Investigations Using the NMF Safety Model

A report for the Rail Safety and Standards Board
November 2008
Issue 1

risksolutions
leave nothing to chance

Investigations Using the NMF Safety Model

A report for the Rail Safety and Standards Board

November 2008

Client reference: T760

Report reference: D4202-RP6

Issue 1

Risk Solutions

59-60 Russell Square

London WC1B 4HP

United Kingdom

☏ 0870 850 4889

🖷 0870 850 4895

www.risksol.co.uk

Executive Summary

Under the Railways Act, DfT and Transport Scotland must each publish a High Level Output Specification (HLOS) that sets objectives for the rail industry in terms of network capacity, train frequencies, journey times, punctuality etc. To support this, DfT commissioned the Network Modelling Framework (NMF), an integrated suite of models that predict demand, revenues, costs, punctuality and safety performance for different investment strategies.

Risk Solutions, supported by RSSB, was asked to develop the NMF Safety Model for the DfT. The model is based on a simplified version of the industry's Safety Risk Model (SRM). A key difference from the SRM is that the NMF Safety Model calculates safety risk for the number of trains, train speed and passenger loading associated with each of Network Rail's 300+ Strategic Route Sections (rather than for the national average train conditions represented in the SRM). This enables users to quantify the safety implications of changes in train/loading patterns in a way consistent with the SRM but at a local level – allowing changes in safety risk to be considered in the appraisal of alternative investment strategies.

As part of its ongoing development of the NMF Safety Model, RSSB commissioned Risk Solutions to undertake three studies using the NMF Safety Model. This report summarises the findings of the work.

Review HLOS modelling assumptions and outputs

The first study was to generate safety outputs, using the NMF Safety Model, that are consistent with the passenger and freight traffic projections described in the High Level Output Specification (HLOS). Before doing so, however, we checked that the input files provided by DfT were consistent with the HLOS and discovered that the freight services file was based on earlier freight forecasts provided by Network Rail. Having commissioned Steer Davies Gleave (SDG) to produce a revised freight services file, we were able to complete the analysis which found that:

- The HLOS predicts a 27% increase in freight tonnes lifted between 2004/05 and 2014/15 and we calculate that, due to the changing traffic mix, this would equate to a 41% increase in freight train kilometres[1]. However, the data supplied by Network Rail (based on the March 2007 Freight Route Utilisation Study on which the HLOS was also based) shows that freight train kilometres are expected to increase by 49% by 2014/15. This suggests that freight trains will carry fewer goods or, more probably, that some commodities are expected to travel further in future.
- Passenger train kilometres are expected to rise by just 9% over the same period, even though passenger kilometres are expected to increase by 58%. Since the average length of trains is not increasing, the discrepancy means that the average train occupancy is expected to rise by 45%. We have not analysed whether such an increase is possible (the NMF itself performs checks on crowding) but have assumed that this will be achieved by making better use of available capacity in the offpeak periods.
- The net effect of these changes on safety is to increase the overall number of Fatalities and Weighted Injuries (FWIs) by 20% from 2005 to 2030, with two-thirds of the increase attributable to increased risk to passengers. However, this is in the

[1] The calculations are based on the assumptions that, for each type of traffic, the trains will carry the same quantity of goods and travel the same average distance.

context of a rapidly growing railway and the results need to be normalised to make such comparisons meaningful. The normalised figures show that for:

- Non-movement accidents the risk (in FWIs per passenger kilometre) is expected to reduce steadily, mainly due to initiatives to improve worker safety and the fact that the risk to workers and the general public increase in proportion to train kilometres[2]
- Movement accidents the risk (in FWIs per train kilometre) stays constant.
- Train accidents the risk (in FWIs per passenger kilometre) increases initially, mainly due to a rapid increase in freight traffic resulting in a higher probability of secondary collisions, before it starts to decline.

Review the SRM loading assumptions

The current version of the NMF Safety Model calculates the safety risk using the nominal passenger train loadings used in the SRM and then applies a 'load factor' to increase or reduce the risk. However, the NMF also calculates passenger train loadings to assess the effects of crowding and the second study was commissioned to establish whether the NMF Safety Model could use the actual passenger train loadings and, if so, whether this had a material effect on the risk profile.

SDG and DeltaRail were commissioned to output passenger train loading data from the NMF and we then used this to calculate the equivalent number of night, offpeak, peak and crush loaded train kilometres on each Strategic Route Section (SRS). We were then able to use the NMF Safety Model to calculate the risk profile for three scenarios:

- The base case, i.e. the approach currently used in the NMF
- Option 1, in which we used the calculated proportions of night, offpeak, peak and crush loaded trains on each SRS
- Option 2, in which we repeated the Option 1 analysis but this time we assumed that night and offpeak loaded trains carried more occupants.

The study found that:

- The current definitions of night, offpeak, peak and crush-loaded passenger trains do not need to be altered in the SRM or NMF Safety Model. However, the proportion of passenger train kilometres that are night, offpeak, peak and crush loaded should be changed to 12%, 64%, 22% and 2% respectively[3] in the SRM and the NMF Safety Model should be recalibrated accordingly.
- The current simplified approach to calculating passenger train loadings works well overall, but could introduce errors locally since:
  - The frequency of offpeak loaded services assumed for a particular SRS in the NMF Safety Model tends to be an overestimate, but the frequency of peak loaded services tends to be a significant underestimate (i.e. approximately half the correct value)
  - There is no correlation between the frequency of night and crush loaded services in the NMF Safety Model and that existing on the network.

