers' errors is 'interlocking', where the signals are interlocked with each other and with the points, so that it becomes impossible to set up conflicting routes, or to authorise a movement for which the route is not correctly set. It has proved more difficult to protect against drivers' errors, but modern electronics has enabled the development of 'Automatic Train Protection' (ATP) or 'Positive Train Control' (PTC) in the USA. Train protection is discussed further in section 4.

Table 2
Number of fatal train collisions and derailments by broad cause: European Union + Norway + Switzerland: 1990–2010.

Broad cause	1990–1999	2000–2010	Total
Signal passed at danger (SPAD)	35	26	61
Overspeeding	13	10	23
Signalling or dispatching error	12	12	24
Other operational error	8	5	13
Rolling stock failure	4	8	12
Infrastructure, track or points failure	9	14	23
External to railway	5	6	11
Total excluding unknown	86	81	167
Unknown	40	17	57
Total including unknown	126	98	224

Source: author, calculated with data updated from Evans (2011a).

However, many railway systems are extensive, and different parts have different traffic characteristics. Therefore it may take many years between the first use of a modern safety device and its application to a whole system. Also a safety device may be economic for some parts of a system but not for others, depending on speeds, traffic density, etc. This may lead to some parts of systems being protected while others are not, and preventable accidents may occur on the unprotected parts. Nevertheless protection is gradually becoming more extensive, and that may be one reason why train accident rates have been falling, as shown in Section 2.3.

2.3. Trends in risks

Table 3 gives estimated medium-term trends in the accident or fatality rates for four major groups of accidents: train accidents per train-kilometre in Table 3(a), personal accidents per train kilometre in Table 3(b), level crossing (LC) accidents per year in Table 3(c) and trespasser fatalities per year in Table 3(d). The countries represented in one or more of the tables are Great Britain, Finland, the European Union, Japan and the USA. The periods covered and the precise definitions of the accidents or fatalities vary, depending on the analyses or data available in the literature; sources are quoted at the foot of the table.

The estimated trends are given in the penultimate column of Table 3; these are all rates of change per year. The model for estimating these trends is the following. Accidents are presumed to occur randomly in year t at a mean rate λ_t per year; λ_t is assumed to be given by

$$\lambda_t = \alpha k_t \exp(\beta t) \tag{1}$$

where

k_t = a 'normalising factor' which allows for year-to-year changes in the scale of activity. For train accidents and personal accidents in Table 3(a) and (b), the normalising factors are taken to be train-kilometres in year t; for level crossing accidents and trespassers in Table 3(c) and (d), the normalising factor is simply taken to be time, which has the effect that if the data are annual all the ks are simply 1.
α is a general scale parameter.
β is the trend parameter whose estimates are given in the tables. β measures the long-term annual rate of change in accidents or fatalities per train-km or per year.

The model was fitted by Poisson regression, assuming that accidents or fatalities occur as Poisson processes. In some cases, the scatter of the data is greater than would be expected of a Poisson process, so negative binomial regression was also explored. The estimated rates of change are all almost the same with Poisson as with negative binomial regression, though in some cases the standard errors are somewhat larger with negative binomial regression. None of these larger standard errors alter the statistical significance of any trend.

The overall picture given by Table 3 is that railway safety has been markedly improving. For train accidents and personal fatal

Table 3
Estimated medium term trends in accident or fatality rates.

Country	Type of accident or fatality	Normalising variable	Period covered	Estimated rate of change in accident rate (SE in brackets)	Source
(a) Train accidents per train-kilometre (excluding level crossing accidents)					
Great Britain	Fatal train collisions and derailments	Train-kilometres	1967–2003	−5.5% p.a. (1.1% p.a.)	(1)
European Union	Fatal train collisions and derailments	Train-kilometres	1990–2009	−6.3% p.a. (1.2% p.a.)	(2)
Japan	Fatal and non-fatal train accidents	Train-kilometres	1971–2006	−6.5% p.a. (0.3% p.a.)	(3)
(b) Personal fatal accidents or fatalities per train-kilometre (excluding level crossing accidents)					
Great Britain	Fatal personal accidents	Train-kilometres	1967–2003	−4.5% p.a. (0.2% p.a.)	(4)
Finland	Personal fatalities to passengers and staff	Train-kilometres	1979–2008	−6.8% p.a. (1.4% p.a.)	(5)
USA	Non-trespasser fatalities excluding train and LC accidents	Train-kilometres	1993–2009	−7.2% p.a. (0.8% p.a.)	(6)
(c) Level crossing (LC) fatal accidents or fatalities per year					
Great Britain	Fatal level crossing accidents	Time	1980–2009	+0.2% p.a. (0.6% p.a.)	(7)
Finland	Fatalities to road users at LCs	Time	1979–2008	−5.8% p.a. (0.6% p.a.)	(8)
European Union	The most serious fatal accidents at LCs	Time	1990–2009	+0.8% p.a. (1.7% p.a.)	(9)
USA	Fatalities at level crossings	Time	1990–2009	−4.6% p.a. (0.2% p.a.)	(10)
(d) Trespasser fatalities per year					
Finland	Fatalities to public excluding LCs	Time	1979–2008	−3.0% p.a. (0.6% p.a.)	(11)
USA	Trespasser fatalities excluding train and LC accidents	Time	1993–2009	−0.8% p.a. (0.2% p.a.)	(12)

Sources: (1) Evans (2007); (2) Evans (2011a); (3) Evans (2010); (4) Evans (2007); (5) calculated by author from data in Silla and Kallberg (2012); (6) calculated by author from data in FRA (2011 and earlier); (7) calculated by author from data in Evans (2011b); (8) calculated by author from data in Silla and Kallberg (2012); (9) calculated by author from data in Evans (2011a); (10) calculated by author from data in FRA (2011 and earlier); (11) calculated by author from data in Silla and Kallberg (2012); (12) calculated by author from data in FRA (2011 and earlier).

accidents the estimated trends for all countries in the table are downwards, statistically significant, and substantial. All the trends are in the range −4.5% per year to −7.2% per year. Such trends imply large reductions in accident rates in the long term. For example, a downward trend of 5% per year gives an overall reduction of 64% when sustained over twenty years. The trends are also statistically significantly downward for trespasser fatalities per year in the two countries for which it is possible to estimate these, but the rates of decrease are smaller.

