The development of railway safety in Finland

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Analysis of railway passenger safety

Finland and Others: Trends and Comparative Analyses

Introduction

This article presents a comparative analysis of railway passenger safety in Finland and other countries. The study aims to evaluate the effectiveness of safety measures and policies implemented over the years. It highlights the reduction in fatalities and the impact of various strategies adopted by different nations.

Prevention

The results indicate a downward trend in railway passenger fatalities in Finland, reflecting the effectiveness of safety measures. The study also compares the accident rates in Finland with those in other European countries, providing insights into the relative safety levels.

The introduction of the ERTMS (European Rail Traffic Management System) and the implementation of safety features such as line-side barriers and warning systems have contributed to the reduction in fatalities. The study examines the role of these technologies in enhancing passenger safety.

Results

The analysis shows that Finland has experienced a decrease in fatalities over the past decade. The annual reduction is consistent with the improvements observed in other European countries. The comparison with the UK, Sweden, and Denmark reveals that Finland has maintained a relatively low number of fatalities per million passenger-kilometres.

Conclusion

The study concludes that safety strategies, including the introduction of new technologies and enhanced regulatory measures, have significantly reduced the number of fatalities in passenger rail travel. The findings suggest that European countries have succeeded in improving railway passenger safety, with Finland and others leading the way in adopting effective safety measures.

Reference


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The development of railway safety in Finland
Anne Silla *, Veli-Pekka Kallberg 1

VTT Technical Research Centre of Finland, P.O. Box 1000, 02044 VTT, Finland

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ABSTRACT

This study reviews the development of railway safety in Finland from 1959 to 2008. The results show
that the level of safety has greatly improved over the past five decades. The total number of rail-
way fatalities did not show any obvious decreasing or increasing trend during the first decade, but
since the early 1970s the annual number of fatalities has decreased from about 100 to 20. The esti-
mated overall annual reduction per year from 1970 to 2008 was 5.4% (with a 95% confidence interval
from −8.2% to −2.6%). The reduction in subcategories per million train-kilometres from 1959 to 2008
was 4.4% per year for passengers, 8.3% for employees, 5.0% for road users at level crossings and 3.6%
for others (mainly trespassers). The safety improvement for passengers and staff was probably influ-
enced by the introduction of central locking of doors in passenger cars and improved procedures to
protect railway employees working on the tracks. The number of road users killed at level crossings
has fallen due to the installation of barriers and the construction of overpasses and underpasses at
crossings with dense traffic, removal of level crossings, and an improvement of conditions such as
visibility at crossings. The number of trespasser fatalities has seen the least decline. Key plans for
the future include further reduction of the number of level crossings on the state railway network from
the current roughly 3500–2200 by 2025, and involving communities in safety work related to railway
trespassers.

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1. Introduction

Rail transportation has been considered one of the safest modes of transport for some time. Risk comparisons for the EU Member
States show that rail and air travel are the safest modes of transport per travelled passenger-kilometre. Specifically, for the years 2001
and 2002, the fatality risk (fatalities per 100 million passenger-
kilometres) was 0.035 for air (civil aviation) and rail travel, and 0.95
for road transport (ETSC, 2003). In addition, train and bus travel has
the lowest passenger fatality risk per time spent travelling, with
two fatalities per 100 million person travel hours. The risk is more
than 12 times less than for car travel (ETSC, 2003).

In spite of the positive safety record of rail transport, fatalities in
rail traffic do occur and the average yearly number of fatalities
(excluding suicides) in Finland was 19.9 during the period

On the European scale, the level of railway safety in Finland
is roughly at the median based on yearly railway fatalities
(excluding suicides) per million train-kilometres (Eurostat, 2007,
2010). As in most European countries, the largest share of rail-
way accident fatalities in Finland involves trespassers (persons
other than passengers and railway employees killed by rolling
stock in motion outside level crossings) and road users at level
Furthermore, in Finland a greater share of all railway accidents
occur at level crossings than in most other countries (Eurostat,
2010). However, in a recent comparison of fatal railway accident
rates and trends on Europe’s mainline railways, the number of
fatal train collisions and derailments in Finland was too small
to allow reliable comparison of Finland with other countries
(Evans, 2011).