It is worth noting, however, that the current version of the NMF Safety Model assumes a linear relationship between passenger train loading and the number of passenger casualties. If this assumption were changed it may be more important to model the distribution of trains around the network more accurately.

---

[2] Since train kilometres are increasing more slowly than passenger kilometres, the normalised figure reduces.

[3] The current proportions are 10%, 72%, 13.5% and 4.5% respectively.

Sensitivity Analysis

The third study was to determine the sensitivity of the safety outcomes to changes in the parameters in the input files, the aim being to identify parameters (and relationships) that may need closer scrutiny when running or developing the model. Since the results would vary depending on the characteristics of the SRS being analysed, the analysis was based on national averages for the whole rail network. This means that the results should be comparable to those for the Safety Risk Model, and the findings should apply to both models.

In general, our approach was to calculate changes in the train accident risk for each module of the NMF Safety Model when we varied each of the parameters by ±20%. However, a number of the variables cannot be varied independently (e.g. the proportion of trains carrying hazardous goods that are either flammable or toxic should always sum to one). To resolve this, simple 'rules' were created to ensure that a change in one parameter resulted in a logical change in any related parameters.

The sensitivity analysis identified a number of parameters that affect multiple modules, and which may benefit from greater scrutiny for future versions of the SRM and NMF Safety Model. The most critical parameter is, not surprisingly, average train speed. Having examined all the speed-related parameters in the NMF Safety Model we conclude that:

- The frequency of collisions and derailments involving passenger trains should be a function of speed – at the moment they are fixed probabilities.
- The speed (and hence consequences) of collisions and derailments is currently assumed to be proportionate to average train speed. This is inappropriate for low speed collisions and derailments and may also be invalid for high speed incidents.
- If the average speed of high speed derailments is related to average train speed, then the probability of trains not maintaining clearances, hitting lineside structures, etc. should also be a function of average train speed.
- The current linear relationship between average train speed and the consequences of an accident may overstate the consequences on low speed lines and understate them on high speed lines[4].

In summary

These studies have demonstrated that the NMF Safety Model is a flexible tool that can be used to:

- Project changes in risk based on planned changes to passenger and freight services
- Test the effect of proposed changes to the SRM, whether they are the sensitivity of individual parameters or the benefits of alternative calculation methods, before going to the expense of modifying the SRM itself.

In terms of future development of the NMF Safety Model, we now recommend that.

- The probability of train-train collisions in HET-01 and HET-02 should be a function of train frequency instead of using national averages from the SRM.
- RSSB should review a number of relationships in the SRM and NMF Safety Model to decide whether they should be related to average train speed and, if so, how.
- The cost and delay minutes attributable to train accidents need to be completed in the consequence tables, so that the model is able to assess the economic cost (as well as the casualties) of changes in safety performance.

---

[4] It has been suggested that the consequences from an accident should be a function of the kinetic energy of the train and, therefore, should be proportional to the square of the train speed.

Table of Contents

1 INTRODUCTION

1.1 In 2006 the Rail Safety and Standards Board (RSSB) commissioned Risk Solutions to develop the NMF Safety Model. The model formed part of the Network Modelling Framework (NMF) being developed by the Department for Transport to calculate the costs and benefits of different investment proposals for the mainline rail network, in order to support development of the High Level Output Specification (HLOS) and accompanying Statement of Funds.

1.2 When developing the NMF Safety Model, RSSB recognised that it had potential applications beyond the NMF and could be a valuable research tool. This is because the model is based on the industry's Safety Risk Model but has some important differences:

- A number of parameters in the SRM have been made variables in the NMF by linking them to appropriate operational parameters (such as average train speed)
- The model calculates safety risk for sections of the network and then sums the risk, rather than calculating the risk from network-wide averages
- Underlying changes in safety performance and changing operational parameters are held in a series of input files so that the risk profile can be modelled over time.

1.3 In January 2008 Risk Solutions was commissioned to undertake three studies using the NMF Safety Model:

1. Review HLOS modelling assumptions and outputs – this task was to predict the changes in safety performance resulting from changes to passenger and freight services, as well as industry initiatives to improve safety.
2. Review the SRM loading assumptions against the NMF analysis – this task was to check that the passenger train loading assumptions in the SRM and NMF Safety Model are appropriate and test the feasibility of calculating the risks using actual train loading data rather than the current approach.
3. Sensitivity Analysis of the NMF Safety Model – this task was to test the sensitivity of the results to changing the input file parameters by ±20%.

1.4 The following sections summarise our approach to each of these tasks and our findings. All of the analysis was performed with Version 1K of the NMF Safety Model.