The picture is mixed for level crossing accidents, where the trends given are the rates of change per year in fatal accidents or fatalities per year. Finland and the USA show downward trends of a similar order of magnitude to those of the other classes of accidents. However, Great Britain and the European Union both have trends not significantly different from zero, which may therefore be regarded as flat. An important qualification to the EU data is that they cover only the most serious LC accidents, specifically those with on-train fatalities and/or those with four or more road user fatalities. These make up only a small fraction of all EU LC accidents – perhaps 3% – so it is possible that complete long term data would show a different trend. The only complete LC data for the EU come from the Common Safety Indicators (CSIs) used in Table 1, but these started only in 2006. As to Great Britain, the absence of improvement in 1980–2009 is real, but Table 1 shows that despite this GB had a good LC safety performance in the 2000s compared with both the EU and the USA. We discuss level crossings further in Section 5.

3. Appraisal of railway safety measures

As noted in Section 2, railways are subject to many different kinds of hazard, and risks are mitigated by a wide range of safety measures. Railway operators and regulators have long recognised that some safety measures represent better value for money than others, but the railways have not adopted conventional cost benefit analysis (CBA) for the appraisal of safety measures as consistently as have highways. Government transport and finance departments tend to promote the use of CBA to encourage the efficient use of resources, but for various reasons the conclusions from CBA are often disregarded, especially for safety measures aimed at the prevention and mitigation of train collisions and derailments. The direction of the disregard is usually that a higher level of safety is provided than would be warranted by CBA. The best-documented examples of this relate to train protection measures, which are discussed below in section 4.

3.1. *'All preventable accidents should be prevented'*

One reason for disregarding CBA is the traditional argument in closely-managed transport modes such as rail (and aviation) that all preventable accidents should be prevented. The argument runs as follows. If

(1) a known risk of accidents exists, and
(2) a safety measure capable of eliminating the risk exists or is developed, then
(3) the safety measure should be implemented.

Not to take step (3) implies the acceptance of preventable accidents, which safety-minded operators, regulators and governments are understandably reluctant to do. Indeed, many organisations have safety policies that explicitly require zero preventable casualties. Furthermore, if and when a preventable accident occurs, the resulting deaths and injuries may be laid at the door of those who decided not to adopt or mandate the safety measure in the first place. This argument is particularly powerful for accidents in which the victims are entirely innocent, such as passengers in train collisions or derailments, in contrast to accidents, say, to trespassers or passengers who fall from station platforms under the influence of alcohol.

The problem about this argument is that, as stated, it makes no reference to the size of the benefits and costs of the safety measure. Although the risk in question may be non-zero, it may be small, and the cost of the safety measure may be high, giving poor value for money. This can place decision-makers in an acute dilemma: they do not want to accept preventable casualties, but they also want reasonable value for the public or private expenditure for which they are responsible. Again train protection, discussed in section 4, illustrates this dilemma.

3.2. *Reasonable practicability and gross disproportion*

A second reason why the conclusions of CBA may be disregarded is the argument surrounding reasonable practicability and gross disproportion. This applies specifically in Britain and Australia, but perhaps also has influence in the EU. The overarching safety legislation covering the railways in Britain is the Health and Safety at Work Act 1974 (HSWA). The HSWA requires employers, including railway operators, to ensure the health and safety of employees and of others "so far as is reasonably practicable" (SFAIRP). The principal legal interpretation of SFAIRP comes from an Appeal Court case of 1949 following the accidental death of a coal miner.[1] In that case, one of the judges, Lord Asquith, said:

> "a computation must be made … in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other, and that, if it be shown that there is a gross disproportion between them – the risk being insignificant in relation to the sacrifice – the defendants [i.e. the employer] discharge the onus on them."

At first sight that seems to be an early and admirable demand for safety cost benefit analysis, and so it is. The problem lies in the phrase "gross disproportion", because it seems to require that the safety benefit: cost ratio (BCR) should be much less than 1 before the law is satisfied. However, that was reasonable in 1949, because there were then no formal valuations of the prevention of fatalities and injuries, and the only financial figures relating to casualties were compensation payments to victims and their relatives. These were low. In particular, in the case in question the compensation paid to the widow of the coal miner after his death was £984, equivalent to about £27,000 at 2009 prices. It is reasonable to suppose that the Court had that figure in mind when specifying the requirement for gross disproportion.

Since the legal case in 1949, economic valuations for the prevention of fatalities (VPF) and injuries (VPI) have been developed. These are much higher than the 1949 compensation payments; for example, the 2009 British official VPF, based on willingness-to-pay (WTP), was £1.59 million, or about 60 times greater in real terms than the 1949 compensation. Therefore there would now seem to be no need for gross disproportion between the WTP-based benefits of safety measures and their costs. However, the problem for today is that while current VPFs are drastically higher than compensation levels in 1949, there has been no corresponding change in the legal phraseology. Therefore the law still seems to require safety BCRs to be much less than 1, even with today's VPFs. The current British railway safety regulator, the Office of Rail Regulation (ORR), says that if Parliament had intended a different test, it would have used different wording in the HSWA 1974 (ORR, 2008). The problem is exacerbated by uncertainty about exactly what the law does require. Nobody wishes to break the law, especially on safety. That encourages decision-makers and lawyers to be cautious and adopt safety measures for which the BCR may be well below 1.