Analysis of historical accident data provides useful background
information when evaluating previous safety work and when plan-
ning future safety strategies. For example, in Great Britain, the
research has focused on fatal transport accidents (Evans, 2003a,b),
railway risks and valuation and the costs of preventing rail fatalities
(Evans, 2005), along with fatal train accidents on Britain’s main-
line railways (Evans, 2006, 2007, 2008, 2009). Furthermore, studies
investigating the effect of privatisation or economic deregulation
on railway safety have been carried out in Great Britain (Evans,
2007), the USA (Savage, 2003) and Japan (Evans, 2010).

This study examined railway accidents in Finland from 1959 to
2008. The objective was to describe and model the trends in the
development of railway safety.
2. Method

2.1. Data

The data for analysis were collected mainly from the statistics of the Finnish railway operator (VR Group Ltd.), and the statistics of the Finnish rail administration (RHK, part of the Finnish Transport Agency since the beginning of 2010). The Finnish State Railways (VR Group Ltd., since 1995) started publishing yearly railway accident and damage statistics in 1959 (State Railways, 1960). The Finnish rail administration (RHK) was established in 1995 and has released yearly railway statistics since its foundation. The accident statistics of RHK are based on data received from the rail operator (there is currently only one rail operator in Finland). The data covers the accidents from the whole Finnish railway network, including private tracks. Metros and tramways are excluded.

Over the years, the accident and damage statistics for railways have undergone several changes (State Railways, 1994). The first important one came in 1985, when the railway administrations in the Nordic countries agreed to harmonise their statistics to improve comparability. According to the Nordic guidelines, only accidents involving fatalities or serious injuries, or accidents causing damage of more than 5000 UIC-francs (a virtual currency unit used by the International Union of Railways) need to be reported (State Railways, 1986). The second substantial change came in 1993, when the limit for reported damage was increased to 10,000 ECU (1 ECU = 1 €). Therefore, since 1993 some features included in the statistics have in certain respects made them incompatible for comparison with those of previous years. In addition, some other changes have taken place over the years, such as new explanations for the concepts used, new information to be collected and minor changes in the classification or table contents.

The data used in this study include the numbers of fatalities in different accident categories, number of all reported level crossing accidents, passenger-kilometres, train-kilometres and number of staff from 1959 to 2008. The data includes only railway accidents caused by rolling stock in motion. Therefore, fatalities that occurred when no train or construction machine was moving are excluded.

The data for 1959–2005 were collected during a national project from the statistics of the Finnish railway operator. This was later extended to 2006–2008 from the statistics of the Finnish Rail Administration. The information on train-kilometres was collected from three sources: for 1959 and 1960 from the railway operator; for 1970–2005 from UIC’s Railsia database; and for 2006–2008 from the Finnish Rail Administration. There was no information available about train-kilometres for 1961–1969; therefore the numbers have been interpolated from the information from 1960 and 1970. The information on the Finnish population and number of registered vehicles was collected from Statistics Finland (2010). The development of railway safety in Finland was evaluated based on fatalities alone, except for level crossings, where also all reported accidents were included. Fatalities resulting from accidents are the most reliable measure of safety, since the definition of the term is clear and practically all fatal accidents have been included in the statistics. The number of injury accidents or resulting injuries is less reliable, because the definitions of reportable injury accidents have varied during the period in question. It is also the case for property-damage-only accidents. The number of fatalities is a suitable measure also in the sense that when improving the level of safety, the most important aim is to reduce the number of fatalities (and serious injuries).

It should be noted that single accident counts are not reliable indicators of safety, especially when the numbers are small. Consequently, the changes in the true level of safety can easily be masked by random variation in accident counts. For example, if the long-term average of the annual number of fatalities is 9, the approximate 95% confidence interval of the observed number of fatalities in any year is 9 ± 2.9. Therefore, the observed annual number of fatalities can vary between 3 and 15 even when there are no significant changes in safety.

Suicides were not included in this study because they have not been included in the accident and damage statistics of the Finnish rail operator since 1985. In Finland, the share of railway suicides of all suicides is small, approximately 4% in 2006 (Peltola and Auttoniemi, 2008). However, suicides represent a significant share of all railway fatalities, since in Finland approximately 70% of railway fatalities are suicides. In general, around 50 railway fatalities that can be classified as suicides occur in Finland each year.

In the following analysis annual data were used except for passenger and employee fatalities, where the data were grouped into 5-year periods, because there were a large number of years with zero fatalities.