List of modules

1.5 Throughout the report we refer to the train accidents using the appropriate SRM codes so, for example, derailment of a passenger train is referred to as HET-12. The full list of modules is:

- HET-01, Collision between two passenger trains
- HET-02, Collision between passenger and non-passenger train
    - HET-02P, passenger train causes collision
    - HET-02NP, non-passenger train causes collision
- HET-04, Collision with object on the line
- HET-09, Collision with buffer stops
- HET-10, Passenger train collision with road vehicle on level crossing
- HET-11, Non-passenger train collision with road vehicle on level crossing
- HET-12, Derailment of a passenger train
- HET-13, Derailment of a non-passenger train
    - HET-13FT, Freight train derailment
    - HET-13E, Empty coaching stock derailment

2 REVIEW HLOS MODELLING ASSUMPTIONS AND OUTPUTS

2.1 The aim of this study was to generate safety outputs, using the NMF Safety Model, that are consistent with the passenger and freight traffic projections described in the HLOS.

2.2 Our first task was to collate the input files that DfT used to represent the final HLOS position and confirm whether the freight services file reflected:

- the freight growth assumptions in the HLOS or
- Network Rail's more conservative assumptions which were used to create the freight services file we provided with Version 1J of the model.

2.3 If the latter, we needed to generate a new freight services file that reflects the HLOS growth assumptions. Using this file, and the files provided by DfT[5], we could then predict a revised safety baseline that takes account of (a) expected safety improvements identified by RSSB and (b) projected changes in rail usage over the period 2009 to 2014. We could also calculate projected national averages for key input parameters (such as passenger train kilometres per year) for comparison with those used in the SRM.

Review of input files

2.4 The NMF Safety Model has five input files:

- **Safety Assumptions** file containing the probability of base events (e.g. the probability of passenger train derailment per train kilometre) for each year from 2005 to 2069. These assumptions match the SRM for 2005 and, in most cases, remain constant over time. However RSSB conducted a 'baselining workshop' with its Safety Policy Group in February 2007 and this projected changes to a number of risk contributors[6] in 2006/07, 2008/09 and over the five years of the HLOS period.
- **Infrastructure** file containing the length of each SRS, the average number of tracks and the number of level crossings (broken down into 6 types) over time. This data was supplied by Network Rail in early 2006 and the figures do not vary for future years – implying there are no plans to change the number/type of level crossings or increase capacity by adding tracks.
- **Track Defects** file containing the number of rail breaks, rail defects and 'level 2 exceedences' per year on each SRS and over time. Again, the data is unchanged from those supplied by Network Rail and do not project any reduction in track defects.
- **Freight Services** file containing, for each SRS in a given year, the number of freight trains per hour in the night, offpeak and peak periods.
- **Passenger Services** file containing, for each SRS in a given year, the average train speed, number of passenger trains per hour in the night, offpeak and peak periods, the proportion of trains that are loco-hauled or multiple units, the average number of carriages per train and the total passenger kilometres travelled on a weekday.

2.5 To avoid unnecessary calculations, the NMF only analyses selected years (i.e. when developing the HLOS, DfT analysed the years 2005, 2007, 2009, 2010, 2014, 2020 and 2030). Passenger train service parameters are provided, by the NMF, for the years being analysed

5 It was assumed that the parameters contained in the infrastructure and track defects files would not be affected by implementation of the HLOS, but that also needed to be confirmed.

6 The risk contributors affected by the baselining workshop were: Category A SPADs, misrouting of trains, road vehicles and pedestrians struck by trains at level crossings, landslips and passenger rolling stock faults leading to derailments, track worker struck by trains, injuries to passengers and the workforce due to sudden train movements, and track worker and other workforce injuries in general.

and the NMF Safety Model then refers to the other input files to identify the relevant parameters for the infrastructure and freight services for the same years.

2.6 Having confirmed that the other four input files were consistent with the data supplied previously by RSSB and Network Rail, we then analysed the freight services file. This was to check that the file represented the changes projected in the HLOS, which were based on Network Rail's March 2007 Freight Route Utilisation Strategy (Freight RUS).

2.7 Using the NMF Safety Model and the freight file provided by Network Rail in September 2006, we calculated the projected growth in freight traffic over the HLOS period. Figure 1 shows that this predicted steady growth (15% overall) from 2004/05 to 2008/09, and no growth thereafter.

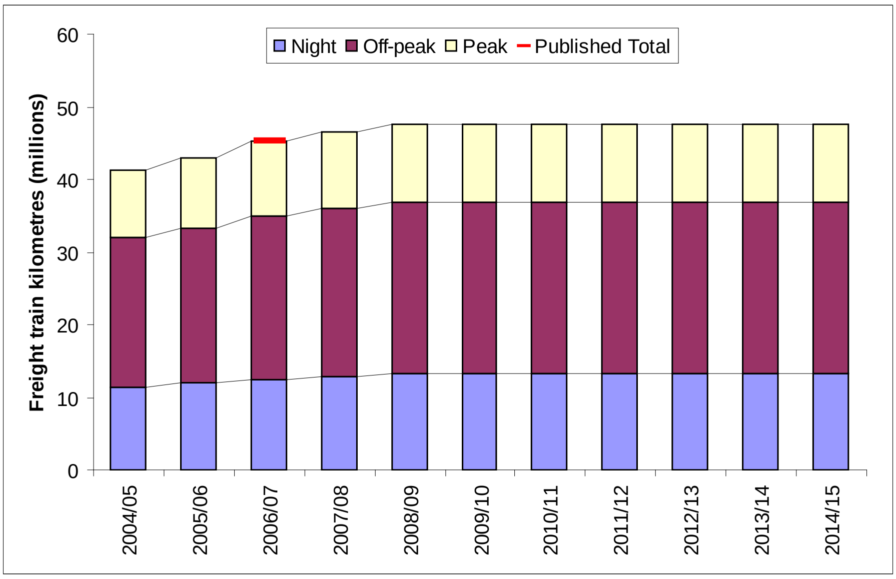

Figure 1: Growth in freight train kilometres based on original data supplied by Network Rail

2.8 Network Rail's March 2007 Freight RUS predicted that freight volumes will increase from 105 million tonnes of freight lifted in 2004/05 to 133 million tonnes in 2014/15; a 27% increase compared to the 15% increase in freight train kilometres predicted above[7]. While the numbers are not directly comparable, we concluded that the current freight file did not reflect the growth projected in the Freight RUS.