3.3. *Valuation of rail and road casualties*

Another question in railway safety CBA is whether the values of preventing fatalities and injuries on the railways should be the same or different from those on the roads. There have been three separate major studies on this in Britain, all by Jones-Lee, Loomes and colleagues. The first of these (Jones-Lee & Loomes, 1995) was for London Underground and investigated whether the VPF for accidents on London Underground should be different or not from the standard roads value. The study also investigated whether the VPF for fatalities in large accidents should be different simply because the accidents were large. The authors concluded that fatalities on London Underground should be valued 50% greater than those on the roads, but fatalities in large accidents should have no specific premium. The first of these results has been superseded by different methods and results in later studies; the second is a consistent finding throughout all three studies.

The second study was for a consortium of UK government departments on the valuations of fatalities on the railways and in fires relative to those on the roads (Beattie et al., 2000; Burton et al., 2001; Chilton et al., 2002). The authors concluded that on average people place much the same value on the prevention of fatalities on the railways as on the roads, and that they did so even in the aftermath of the very serious train collision at Ladbroke Grove in October 1999 (Cullen, 2001). Partly in consequence, the official rail VPF in the UK is now set equal to the roads value.

The third study was for the Rail Safety and Standards Board (Covey, Robinson, Jones-Lee, & Loomes, 2010; Covey, Robinson, Jones-Lee, Loomes, & Thomson, 2008). The authors concluded that not only should the railway VPF for a single responsible adult be taken as equal to the roads VPF, but that the VPFs for all railway fatalities where the victim had been acting responsibly should be the same. However, they recommended a VPF 60% lower for irresponsible adults such as trespassers. In Europe there has been less work on railway VPFs, but a 2004 project on developing Harmonised European Approaches for Transport Costing and project Assessment (HEATCO) recommended the same VPFs for railways as roads (Universität Stuttgart, 2006).

There has also been less work on railway VPIs than VPFs. In the early 1990s British Rail adopted VPIs of 10% of the VPF for a serious injury and 0.5% for a slight injury. These were not based on specific empirical evidence, but they seemed reasonable and are not very different from the corresponding road VPIs. These percentages have survived with minor changes.

3.4. *A public transport economic model including safety*

Economic models of public transport are well established in the literature. Demand is expressed as a function of generalised cost per journey (or per passenger-kilometre); generalised cost per journey depends on fare levels and service levels, and incorporates valuations of travel time; operating costs depend on service levels. The principal policy variables in these models are fare levels and service levels. Such models can be used to estimate welfare-maximising fare and service levels with or without constraints on the level of available subsidy. Evans and Morrison (1997) provide an extension of the model to incorporate safety. The formulation of generalised cost was extended to include a term representing passenger fatalities per journey, which were valued using the VPF. System costs were extended to include a term representing the costs of safety measures as a function of the safety level provided. The extended model was successfully fitted to a hypothetical high-density urban rail system with the traffic characteristics of the London Underground and the safety characteristics of British Rail. The model found that, using the standard road VPF, the net benefit of reducing safety risk below its then current level was marginal.

4. Train protection systems

4.1. *The Automatic Train Protection dilemma*

As noted in section 2, a major class of safety measures aimed at reducing the frequency of train collisions and derailments are those designed to protect against 'human error' by signallers or train drivers. Over the long term, it was easier to develop devices to

[1] Edwards v National Coal Board [1949]. 1 ALL ER 743 at 747. It may be noted that this case long predates the HSWA 1974, but the phrase SFAIRP was in use in the previous relevant legislation.

protect against signallers' errors than driver's errors, but by the late 1980s electronics had developed to the point at which it was possible to protect against drivers' errors by installing systems that continuously supervise the movement of trains and automatically apply the brakes if a train is going too fast for current track and signalling conditions. Such systems are called 'Automatic Train Protection' (ATP) in the UK and EU, and 'Positive Train Control' (PTC) in the USA.

Once ATP systems became available, many train accidents due to drivers' errors became preventable. Therefore there was strong pressure to install ATP, under the principle discussed in section 3.1 that 'all preventable accidents should be prevented'. The problem is that ATP generally represents poor value for money. That is first because ATP is expensive, especially when installed as an overlay on existing signalling, because it requires extensive additional equipment both on the tracks and on the trains. Secondly, notwithstanding the occurrence of a number of very serious ATP-preventable train accidents, the performance of train drivers in obeying signals and speed restrictions without ATP is generally very good. Therefore the frequency of ATP-preventable accidents is low, and the numbers of casualties preventable by ATP is also relatively low. The consequence is that, using the standard valuations of preventing fatalities and injuries, the safety benefit: cost ratio of ATP is typically very low.

That places decision-makers in the dilemma mentioned in section 3.1, and they have responded in different ways. The histories of ATP in the UK and PTC in the USA are outlined below. The EU has seen a variety of responses in different countries, illustrated by differences in the proportions of track fitted with ATP in 2009 given as one of the ERA's 'Common Safety Indicators' (CSI) in Table 10 of ERA (2011). A sample of reported proportions are 4.2% in the UK, 47.2% in France, 90.0% in Germany, 92.4% in Italy, and 99.0% in the Netherlands. Where given, the proportions of train-kilometres operated with ATP tend to be higher than the proportions of fitted track, because the more heavily trafficked routes are more likely to be fitted; in particular 79.1% of train-kilometres in France were operated with ATP in 2007.