2.2. Accident model

Models were fitted to data to describe numerically the trends in the development of railway safety. We used the model introduced by Evans (2007, 2010, 2011). The model assumes that fatalities occur randomly in year $t$ at a mean rate $\lambda_t$ per year; $\lambda_t$ is assumed to be given by

$$\lambda_t = ak_t \exp(\beta t)$$

where $k_t$ is a variable describing exposure to accidents in year $t$, $a$ is a scale parameter, and $\beta$ is a parameter measuring the long-term annual rate of change in accidents per unit of exposure. Depending on the model, $k_t$ is either train-kilometres, passenger-kilometres, number of employees, population, or the number of level crossings. The model assumes that the mean number of accidents per unit time is proportional to exposure (e.g. train-kilometres) and to an exponential function of time, which represents the effects of general improvements in railway safety taking place over the long term (Evans, 2010). The model was fitted by Negative Binomial regression for fatality data and by Poisson regression for accident data (level crossing accidents). However, as noted by Evans (2007, 2010), the decision of whether to use Poisson or Negative Binomial distribution makes little difference to the results.

3. Results

3.1. Descriptive statistics

The annual fatality data used in the analysis is presented in Table 1. The category Road users means road users killed in level crossing accidents. In the category Others practically all cases concern trespassers (i.e. pedestrians walking on the track or crossing the track outside level crossings).

The total annual number of railway accident fatalities fell from about 100 to around 20 during the observation period, and most fatalities were either road users or others. At the same time the population of Finland grew from 4.4 to 5.3 million, and the number of train-kilometres increased by 25% from 42.5 to 53.3 million. The number of level crossings was reduced from 7570 to 4218. Of the 4218 level crossings at the end of 2008, 3515 were on the state railway network and 703 on private railways.

Fig. 1 shows that the trends of road user fatalities at level crossings and fatalities of others have been quite similar with three exceptions. First, the fatalities of others seemed to have a decreasing trend from 1961 to 1970, when there was a sharp increase back to the level of 1961. Second, the fatalities of others were at an exceptionally low level from 1987 to 1991. And third, there was an increasing trend in the fatalities of others from 1996 to 2006.
Table 1

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of fatalities</th>
<th>Number of train-km (million)</th>
<th>Population (million)</th>
<th>Number of level crossings</th>
</tr>
</thead>
</table>
| 1959 | 4 9 34 33 80 42.5 4.41 7570 | 1960 | 4 8 43 25 80 45.3 4.45 7583 | 1961 | 3 10 43 37 93 45.0 4.48 7740 | 1962 | 7 12 42 29 90 44.7 4.51 7893 | 1963 | 8 9 55 30 102 44.4 4.54 7921 | 1964 | 8 7 46 28 89 44.1 4.56 7952 | 1965 | 10 8 51 29 98 43.8 4.57 7815 | 1966 | 12 7 55 26 100 43.5 4.59 7752 | 1967 | 7 8 47 22 84 43.2 4.62 7826 | 1968 | 3 9 40 24 76 42.9 4.63 8008 | 1969 | 7 4 42 21 74 42.6 4.61 8110 | 1970 | 5 5 53 37 100 42.3 4.60 7851 | 1971 | 6 9 57 38 110 41.4 4.63 8016 | 1972 | 11 4 45 31 91 43.4 4.65 7968 | 1973 | 9 6 57 36 108 44.4 4.68 7975 | 1974 | 9 2 54 42 107 46.1 4.70 7972 | 1975 | 5 1 33 35 74 44.4 4.72 7915 | 1976 | 1 3 51 29 84 43.3 4.73 7864 | 1977 | 4 2 32 27 65 42.4 4.75 7726 | 1978 | 3 4 32 30 69 41.5 4.76 7415 | 1979 | 2 2 24 26 54 43.0 4.77 7362 | 1980 | 4 4 35 22 62 44.9 4.79 7092 | 1981 | 3 1 22 21 47 45.5 4.81 8395 | 1982 | 3 0 35 26 64 44.5 4.84 7947 | 1983 | 3 2 26 18 49 43.8 4.87 7836 | 1984 | 8 0 25 17 50 43.3 4.89 7710 | 1985 | 2 1 27 10 40 43.5 4.91 7556 | 1986 | 0 20 17 37 38.3 4.93 7484 | 1987 | 3 1 19 3 26 43.4 4.94 7368 | 1988 | 4 1 12 6 23 42.0 4.95 7293 | 1989 | 4 0 14 3 21 39.3 4.97 7163 | 1990 | 0 2 26 8 36 41.0 5.00 6974 | 1991 | 9 1 20 4 34 40.1 5.03 6634 | 1992 | 1 3 16 11 31 40.2 5.05 6200 | 1993 | 0 0 8 12 20 40.9 5.08 6161 | 1994 | 3 3 12 12 30 41.3 5.10 5970 | 1995 | 1 1 8 7 17 41.0 5.12 5761 | 1996 | 3 1 5 3 12 40.6 5.13 5500 | 1997 | 1 1 13 6 21 44.1 5.15 5398 | 1998 | 10 1 11 2 24 44.5 5.16 5283 | 1999 | 1 0 10 5 16 44.3 5.17 5216 | 2000 | 2 0 10 8 20 44.8 5.18 5162 | 2001 | 2 0 12 6 20 45.5 5.19 5107 | 2002 | 0 4 10 14 47.2 5.21 4956 | 2003 | 0 6 11 17 48.1 5.22 4846 | 2004 | 2 0 7 15 24 48.7 5.24 4635 | 2005 | 0 8 14 22 48.2 5.26 4510 | 2006 | 1 5 17 23 50.9 5.28 4430 | 2007 | 0 10 7 18 52.6 5.30 4334 | 2008 | 0 8 13 21 53.3 5.33 4218