Effect of changing freight mix

2.9 Tables 3.1 and 3.2 of Network Rail's March 2007 Freight RUS[8] shows the freight tonnes lifted and freight tonne kilometres broken down by commodity from 2000/01 to 2004/05 (the industry base year). Table 4.1 then shows two projections for freight tonnes lifted in 2014/15 (based on bottom-up and top-down forecasts) and the approximate growth over the 2004/05 base year.

2.10 Unfortunately, Table 4.1 does not show the projected freight tonne kilometres and cannot be compared directly with the other two tables because the commodities are at a greater level of detail (e.g. ore, waste, maritime containers and automotive are all listed separately). However, using the growth figures in Table 4.1 we were able to back-calculate a more detailed breakdown of the freight tonnes lifted in 2004/05. By assuming that the average distance

7 Note that, depending on the mix of traffic, an increase in freight tonnes lifted could result in a larger or smaller increase in freight tonne kilometres (and hence freight train kilometres).

8 Network Rail's March 2007 Freight RUS can be downloaded using the following link: http://www.networkrail.co.uk/browse%20documents/rus%20documents/route%20utilisation%20strategies/freight/freight%20rus.pdf

each commodity travels will not change, we were then able to convert the freight tonnes lifted to freight tonne kilometres. The calculations are shown in Table 1 below.

Table 1: Calculating the change in freight tonne kilometres

Commodity	Freight tonnes lifted in 2014/15* (millions)		% change from 2004/05*		Inferred tonnes lifted in 2004/05 (millions)		Average km/ tonne**	Estimated freight tonne kilometres (billions)		Estimated freight tonne kilometres in 2004/05	
	bottom-up	top-down	bottom-up	top-down	bottom-up	top-down		2004/05	2014/15	bottom-up	top-down
Coal	50.5	43.1	9%	-8%	46.3	46.8	153.8	7.2	7.2	7.8	6.6
Metals	14.6	11.8	39%	12%	10.5	10.5	149.4	1.6	2.0	2.2	1.8
Ore	5.9	6	-3%	-5%	6.1	6.3	149.4	0.9	0.9	0.9	0.9
Construction	23.6	31.5	20%	45%	19.7	21.7	122.8	2.5	3.4	2.9	3.9
Waste	1.8	2.3	-9%	14%	2.0	2.0	122.8	0.2	0.3	0.2	0.3
Petroleum & Chemicals	7.1	7	5%	4%	6.8	6.7	157.9	1.1	1.1	1.1	1.1
Channel Tunnel	6	6.5	200%	266%	2.0	1.8	416.7	0.8	2.6	2.5	2.7
Domestic Intermodal	2.5	6.5	177%	838%	0.9	0.7	459.8	0.4	2.1	1.1	3.0
Maritime Containers	20.3	18.8	83%	42%	11.1	13.2	459.8	5.6	9.0	9.3	8.6
Auto/Other	0.5	0.6	25%	76%	0.4	0.3	1388.9	0.5	0.8	0.7	0.8
Totals	**132.8**	**134.1**	**26%**	**28%**	**105.4**	**104.8**	**196.2**	**20.8**	**29.2**	**26.1**	**26.3**

* From Table 4.1 of Network Rail's March 2007 Freight RUS
** Derived from Tables 3.1 and 3.2 of Network Rail's March 2007 Freight RUS

2.11 The calculations suggest that the 27% increase in freight tonnes lifted between the 2004/05 base year and 2014/15, probably equates to a 41% increase in freight tonne kilometres (i.e. from 20.8 billion freight tonne kilometres to 29.2 billion freight tonne kilometres). Assuming that freight trains carry the same weight of goods, on average, we would expect to see a comparable increase in freight train kilometres across the network. Based on this analysis we concluded that the current freight services file significantly underestimated the growth in freight traffic on the network over the HLOS period.

2.12 Furthermore, our analysis shows that the carriage of petroleum and chemicals is expected to be constant at 1.1 billion freight tonne kilometres per year. If this is indicative of all hazardous goods, the percentage of freight trains carrying toxic or flammable materials is likely to reduce as freight volumes increase; this also needs to be reflected in the NMF Safety Model.

Revised freight data

2.13 In order to calculate the changing safety risk profile over the HLOS period (April 2009 to March 2014), we commissioned Steer Davies Gleave to acquire updated freight data from Network Rail and generate a new freight services file that was consistent with Network Rail's March 2007 Freight RUS.