4.2. Automatic Train Protection and the Train Protection and Warning System in Britain

The UK is stated to have had the lowest proportion of track fitted with ATP in Europe in 2009, though it does now have a less comprehensive system entitled the Train Protection and Warning System (TPWS). The story of Great Britain's decision in 1995 not to install ATP is written up in Evans (1996), and we here summarise it. In the late 1980s British Rail (BR), the former nationalised operator, intended to install system-wide ATP, and established two major pilot projects. In 1994, the pilot projects had proved technically viable, but their poor value for money had also become clear. The first column of figures in Table 4 gives the present writer's summary CBA of BR's ATP, based on Evans (1996) and the official documents referenced therein. The overall BCR is estimated to be 0.12. With hindsight, the cost assumed for BR's ATP in 1994 looks too low, and a more accurate cost estimate might well have given a lower BCR. On the other hand, the discount rate was 8 percent, which is higher than would now be used, and a lower rate would have given a higher BCR. The poor value for money led the then rail safety regulator to write to the transport Minister that

> "HSE [the Health and Safety Executive] have told us that the introduction of ATP as piloted on a network-wide basis could not be regarded as reasonably practicable by the criteria they usually apply, and that there are alternative safety investments which would be likely to yield greater effectiveness in terms of lives saved, and better value for money." (HSE, 1995, page 84).

Table 4
Safety benefits and costs of train protection systems.

Country	Great Britain	Great Britain	USA
System	ATP	TPWS	PTC
Background assumptions			
Base year	1994	2002	2009(?)
Period of appraisal	20 years	20 years	20 years
Discount rate	8% pa	Not discounted	3% pa
Value of preventing a fatality	£0.784m	£1.250m	$6.0m
Costs and safety benefits			
Present value of costs	£482m	£550m	$13,205m
Present value of safety benefits			
Prevented casualties	£25m	£59m	$473m
Prevented damage, disruption, etc	£32m	£40m	$201m
Present value of all safety benefits	£57m	£99m	$674m
Safety benefit/cost ratio	0.12	0.18	0.05
Was or will system be implemented?	No	Yes	Yes

Sources: Great Britain ATP derived from Evans (1996); TPWS from Evans (2004); USA PTC from FRA (2010, p328).

In March 1995 the Minister decided not to go ahead with ATP. A caveat to this decision was that the railways should develop a less comprehensive system to reduce the risks of accidents from drivers' errors. This eventually became TPWS and was installed throughout the whole system of Great Britain in 2002 and 2003. TPWS does not supervise trains continuously, but it does intervene to apply the brakes of trains approaching signals at danger or caution too fast. It appears to have been effective: at the time of writing (early 2012) there have been no fatal ATP-preventable accidents since TPWS was installed. The success of TPWS implies that the safety benefits of further more comprehensive forms of ATP in Britain are now even lower than in the 1990s; therefore the case for comprehensive train control systems now rests almost entirely on their non-safety benefits.

The second column of figures in Table 4 give the present writer's simple CBA of TPWS, taken from an unpublished but public working paper (Evans, 2004). TPWS is estimated to have had a BCR of 0.18. The question of whether TPWS was reasonably practicable was sidestepped by Parliament passing specific regulations mandating TPWS (and also the withdrawal of specified older passenger rolling stock) (HSE, 1999). This has the effect of imputing higher values for preventing casualties in the specified context than the standard values. An interesting but unanswered question is how wide that context is taken to be. Despite the low BCR, TPWS was introduced with widespread support both from passengers and from the industry, though its costs are likely to have fallen mainly on the taxpayer through subsidy.

A wider argument about low benefit/high-cost safety measures such as ATP is that they may induce responses which diminish rather than improve safety and thus be self-defeating. Evans and Addison (2009) investigated this possibility for a generic safety measure in Great Britain similar to ATP. The argument is that if such safety measures are funded by rail passengers, they require an increase in fares, and these may induce some passengers to switch to the car, which is less safe. Thus total casualties could rise. Evans and Addison found that although some passengers would switch to the car, for various reasons the induced change in overall safety would be small. Of course the low benefits of ATP still remain, but at least in that case the benefits were not actually negative.

4.3. Positive Train Control in the USA

In the USA, ATP is called 'Positive Train Control' (PTC). As in Great Britain, PTC has been under consideration for many years, but until recently had been rejected as poor value for money. However, attitudes changed following the PTC-preventable accidents at Graniteville, South Carolina, in 2005 with 9 fatalities (National Transportation Safety Board (NTSB) 2005) and at Chatsworth, California, in 2008 with 25 fatalities (NTSB, 2010). In 2008 Congress passed the Rail Safety Improvement Act (RSIA08) mandating network-wide PTC by the end of 2015. The final column of Table 4 presents the Federal Railroad Administration's CBA of PTC, which estimates that the safety BCR of PTC is as low as 0.05 (FRA, 2010, page 328). Nevertheless, the FRA says that

> "The Congress was aware that the monetised safety benefits of PTC were not large in comparison with the loss of life and injuries associated with PTC-preventable accidents. With the passage of RSIA08, Congress has in effect set its own value on PTC and directed implementation of PTC without regard to the rules by which costs and benefits are normally evaluated in rulemaking." (FRA, 2010, page 75).

Similar considerations may have applied to the extensive use of ATP in Europe. Thus ATP/PTC illustrate that railway safety measures are sometimes implemented beyond what would be warranted by CBA, especially to prevent train collisions and derailments.