Fig. 1. Annual number of road user fatalities at level crossings and fatalities of others 1959–2008.
551 in 1980 and 404 in 1996. It should be noted that fatalities of road users at level crossings are included in both statistics.

The 5-year fatality data concerning passengers and employees are presented in Table 2. Fatalities among railway employees include only accidents caused by rolling stock in motion. Therefore, fatalities that occurred during, e.g. track works where no train or construction machine was moving are excluded. Instead, these are included in occupational accident statistics. This means that fatalities caused by, e.g. falling from heights and electrocution are excluded from the railway accident statistics. Therefore the figures presented here provide only a partial picture of all fatalities among railway employees, and especially personnel working on the tracks. Correspondingly, the passenger fatalities and the fatalities of others include only accidents caused by rolling stock in motion.

During the observation period the number of both employee and passenger fatalities decreased from approximately eight per year to less than one per year. The development of employee fatalities has been especially remarkable, since during the last 10 years only one employee was killed in a railway accident. The number of employees has decreased by 67% from 35,511 to 11,754, and the number of passenger kilometres has increased by 58% from 2.3 to 3.6 billion.

The increase in the number of passenger fatalities to 40 in 1964–1968 from 26 in 1959–1963 in Table 2 makes an exception to the overall decreasing trend. There were no major multiple-fatality accidents during the latter period that would have explained the increase. Other obvious explanations for this increase could not be found either. It is possible, however, that the exceptionally low figure of 26 in 1959–1963 may not reflect correctly the actual state of safety but was influenced by random variation, which is always inherent in accident counts.

Potentially the most disastrous railway accident types are train collisions and derailments, where the risk of multiple passenger fatalities is greatest. During the study period two such major accidents occurred: four people died in a derailment in Jokela in 1996 and 10 in a derailment in Jyväskylä in 1998. Table 3 summarises the information on fatal train collisions and derailments. Unfortunately, data on individual accidents have only been included in the statistics since 1996. For earlier years only annual numbers of fatalities are available; thus the number of fatal collisions in the first two decades is uncertain. For 1959–1968, for example, we only know for certain that the number of fatal collisions was between two and six because the six fatalities occurred in two different years. The three fatalities concerning derailments in the same period occurred in different years. Therefore we know that they resulted from three different accidents.

It seems that the number of fatal train collisions and derailments has decreased from the first to the last half of the observation period. The reasons for this positive development are not clear. It cannot be excluded, however, that the reduction in fatal train collisions may be due at least partly to changes in the allocation of accidents to different categories. In the course of this study we managed to trace and correct some classification errors, but there may still be some inaccuracies in the data that cannot be corrected because of the lack of records on individual accidents, especially in the early decades.

The implementation of automatic train protection (ATP) started in the early 1990s and gathered pace following the two major derailments in 1996 and 1998. Although there have been no fatal train collisions or derailments in the last decade, the data in Table 3 are too sparse for estimating the impacts of ATP on fatal accidents.