2.14 Using the NMF Safety Model, we recalculated the growth in freight train kilometres up to 2014/15 and the results (divided into trains travelling in the peak, off-peak and night periods) are shown in Figure 2. The graph also shows the actual freight train kilometres carried in 2006/07 using a red horizontal line.

2.15 This analysis shows that freight train kilometres are projected to grow by 49% over the ten year period. This figure is higher than the estimated 41% growth in freight tonne kilometres calculated earlier and implies that freight trains will either be carrying less goods in future or, more probably, some goods are expected to be travelling further. However, the figures are broadly consistent.

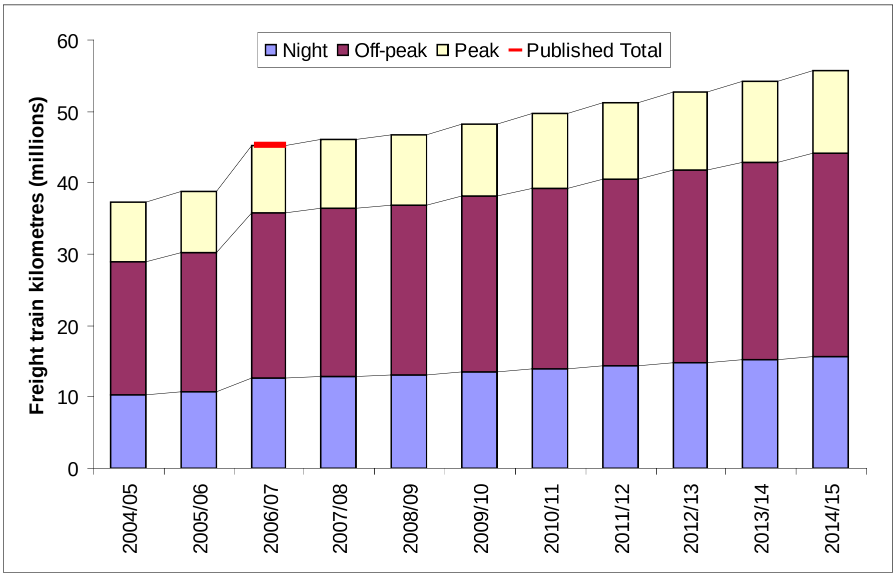

Figure 2: Growth in freight train kilometres based on latest data supplied by Network Rail

Changing risk profile

2.16 Having derived a freight file that reflected the projected traffic growth over the HLOS period, we were then able to use the NMF Safety Model to predict the changing risk profile resulting from projected changes to both passenger and freight services.

2.17 Table 2 shows the projected change in the key network operating parameters over the period modelled by DfT.

Table 2: Projected changes in operating parameters

Year	Passenger km (billions)	Passenger train km (millions)	Freight train km (millions)
2005	42.0	443.4	37.3
2007	44.3	458.3	45.4
2009	47.0	477.7	46.6
2010	48.7	481.4	48.1
2014	53.5	481.4	54.1
2020	60.5	481.4	61.4
2030	66.2	481.4	61.4

2.18 These show growth in terms of the number of train kilometres (both passenger and freight) as well as increasing passenger kilometres. Figure 3 shows the rate of growth compared to the baseline year of 2004/05.

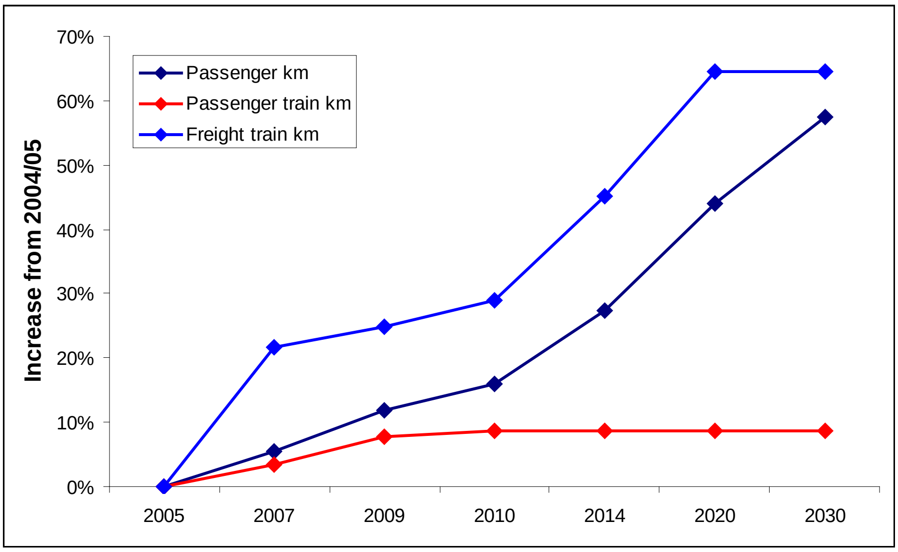

Figure 3: Growth in operating parameters since 2004/05

2.19 The graph shows that passenger kilometres are increasing at a much higher rate than passenger train kilometres, which implies that the trains either contain more carriages or are more heavily loaded. Our analysis shows that the average number of carriages per train is broadly constant and that the increased numbers of passengers would result in an average increase in passenger train loadings of 45%. This may, of course, be accommodated by better utilisation of capacity at night and during the off-peak but means that trains involved in collisions at these times would suffer increased casualties.