In all countries, it is possible that comprehensive train control systems such as ATP and PTC could provide benefits other than improved safety, such as increased capacity, higher average speeds, fuel economy, etc. Indeed, given the low safety benefits, such other benefits may be their main justification. However, identifying and quantifying these benefits more precisely is proving elusive.

5. Level crossings (LCs)

Level crossings (or 'grade crossings' in the USA) are places where roads or footpaths cross railway lines on the level, and there is a risk of collision between trains and road vehicles or pedestrians. Table 1 shows that of non-trespasser fatalities 89% in the USA in 2000–2009 were at LCs, 75% in the EU in 2006–2009 were, and 39% in GB in 2000–2009 were. Table 3(c) shows that the USA has been successful in greatly reducing the numbers of level crossing fatalities since 1990, and Savage (1998) indicates that this progress goes back well before 1990. Great Britain saw a fall of about two thirds in LC fatalities between the late 1940s and the late 1970s (Evans, 2011b), but Table 3(c) shows that there was no reduction in 1980–2009. Despite this, Table 1 shows that GB's recent LC safety performance was good by international standards. Road users – pedestrians and road vehicle occupants – make up a large majority of LC fatalities, but occasionally train occupants are killed, and some of these are in multiple-fatality accidents.

Table 1 shows that LCs are numerous, with 1.23 per route-kilometre in the USA, 0.61 in the EU, and 0.46 in GB. That is despite long-term programmes in many countries to reduce their numbers by amalgamation of neighbouring LCs, by replacement with bridges, or by closure. In general, trains have priority over road users at LCs because the stopping distance of trains is much longer than that of road vehicles.

There are two broad types of crossing: 'passive' and 'active'. Passive crossings are indicated to the road user by fixed warning signs – typically a St Andrew's Cross or 'crossbucks' – but there is nothing to inform the road user whether or not a train is approaching. Road users must therefore ensure safety by looking out for trains themselves, and if necessary waiting for a train to pass. Active crossings have some combination of flashing lights, audible warnings, and barriers, which operate only when a train is approaching or is on the crossing. In this case, road users ensure safety by obeying the warnings. If the warnings are not operating, road users may assume that it is safe to cross. Active crossings may be divided into automatic and railway-controlled. The warnings at automatic crossings are triggered automatically by approaching trains; typically the minimum interval between the start of the warning cycle and the arrival of the train is about 30 s. At railway-controlled crossings, the closure of the crossing to the road is initiated by a railway signaller or crossing keeper. The crossing may be interlocked with the railway signals, so it is not possible to clear the signals for a train unless and until the crossing has been closed to the road. These are the safest crossings because they have most protection, but they require staff and they tend to impose longer delays on road users.

The usage of crossings varies greatly. At one end of the scale there are crossings on private or farm roads in rural areas that see at most a few trains and road vehicles per day. At the other end of the scale there are busy public roads crossing busy railways. Generally, the greater the usage of a crossing, the better is the case for providing active protection. In most countries the majority of crossings are passive and little used: for example, 77% of crossings in GB in 2006–2009 were passive. This presents the problem that most passive crossings individually carry a low risk and do not justify more than minor upgrades, but they are so numerous that collectively their risk is substantial: Evans (2011b) estimates that a mean of 41% of GB LC fatalities were at passive crossings in 2009.

There are two major streams of analytical work related to level crossings in the literature. The first develops models to estimate risks at individual crossings as a function of characteristics of the crossing, such as the protection, road flows, rail flows, speeds, sight distances, etc. The second works at the level of accidents or casualties and attempts to account for the observed long term trends. The purpose of models of the first type is to inform decisions about detailed changes or upgrades to individual crossings: for example, if more trains were operated, or the road traffic flow increased, or if specific changes were made to the protection arrangements, what changes in accidents and casualties would be expected? Such models have been developed both by researchers (for example, Austin & Carson, 2002 in the USA) and by practitioners, for example the All Level Crossing Risk Model (ALCRM) in GB (RSSB, 2010a) and the GradeDec software in the USA (FRA, 2005, 2006). The ALCRM has about 200 input variables for each crossing.

A noteworthy feature of such models, originally noted by Stott (1987) and then again by Heavisides and Barker (2008) and by RSSB (2010a) is that at automatic crossings one should not expect a proportionate relationship between road traffic flow and motor vehicle accidents. Rather, the relationship is gamma-shaped, in which accidents rise proportionately with road traffic at low flows, but then reach a maximum and fall off at higher flows. This is because after an approaching train has initiated the crossing sequence, at high road traffic flows the first road vehicle to arrive is likely to arrive before the train; it then stops and its presence to some degree protects later road vehicles against colliding with the train. At lower road traffic flows such queues of waiting vehicles are less likely, so it is more likely that the first vehicle arrives at the same time as the train, with greater risk of collision. This is an example of a positive safety externality: the marginal extra road vehicle reduces the risk for other vehicles.

On the analysis of trends, Mok and savage (2005) use negative binomial regression with state-level data to disaggregate the causes of the long-term reduction in rail/road motor vehicle collisions at LCs in the USA. They estimate that about 40% of the improvement was due to factors related to improved road safety in general and 20% to the upgrading of LCs with improved warning and protection arrangements. Other contributions came from the 'Operation Lifesaver' public education campaign (see also Savage, 2006), additional lights on locomotives, and reductions in the numbers of crossings. Silla and Kallberg (2012) suggest that the improvement at LCs in Finland shown in Table 3 was due to the replacement of some passive by active crossings, grade separation, the removal of some crossings, and the improvement of sightlines. Evans (2011b) examines trends in GB UK; he does not attribute causes to reductions in accidents, but ascribes the absence of improvement in 1980–2009 to the replacement of many railway-controlled by automatic crossings, mentioned again below.