In addition to the analysis of fatalities, the improvement of level crossing safety was analysed based on all reported level crossing accidents with or without casualties. Table 4 shows that the number of level crossings (including private tracks) has decreased over the years from 7570 in 1959 to 4218 in 2008. Specifically, in the

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**Table 2**

Number of passenger and employee fatalities and potential explanatory variables on Finnish railways over 5-year periods from 1959 to 2008.

<table>
<thead>
<tr>
<th>Period</th>
<th>Passenger fatalities</th>
<th>Railway employee fatalities</th>
<th>Average annual passenger-km (million)</th>
<th>Average number of staff members</th>
<th>Average annual train-km (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1959–1963</td>
<td>26</td>
<td>48</td>
<td>2306</td>
<td>35,511</td>
<td>44.4</td>
</tr>
<tr>
<td>1964–1968</td>
<td>40</td>
<td>39</td>
<td>2115</td>
<td>34,184</td>
<td>43.5</td>
</tr>
<tr>
<td>1969–1973</td>
<td>38</td>
<td>28</td>
<td>2407</td>
<td>27,666</td>
<td>42.8</td>
</tr>
<tr>
<td>1974–1978</td>
<td>22</td>
<td>12</td>
<td>3025</td>
<td>28,909</td>
<td>43.5</td>
</tr>
<tr>
<td>1979–1983</td>
<td>15</td>
<td>6</td>
<td>3235</td>
<td>28,501</td>
<td>44.3</td>
</tr>
<tr>
<td>1984–1988</td>
<td>17</td>
<td>3</td>
<td>3096</td>
<td>25,499</td>
<td>42.1</td>
</tr>
<tr>
<td>1989–1993</td>
<td>14</td>
<td>6</td>
<td>3167</td>
<td>19,765</td>
<td>40.3</td>
</tr>
<tr>
<td>1994–1998</td>
<td>18</td>
<td>7</td>
<td>3246</td>
<td>15,141</td>
<td>42.3</td>
</tr>
<tr>
<td>1999–2003</td>
<td>5</td>
<td>0</td>
<td>3352</td>
<td>12,245</td>
<td>46.0</td>
</tr>
<tr>
<td>2004–2008</td>
<td>3</td>
<td>1</td>
<td>3640</td>
<td>11,754</td>
<td>50.7</td>
</tr>
</tbody>
</table>

**Table 3**

Number of fatal train collisions and derailments and resulting fatalities on Finnish railways over 10-year periods from 1959 to 2008.

<table>
<thead>
<tr>
<th>Period</th>
<th>Fatal accidents</th>
<th>Fatalities</th>
<th>Derailments</th>
<th>Fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1959–1968</td>
<td>2–6</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1969–1978</td>
<td>3–7</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1979–1988</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1989–1998</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>1999–2008</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

---
1960s and early 1970s the number of level crossings remained quite steady and even increased slightly. The effective removal of level crossings began in the mid-1970s when increased attention was paid to road safety in general. At the same time, an increasing number of remaining level crossings were fitted with active warning devices. Specifically, 2.7% of level crossings were equipped with active warning devices in 1959 while the corresponding number in 2008 was 20.1%.

Level crossing accidents decreased quite steadily from the late 1960s to the mid-1990s. This increase coincided with rapid growth of the motor vehicle fleet. Most level crossing accidents occurred at level crossings without an active warning device such as automatic barriers or light and sound warning devices, and the proportion did not change much during the observation period even though the number and proportion of level crossings with warning devices increased substantially.

### 3.2. Accident models

Fig. 3 shows the model fitted to the annual data on all fatalities in Table 1, assuming that fatalities have a negative binomial distribution. The annual rate of change in the fatality rate is $-4.5\%$ per year with a 95% confidence interval from $-6.5\%$ to $-2.5\%$. The estimated fatality rate in 2008 is $0.34$ fatalities per million train-kilometres, giving an estimated mean number of fatalities in 2008 of 18. Based on the modelling results the railway fatality rate has fallen by a factor of 10 from 1959 to 2008. However, it is also clear from Fig. 3 that the model overestimates the trend during the first decade when the actual fatality rate did not show any significant decrease. Therefore, the real reduction in the fatality rate from 1959 to 2008 is clearly less than the model indicates.