2.20 Figure 4 shows the overall projected change in FWIs for all accidents and broken down into Train Accidents, Movement Accidents and Non-movement Accidents over the period from 2005 to 2030.

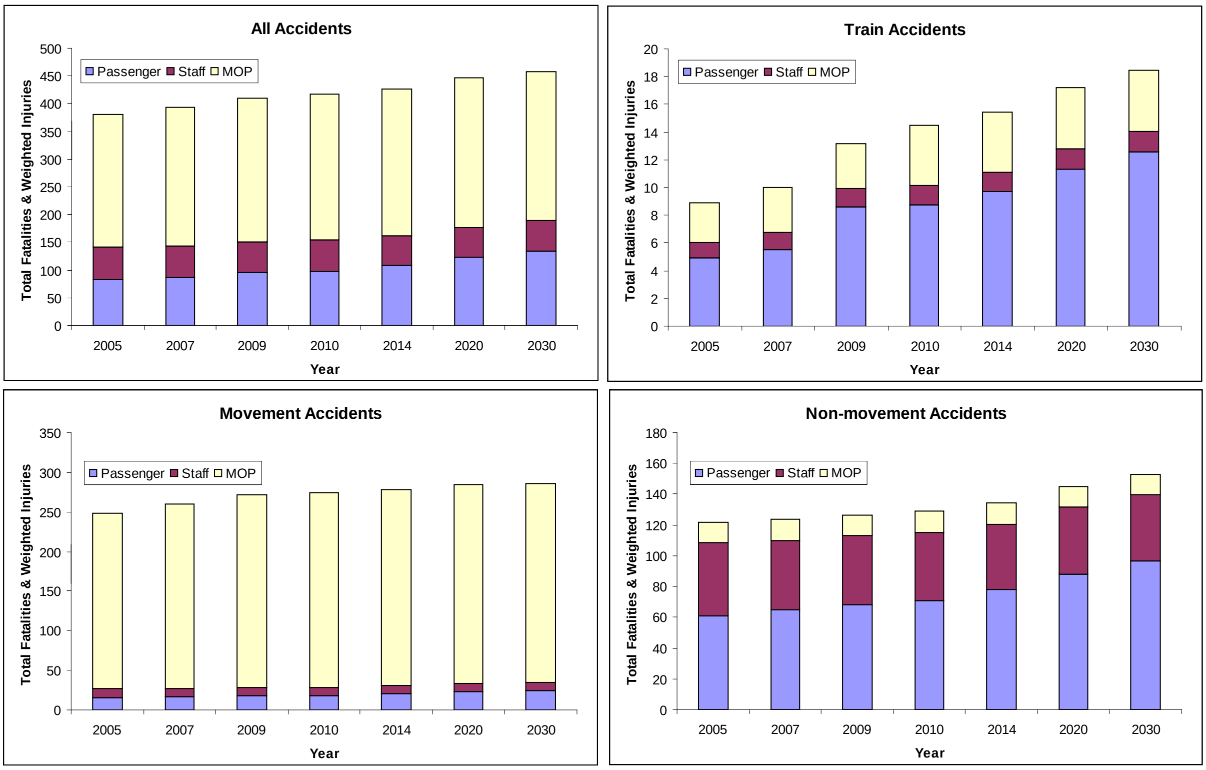

Figure 4: Total FWIs Overall and by Accident Type

2.21 The graphs show:

- A 63% increase in passenger FWIs, mainly due to the increased occupancy of carriages described above.
- A 6% reduction in staff FWIs due to safety initiatives resulting in reduced non-movement accidents offsetting the additional risk due to increasing train kilometres (and hence time spent by workers on the track).
- A 12% increase in FWIs for members of the public, largely due to the 13% increase in train kilometres increasing the risk to trespassers and level crossing users.

2.22 Overall, the number of FWIs is projected to increase by 20% from 2005 to 2030, but this in the context of substantial increases in passenger and freight traffic so needs to be normalised to allow meaningful comparisons to be made.

2.23 Figure 5 shows the predicted risk of FWIs per billion passenger kilometres for non-movement accidents[9]. This indicates a steady reduction in the normalised risk due to:

- The safety assumption that the probability of track worker and other workforce injuries will reduce over time (to 60% and 89% respectively of the 2004/05 levels by 2012/13)
- The fact that risk to staff is modelled as a function of train kilometres (increased traffic is likely to necessitate increased maintenance etc.); since passenger kilometres are expected to rise more rapidly than passenger train kilometres, the risk to staff per passenger kilometre therefore reduces.