There are few explicit examples of cost benefit analyses of level crossing improvements in the literature, even though the upgrade or replacement of LCs would seem to be a good subject for CBA. Most work appears to have been carried out by practitioners. In the USA the Federal Highway Administration (FHWA, 2007) has published a comprehensive handbook on LCs, which includes a chapter on economic analysis for upgrading them. As noted above, the FRA has produced cost benefit analysis software called GradeDec.net to appraise upgrading proposals. In GB the RSSB (2010b) has an assessment process for assessing the economics of replacing LCs by bridges. An important trade-off in GB is that between railway-controlled and automatic crossings: the former are safer but have higher operating costs and impose longer delays on road users. However, there have been no published quantitative analyses.

6. Rail privatisation and deregulation

6.1. Rail restructuring and safety

Over the period 1980 to the present, the economic status of the main line railway systems in many developed countries has changed, by privatisation or economic deregulation or both. These changes are continuing. The principal aims of the changes have been to improve the economic performance of the railways, and not specifically to change their safety performance. Nevertheless, it is realised that changing the economic organisation of railways might affect safety, and many countries have wished to ensure that the generally good safety performance of railways did not deteriorate.

A review of safety and regulatory reform of railways drafted by the present writer and published by the Joint Transport Research Centre of the OECD and the International Transport Forum (OECD/ITF, 2010) mentions the following safety risks that might be associated with privatisation or economic deregulation.

- Activities that had previously been within the same organisation, such as infrastructure provision and train operation, might be separated, and the new safety responsibilities ill-defined or uncoordinated.
- Safety-critical information might be attenuated across organisational boundaries.
- New companies with little previous experience of safe railway operation might enter the industry and be less safe than more experienced operators.
- Changes in working practices were likely.
- Private operators might choose to spend less on safety than public operators in order to increase their profit.

Any of these could affect safety. Whether safety was in fact affected is an important empirical question. Most of the professional and political concern, and the majority of academic work, has been concerned with the possibility that safety might deteriorate, but some of the work, particularly related to deregulation in the USA, has found improvements. The possibility that safety might be affected by deregulation or privatisation has prompted measures such as enhanced Safety Management Systems (SMS), more explicit safety regulations, the creation of new safety regulatory bodies, and increased staff in existing bodies.

The literature contains two major reviews of the effects of deregulation or privatisation on health and safety more widely than railways. Elvik (2006) published a synthesis of evidence from evaluation studies of the effect of transport economic deregulation on safety. He found 25 studies meeting the criteria for inclusion in his analysis. Of these, 10 were concerned with aviation, 8 with road goods transport, 3 with road passenger transport, 2 with modal shift, and 2 with rail transport. The rail studies were Savage (2003) and an early version of Evans (2007). Egan, Petticrew, Ogilvie, Hamilton, and Drever (2007) reviewed evidence on the effects of privatisation (but not economic deregulation on its own) on health and safety in all industries in all OECD countries since 1945. This wide remit led the authors to identify 13,359 titles of potentially relevant articles, but this number fell to only 11 that contained useable findings. Of these 11, 3 were in road passenger transport, 1 was in railways (Evans, 2007) and 7 were in non-transport industries. The authors commented that “considering the prominent role of health and safety in the public and academic debates on privatisation, our review suggest that much of this debate has been conducted in an empirical void” (Egan et al., 2007, page 867).

Elvik’s overall conclusion was that “deregulation of transport does not appear to have adversely affected transport safety. Continued monitoring of the impacts of deregulation on transport safety is recommended, as the process of deregulation is still in its infancy in many countries, and is likely to continue for many years” (Elvik, 2006, page 685). On railways, he says “summary estimates of the effects of deregulation of railways indicate that safety has improved. There are, however, only two studies and both of them are observational. One should therefore regard the continued improvement of railway safety following deregulation as a statistical association only, not necessarily a causal relationship” (page 684). Egan et al.’s conclusion is that “the most robust study found increases in the measures of stress-related ill-health among employees after a privatisation intervention involving company downsizing. No robust evidence was found to link privatisation with increased injury rates for employees or customers” (page 862).

Elvik (2006) notes that

> “evaluating the effects of transport deregulation on transport safety is complex. In the first place, obtaining reliable and valid safety data is difficult. … A major difficulty in evaluating the effects of deregulation on transport safety is to control for confounding factors. Essentially controlling for confounding factors is trying to answer the question: what would have happened if deregulation had not taken place? … The answer most studies give to the question of what would have happened in the absence of deregulation is that past long-term trends in accident rates would have continued. Provided the description of past long-term trends in accident rates is adequate, this is perhaps the most reasonable answer that can be given” (pages 684/5).

There are three countries for which railway accident data are currently available in the public domain in a form suitable for evaluating the effects of deregulation or privatisation on safety. These are Great Britain, Japan, and the USA. The principal problem in most other countries is the absence of long-term data based on consistent definitions by which to establish pre-restructuring trends. A further difficulty is that, although major railway accidents are well recorded in most countries, such accidents are infrequent, so data can be sparse. Many countries also record less serious accidents, but it is these that are more liable both to incomplete recording and to changes in definitions over time. International comparisons are made difficult partly by differences in definitions and partly by differences in the nature of railways in different countries; for example, as mentioned in Section 2, some railways are mainly passenger and some are mainly freight (Burrows, 2006). Finally, railway restructuring has been a gradual process in some countries, so there is no clear date when it could be regarded as taking place.