In order to improve the fit of the model, the same model was fitted to the annual data from 1970 to 2008. The results show a
stronger decrease (−5.4% per year with a 95% confidence interval from −8.2% to −2.6%) in the annual rate of change in the fatality rate than the model for the whole period. According to this model the fatality rate decreased by a factor of 9 from 1970 to 2008. The estimated fatality rate in 2008 was 0.29 fatalities per million train-kilometres, giving an estimated mean number of fatalities in 2008 of 16.

The models for different fatality categories were first calculated by using train kilometres as exposure variable for all categories. Fig. 4 shows these models fitted to the data in Table 1 (road user fatalities and fatalities of others) and Table 2 (passenger and employee fatalities). Fig. 4 shows that the absolute decrease in fatality rates was greatest for road users at level crossings followed by others (mostly trespassers), and much smaller for passengers and employees.

Furthermore, separate models were calculated for the rates in all four fatality categories using different exposure variables: passenger-kilometres for passenger fatalities, number of staff members for employee fatalities, the number of level crossings for road users killed in level crossing accidents, and Finnish population for trespasser fatalities. Table 5 presents a summary of these models and the models where train-kilometres were used as an exposure variable.

The trends per million train-kilometres in different victim categories in Table 5 show that the annual rate of change was most favourable for employees (−8.3%), followed by road users (−5.0%), passengers (−4.4%) and others (−3.6%). The annual number of passenger fatalities per billion passenger-kilometres fell at a rate of 5.5% per year, indicating that from 1959 to 2008 the number of passenger fatalities dropped by a factor of 16. Correspondingly, the number of employee fatalities per 1000 employees fell by a factor of 19, the number of fatalities of road users per 1000 level crossings by a factor of 6, and the number of fatalities in the category others per million inhabitants by a factor of 6.

The mean annual rates of change per million train-kilometres for different fatality categories in Table 5 range from −5.0% for road users to −3.8% for the category others, except for employees for whom the corresponding rate is −8.3%. With this exception the rates are fairly close to each other. This fact together with overlapping confidence intervals of the rates suggests that the rates do not substantially differ from each other.

The model estimates for the mean fatality rates in 2008 in the rightmost column of Table 5 are close to the observed numbers in Tables 1 and 2. The estimated mean fatality rate of road users in 2008, for example, is 5.9 (the product of 1.40 in Table 5 and the 4.2 thousand level crossings in the last row of Table 1), when the observed number in Table 1 is 8.

Regarding all reported level crossing accidents, Table 6 shows the results after fitting the model to the annual data in Table 4, assuming that level crossing accidents have a Poisson distribution. The estimated annual rate of change in the accident rate is −9.2% per year per million registered vehicles and −3.9% per year per million train-kilometres. The estimated rate of change per million train-kilometres was somewhat smaller than the corresponding rate for road user fatalities at level crossing accidents (−5.0%, see Table 5).

Table 6 shows that level crossing accidents per registered vehicle decreased much more than level crossing accidents per

Table 5

<table>
<thead>
<tr>
<th>Category</th>
<th>Estimated annual rate of change over 1959–2008 (95% confidence limits in brackets)</th>
<th>Estimated mean fatality rates in 2008 (95% confidence limits in brackets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>Per million train-km: −4.5% (−6.5%, −2.6%)</td>
<td>0.34 (0.19, 0.59)</td>
</tr>
<tr>
<td>Passengers</td>
<td>Per billion passenger-km: −5.5% (−10.0%, −1.0%)</td>
<td>0.30 (0.08, 1.10)</td>
</tr>
<tr>
<td>Employees</td>
<td>Per million train-km: −4.4% (−8.9%, 0.0%)</td>
<td>0.03 (0.01, 0.10)</td>
</tr>
<tr>
<td>Road users</td>
<td>Per thousand level crossings: −3.5% (−5.5%, −1.5%)</td>
<td>1.40 (0.79, 2.49)</td>
</tr>
<tr>
<td>Others</td>
<td>Per million inhabitants: −3.7% (−5.7%, −1.7%)</td>
<td>0.15 (0.09, 0.27)</td>
</tr>
<tr>
<td></td>
<td>Per million train-km: −5.0% (−7.0%, −3.0%)</td>
<td>0.97 (0.79, 2.47)</td>
</tr>
<tr>
<td></td>
<td>Estimated annual rate of change over 1959–2008 (95% confidence limits in brackets)</td>
<td>0.34 (0.19, 0.59)</td>
</tr>
<tr>
<td></td>
<td>Estimated mean fatality rates in 2008 (95% confidence limits in brackets)</td>
<td>0.30 (0.08, 1.10)</td>
</tr>
</tbody>
</table>
train-kilometre. During the observation period the number of registered motor vehicles increased rapidly (from 0.2 million to 3.2 million). It seems likely, however, that the number of motor vehicles traversing level crossings did not necessarily increase as much as the vehicle fleet because at the same time the number of level crossings was reduced.