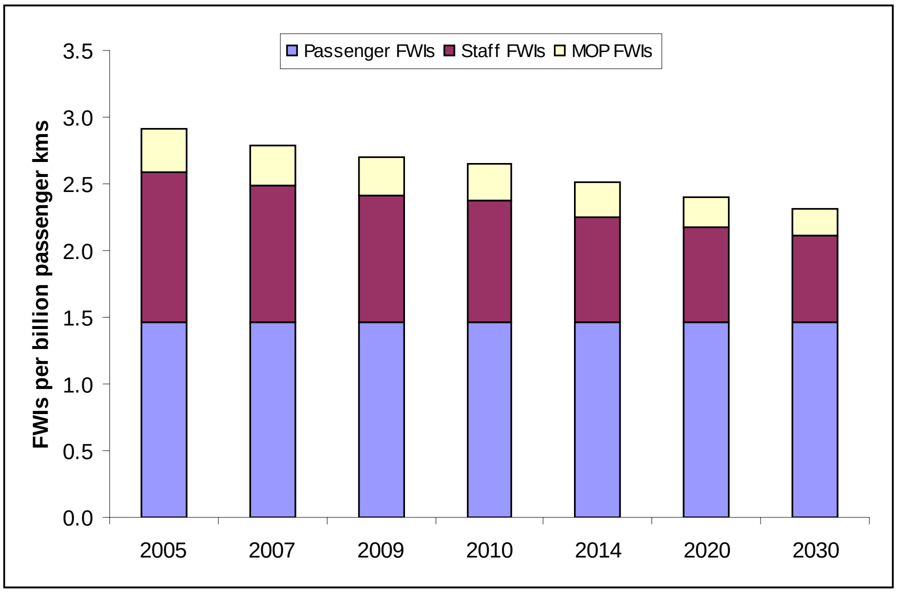

Figure 5: Change in normalised risk from non-movement accidents

9 Passenger kilometres is used as a surrogate for passenger journeys, which is valid if the average length of journey remains constant.

2.24 Figure 6 shows that the predicted risk of FWIs due to movement accidents is virtually constant. This is because, with the exception of some on-train accidents, the risk is assumed to increase in proportion to the number of train kilometres on the SRS. Normalising by train kilometres therefore cancels the effect.

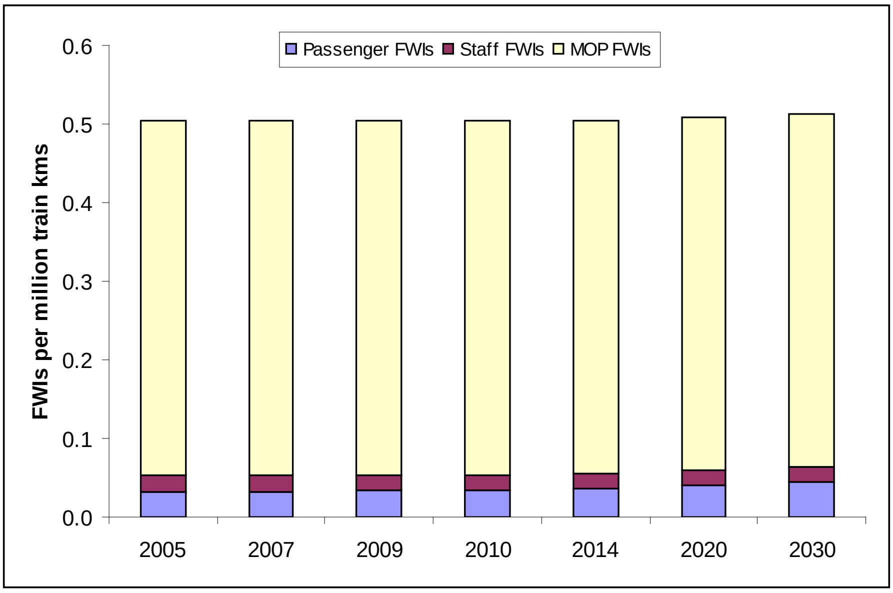

Figure 6: Change in normalised risk from movement accidents

2.25 Figure 7 shows the changing risk profile for train accidents (normalised by passenger kilometres). This shows increasing risk from all accident types but particularly for derailment risks (HET-12 and HET-13), particularly over the first few years.