6.2. Rail privatisation in Britain and Japan

Evans (2007) evaluates the effects on safety of the privatisation of British Rail (BR) in Great Britain in 1994; Evans (2010) does so for the privatisation of Japanese National Railway (JNR) in 1987. In both countries the pre-privatisation nationalised railway operators had achieved downward trends in accidents per train-kilometre in the years before privatisation, and the evaluation takes the extrapolation of these favourable trends as the baseline with which to compare the safety performance of the privatised railways. Evans (2007) examines four classes of accident for Great Britain, including the high-profile fatal train collisions and derailments; Evans (2010) examines all train collisions and derailments in Japan, whether fatal or not, with and without the high-speed Shinkansen lines. For both countries and for all classes of accident examined, the accident rates after privatisation were below those that would be expected by extrapolating the pre-privatisation trend. For some classes of accident the difference is statistically significant; for some classes not. Evans does not claim that privatisation improved safety, but he does say that the results are strong evidence against the opposite hypothesis, that privatisation made safety worse.

Figs. 1 and 2 illustrate Evans' method and results. The solid data points in Fig. 1 are the observed train accidents per train-kilometre in Japan in the 16 pre-privatisation years 1971–1986. The solid curve is the trend fitted to these points. The dashed line is the extrapolation of the curve to the post-privatisation period, and the open data points are the observed post-privatisation accident rates. It can be seen that almost all the post-privatisation data points are below the extrapolated curve, indicating that the safety performance after privatisation did not deteriorate. Fig. 2 shows the corresponding analysis for fatal train accidents per train-kilometre in Great Britain. In this case, the data points cover five-year periods, because fatal train accidents are much less frequent than non-fatal train accidents, so the data are sparser. (No comparison can be made between the safety performance of GB and Japan, because of the different coverage of the data.) Table 5 gives some numerical details for these two sets of data, and also for fatal personal accidents (that is, fatal non-train accidents) in Great Britain. The principal findings are the minus signs in the bottom row of each column, indicating that the observed numbers of accidents in the post-privatisation period were less than the expected.[2]

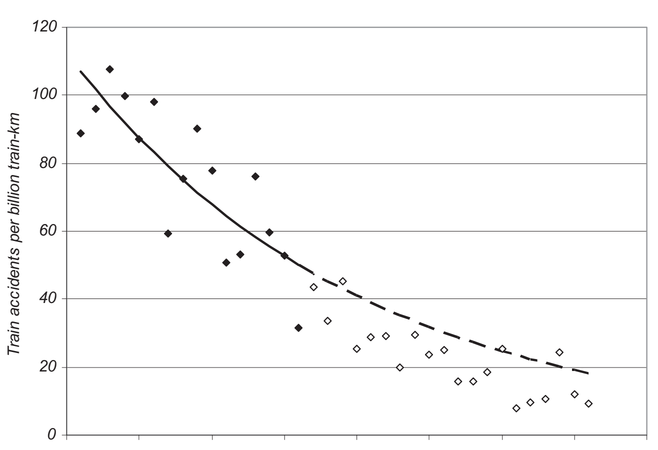

Fig. 1. Train accidents per billion train-km: Japan: JNR/JR including Shinkansen: 1971–2006.

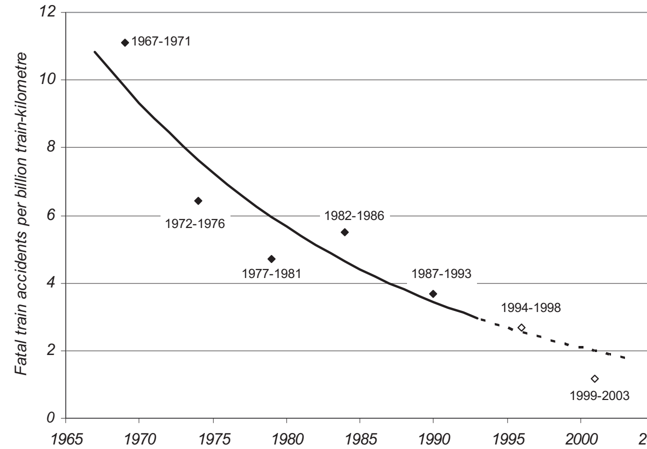

Fig. 2. Fatal train collisions, derailments and overruns: Great Britain: 1967–2003.

6.3. Rail deregulation in the USA

Rail restructuring was different in the USA, and generally took place earlier than in Europe (Clarke & Loeb, 2005; OECD/International Transport Forum 2010; Savage, 1998, 2003). The principal railways in the USA have always been in the private sector, so restructuring did not entail privatisation. The changes considered in Savage's (2003) evaluation are:

(1) Economic deregulation – that is giving freedom to operators to fix their own prices and decide which traffic to accept; the previous economic regulation prevented railways from competing effectively with other modes.
(2) the provision of stronger safety regulatory powers to the Federal Railroad Administration (FRA); and
(3) Federal funding for the improvement of level crossings.

As noted in Section 2.1, the major groups suffering fatalities in the USA are staff, level crossing users, and trespassers. Savage's paper shows that following a worsening safety record in the 1960s, there were then reductions in the numbers of fatalities to each of these groups. On the worsening safety record in the 1960s, Savage says:

> "The causes are not difficult to understand. … Financial difficulties … led to railroads disinvesting in their track and capital stock. The situation was made worse because new and heavier freight cars were being introduced. This led to a sharp rise in derailments that were caused by broken rails. These derailments became more of a public concern because of the expanded carriage of hazardous materials" (page 4).

After deregulation, the greatest improvement was for level crossing users, then employees, and the least improvement was for trespassers. Savage discusses the causes of these improvements. He suggests that they were partly because the improving financial position of the railways enabled more investment, and partly

[2] One qualification is necessary for Great Britain. Although the frequency of fatal train accidents in the post-privatisation period was less than expected, the number of fatalities was greater. That was because of the unusual severity of the train collision at Ladbroke Grove in 1999 with 31 fatalities (Cullen, 2001). However, there is no reason to attribute its severity to privatisation.