The decrease in the number of accidents at level crossings with a warning device per number of such crossings was higher (6.7% per year) than the decrease in number of accidents at such level crossings without a warning device (2.7% per year), and the difference was statistically significant (Table 6). A potential explanation is that the reduction in the number of level crossings has concerned especially passive level crossings (without an active warning device) where there was little road traffic and therefore relatively small accident potential. Consequently, the average volume of road traffic per passive level crossing (and respective accident potential) increased with time. For level crossings with an active warning device the average volume of road traffic per level crossing probably decreased with time as the number of level crossings with such a warning device increased year by year, because warning devices were implemented first at level crossings with large volumes of road traffic. The differences in development of the average volume of road traffic per level crossing between level crossings with and without an active warning device may therefore largely explain the differences in accident trends between the two level crossing categories.

4. Discussion

The main results of this study showed that the level of railway safety in Finland has greatly improved over the five decades from 1959 to 2008. A similar decreasing trend of train accidents has also been found in other countries (see, e.g. Evans, 2007, 2010, 2011). The development of railway accident fatalities was similar to that of road accident fatalities from 1960 until the early 1980s. Thereafter numbers of fatalities decreased more on railways than on roads.

The total number of railway fatalities did not show any obvious decreasing or increasing trend during the first decade, but since the early 1970s the annual number of fatalities has fallen from about 100 to 20. The estimated overall annual reduction per year from 1970 to 2008 was 5.4%. The improvement of railway safety concerns all victim categories: passengers, railway employees, road users at level crossings and others (mainly trespassers). The annual reduction in fatalities per million train-kilometres from 1959 to 2008 was 4.4% for passengers, 8.3% for employees, 5.0% for road users at level crossings and 3.6% for others (mainly trespassers).

The models used in this study were similar to those used by Evans (2007, 2010, 2011) to preserve comparability with earlier international studies. The models were simple in the sense that they included only one variable describing exposure. More complex model forms including several explanatory variables could have been used, but interpretation of the results would probably have become difficult because of multicollinearity problems. Even though such models could have increased the information on which variables have affected the development of railway safety, it is questionable whether the true effects of different variables could have been quantified with reasonable accuracy. It also became clear during the study that data were not available on all variables that could and probably would have influenced the development of railway safety since 1959. For example, data on the number of road vehicles traversing level crossings annually or frequency of trespassing probably have a major influence on railway accidents, but such information was not available. When data on major explanatory variables is missing there is little point in building models based on secondary variables.

The reduction in fatalities was most spectacular for railway employees: between 1999 and 2008 there was only one employee fatality, whereas during the first decade of the observation period the number was 87. Potential reasons for the reduction of employee fatalities include the introduction of new guidelines and procedures to protect railway employees working on the tracks, as well as a reduction in the number of people working on the tracks since human labour has largely been replaced by machines. It is also possible that the volume of major track construction and maintenance works decreased during the observation period.

The number of passenger fatalities decreased from 66 in the first decade to eight in the last decade of the observation period. Most passenger fatalities concern falling from a moving train or people boarding or getting off the train. The decline in passenger fatalities was probably brought about by the introduction of central locking of doors in passenger trains, which took place at the turn of the century. Another issue that might have had an influence on the increased safety of passengers is the replacement of old wooden passenger carriages with steel carriages in the 1980s. The stairs in the old carriages were outside the doors, whereas in the new carriages the stairs are inside. Jumping from and especially onto a moving train became much more difficult after the introduction of the new carriages.

The most disastrous railway accidents are typically train collisions and derailments where multiple passenger fatalities are more likely than in other types of accidents. The number of fatal train collisions and derailments fell from between eight and 16 in the first half of the 50-year observation period to two in the latter part, which indicates a positive development of safety. However, it cannot be ruled out that part of this reduction is due to changes in the categorisation of accidents. Some but not necessarily all classification errors could be detected and corrected during this study. The number of fatalities in train collisions and derailments decreased less, from 17 to 14, because of two major derailments in 1996 and 1998 resulting in four and 10 fatalities. Because of these two accidents the implementation of automatic train protection (ATP) that had begun in the early 1990s was accelerated. Currently ATP covers practically all railway sections on the Finnish state-owned railway network (excluding some railway sections with low traffic volumes and used only by freight trains). The accident data, however, is too sparse to allow for the estimation of the effects of ATP on safety.

The annual number of level crossing accidents was fairly stable during the 1960s and typically close to 250 resulting in around 50 fatalities. Then the numbers started to decline, such that since the mid 1990s the annual number of accidents has been about 50 and the number of fatalities close to 10. The levelling off since the mid-1990s is in agreement with the results of the European analysis, which showed that the rate per train-kilometre of serious accidents at level crossings has remained largely unchanged during the last 20 years (Evans, 2011).

The decrease in the number of road users killed at level crossings was affected by the removal of level crossings, the construction of overpasses or underpasses at crossings with dense traffic, the installation of barriers and the improvement of conditions such as visibility at crossings (e.g. by clearing vegetation and other obstacles from sight lines). The removal of level crossings and construction of overpasses or underpasses have focused on railway sections where the maximum speed is over 140 km h⁻¹ and on railway sections where dangerous goods are frequently transported. According to the Finnish Railway Agency’s guidelines, level crossings are not allowed on track sections where the train speed exceeds 140 km h⁻¹. The improvement of conditions is important for safety especially at level crossings situated on minor gravel roads (like most level crossings in Finland), where traffic volumes are often less than 10 vehicles per day and the crossings have no active warning devices. These are the level crossings where most
accidents happen. However, improvement of visibility at the crossings to achieve adequate sight conditions is not always possible and in these cases accident risk has been reduced, for example, by setting a driving ban for long and slow vehicles or reduced spot speed limits for trains (Kallberg, 2008).

The improvement of safety at passive level crossings is challenging because it is not feasible to provide any significant number of them with automatic barriers or flashing lights and bells. In addition to the measures mentioned above, the safety of level crossings on minor roads can be improved by, e.g., reducing the speeds of road vehicles so that drivers have more time to stop before the railway if needed (e.g. by installing stop signs or speed bumps), improving the vertical alignment of the road, or introducing technical solutions to help drivers spot an approaching train (e.g. in vehicle devices in cars to warn of approaching trains). The number of accidents per level crossing was higher for active than passive level crossings until the 1990s. This does not, however, mean that passive crossings were safer than active ones, because traffic volumes on the road are typically much higher at active crossings.

The number of fatalities in the category Others (mainly trespassers who cross the railway lines at places that are not meant for that purpose or who are walking along the tracks illegally or loitering in the railway area) decreased from 286 in the first decade to 106 in the last decade of the observation period. Over the past 10 years, most railway fatalities have been in this category. The number of trespasser fatalities has not decreased as much as have fatalities in other categories. The prevention of trespassing is hard, because nearly everyone is a potential trespasser and the railway lines in Finland, unlike in some other countries, are usually not isolated from the surrounding areas by fences. Trespassing is most frequent in cities that are divided by railway lines (Silla and Luoma, 2008). Railway lines have always divided communities, and in some cases this separation has become even more marked over the years. This means that new developments within the city such as living areas, shopping areas and schools are often located on both sides of the railway lines, increasing people’s need to cross the tracks. However, stakeholders in the railways have only limited possibilities to improve matters. The railway authorities can reduce trespassing by restricting the access to railway lines (e.g. by building fences or landscaping) at locations where trespassing is frequent, but due to the great number of such locations, it is important that stakeholders in society (e.g. policy makers, urban planners and school teachers) also participate in prevention. In spite of this shared responsibility, these fatalities affect the image of railways and their safety level as experienced by the general public.

Consequently, there is still work to be done to improve the safety of Finnish railways. The implementation of safety management systems has made safety work more organised and enhanced preventive safety work in order to recognise safety risks before they lead to accidents. A key strategy for the future includes the removal of 1500 level crossings by 2025; according to estimates, this will reduce the number of level crossing fatalities by 50% (Finnish Rail Administration, 2006). Additionally, more research is needed to find solutions for increasing the safety of passive level crossings. Another goal is to involve communities in the safety work related to railway trespassers in order to decrease the large amount of trespassing accidents.

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References