Table 5
Selected results on railway accidents in Japan and Great Britain.

	Great Britain: Fatal train collisions, derailments and overruns	Japan: All train accidents: JNR/JR	Great Britain: Fatal personal accidents
Pre-privatisation period	1967–1993	1971–1986	1967–1993
Post-privatisation period	1994–2003	1987–2006	1994–2003
Trends in accident rates before privatisation	−5.0% p.a. (1.6% p.a.)	−5.0% p.a. (0.8% p.a.)	−3.6% p.a. (0.3% p.a.)
Numbers of accidents			
In pre-privatisation period	71	806	1748
In post-privatisation period			
Observed, O	9 (3.0)	331 (18)	209 (14)
Expected, E	10.8 (4.0)	452 (68)	319 (22)
Observed − Expected ($O - E$)	−1.8 (5.0)	−121 (70)	−110 (26)

Figures in brackets are standard errors.

because the new enforcement and standard setting activities of the FRA ensured that the investment was made, both in infrastructure and rolling stock. In addition, the federal funding directly improved the safety of level crossings. The investment in track and rolling stock reduced train accidents, and benefited those at risk from train accidents, who in the freight-dominated railways of the USA are mostly on-train staff. Trespassers are likely to benefit least from these measures.

Clarke and Loeb (2005) consider the effect of deregulation in the USA under the Staggers Act of 1980 on railway fatalities, using data over the period 1976–1992. They develop separate models for three different classes of fatalities: trespassers, level crossing users, and employees and passengers taken together. Their conclusions are similar to those of Savage:

> “The statistical results … do not support the hypothesis that deregulation of the railroad industry … led to additional fatalities. … The coefficients associated with deregulation in all three fatality equations were actually negative and tended to be statistically significant. We suspect that this reduction associated with deregulation is due to increased profitability of the railroads after the passage of the Staggers Act” (page 155).

6.4. *Safety effects of modal shift induced by deregulation*

Even if rail deregulation has no effect on the accident and casualty rates within the rail sector itself, it might cause changes in overall transport safety by inducing modal shift between transport modes with different levels of safety. Boyer (1989) investigated this for road and rail freight transport in the USA in the period 1973–1984, spanning the economic deregulation of both modes in 1980. He found that deregulation had induced a small shift in freight traffic from rail to road compared with what was otherwise expected. Because rail is safer than road, that led to a small increase in total casualties. However, because both road and rail freight were deregulated at about the same time, it was not possible to identify which modal deregulation led to the modal shift. There have been no studies of modal shift by passengers as a result of rail deregulation. The closest such study is perhaps that by Evans and Addison (2009) mentioned in section 4.2, but that was concerned with the effects of rail safety measures rather than deregulation.

7. Conclusions

This paper focuses on railway safety in developed countries, specifically Great Britain, the European Union and the USA, and also including some results for Finland and Japan. In these countries railway safety has improved over the last two or three decades. This improvement applies both to train accidents and to personal accidents such as persons struck by trains. The largest groups of fatalities are level crossing users and trespassers. Fatal train collisions and derailments account for relatively few fatalities because they are infrequent, but they command much more attention than other types of fatal accident.

Great Britain, the EU and the USA formally espouse conventional cost benefit analysis for the appraisal of railway safety measures, using the same valuations for the prevention of casualties as are used in road safety appraisal. However there are sometimes strong institutional, legal and political pressures towards adopting railway safety measures with safety benefit: cost ratios (BCRs) well below 1.

The best documented examples of adopted safety measures with low BCRs are train protection systems, which automatically intervene to apply the brakes of trains if necessary to prevent them passing signals at danger or overspeeding. These systems have low BCRs partly because they are high-cost and partly because the number of accidents they can be expected to save is small; that is because the performance of train drivers in obeying signals and speed limits is generally very good without them. Nevertheless, the legislatures in both GB and the USA have mandated train protection systems, thus ascribing much higher values than usual to casualties preventable by these systems. The rail safety regulators then have the task of interpreting the legislatures’ intentions: for example, do the higher valuations apply to all casualties in train accidents?

Apart from trespassers, the largest group of railway fatalities occurs at level crossings. Most of these are road users, either road vehicle occupants or pedestrians, but a small proportion is staff or passengers on trains. Most fatalities occur in small numbers, but occasionally there are multiple-fatality accidents. Level crossing fatalities have been falling in the USA, but not in Britain; nevertheless, Britain’s level crossing safety performance remains good by international standards. There are many different types of crossing and many different levels of usage both by road users and by trains. Level crossing safety measures would seem to be an appropriate subject for cost benefit analysis, but there are few case-studies in the literature.

Over the last few decades, the economic status of the railway systems in many developed countries has been changed, by privatisation or economic deregulation or both, with the aim of improving their economic performance. However, changing the organisation of railways might affect safety, so it is desirable to investigate whether it is doing so. Empirical evidence on safety performance before and after privatisation is available only for Great Britain and Japan. In neither country is there evidence that safety deteriorated after privatisation. Economic restructuring of railways in the USA took the form primarily of deregulation – that is giving the railways more freedom to set prices and enter or withdraw from markets. The evidence is that this has contributed to improving safety primarily by improving the financial health of the operators and enabling them to renew and improve their assets.

Acknowledgements

The author is grateful to Michael Jones-Lee, Ian Savage, Michael Spackman and an anonymous referee for comments on an earlier version of this paper. However, the contents are solely the author's responsibility.

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