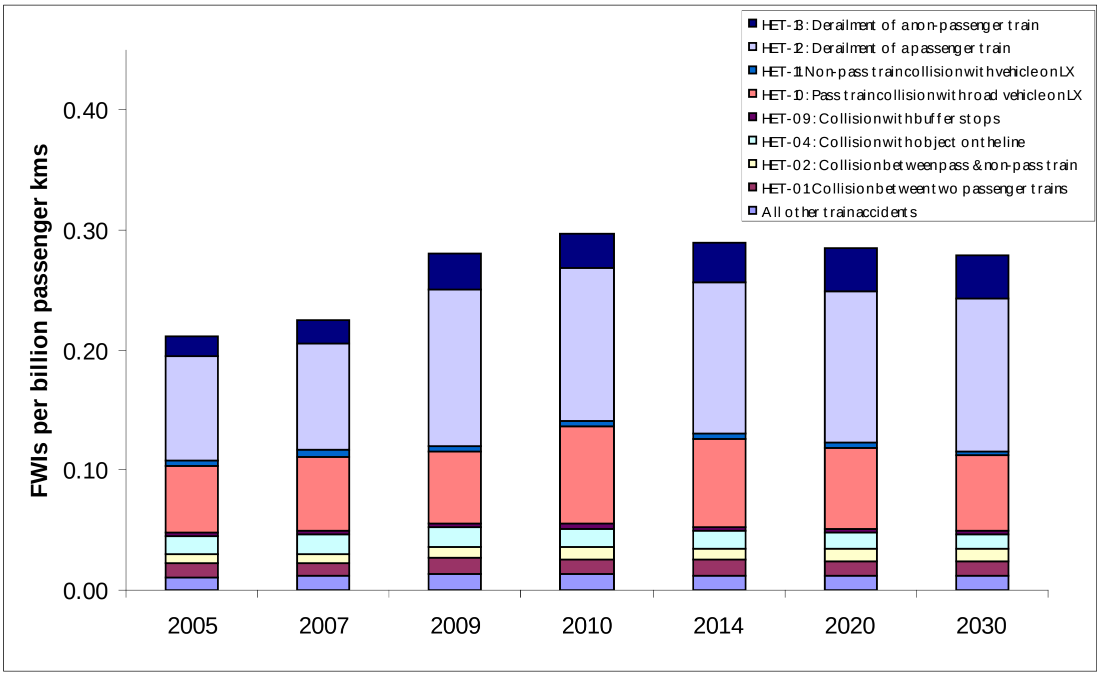

Figure 7: Change in normalised risk from train accidents

2.26 The increase in train accident risk is caused by significant increases in freight traffic (64% increase from 2005 to 2020). This affects the risk associated with collisions (secondary collisions in particular) involving non-passenger trains.

Conclusions

2.27 This part of the study found that:

- The freight services file used by DfT when analysing changes to safety performance over the HLOS period had not been updated to reflect Network Rail's March 2007 Freight RUS. The freight services file used by DfT showed a 15% increase in freight train kilometres over the period 2004/05 to 2014/15 (with all the growth occurring before 2008/09). The revised data supplied by Network Rail shows that freight train kilometres are now projected to increase by 49% with growth expected throughout the whole ten year period.
- Our analysis of the Freight RUS implied that (assuming the distance travelled by each commodity remained constant) the growth in freight train kilometres would have been 41%. If freight train kilometres are actually predicted to grow by 49%, this suggests that freight trains may be shorter or less heavily loaded in future.
- By contrast, our analysis of passenger train services shows that passenger kilometres are likely to grow by 58% by 2014/15, despite passenger train kilometres increasing by just 9%. This growth has not been accommodated by longer trains (the average number of carriages per train is projected to remain virtually constant) so the implication is that the carriages will become more heavily loaded on average. This may be possible by, for example, making better use of available capacity in the night and offpeak periods but this has a significant effect on the risk of passenger casualties in train accidents and needs to be confirmed.
- The net effect of these changes on safety is to increase the overall number of Fatalities and Weighted Injuries by 20% from 2005 to 2030, with two-thirds of the increase attributable to increased risk to passengers. However, the results should be normalised to make such comparisons meaningful.
- The model predicts a steady reduction in FWIs per billion passenger kilometres for non-movement accidents. This is primarily due to two factors:
  - expected improvements in worker safety resulting from industry initiatives
  - non-movement accidents for workers are assumed to rise in proportion to the number of train kilometres but have been normalised by passenger kilometres.
- For train accidents, the FWIs per billion passenger kilometres is expected to rise initially, primarily due to a rapid increase in freight train kilometres resulting in a higher probability of secondary collisions, but then declines slowly.

3 REVIEW THE SRM LOADING ASSUMPTIONS

3.1 The current version of the NMF Safety Model calculates the safety risk using the nominal passenger train loadings used in the SRM and then applies a 'load factor' to increase or reduce the risk. The load factor is calculated by dividing the number of passenger kilometres carried on a weekday on the SRS by the number that would have been carried had the nominal passenger train loadings been correct. However, the NMF Demand Model also calculates passenger train loadings, to assess the effects of crowding, and this analysis was commissioned to establish:

- whether it is possible to modify the NMF Safety Model to use projected passenger train loadings and, if so,
- whether this had a material effect on the level of risk nationally or on specific SRSs.

3.2 Having discussed the problem with the NMF developers, we commissioned DeltaRail to export passenger train loading data for each Demand Section. We then converted this to an equivalent number of night, offpeak, peak and crush loaded train kilometres on each Demand Section, and hence calculated the equivalent numbers for each SRS.

3.3 Using these data, we were then able to use the NMF Safety Model to calculate the risk profile for three scenarios:

- The base case as currently used in the NMF – i.e. assuming that the proportion of night, offpeak, peak and crush loaded trains is the same on each SRS but factoring up the number of trains so that the total passenger kilometres travelled on each SRS is correct.
- Option 1, in which we used the calculated proportions of night, offpeak, peak and crush loaded trains instead, where the definition of a night loaded train etc. was the same as in the SRM.
- Option 2, in which we repeated the Option 1 analysis but this time we assumed that night and offpeak loaded trains carried more occupants (as explained below).

3.4 The total train kilometres travelled on each SRS would be unaffected by the changes, but the proportion that were night, offpeak, peak and crush loaded would vary from one SRS to the next. This would affect the frequency of accidents involving each type of train, and hence the risk. The consequences on an accident would be unaffected for Option 1 but would be higher for night and offpeak loaded trains in Option 2 (because the trains would be more heavily loaded). The question was how these inter-related factors would affect the overall risk.

Analysis of loading data

3.5 Using the passenger train loading dataset provided by DeltaRail, we were able to create a cumulative distribution of the number of passengers per carriage, as shown in Figure 8. We then superimposed on the graph the nominal passenger train loadings used by the SRM:

- 2 passengers per carriage (night loading)
- 10 passengers per carriage (offpeak loading)
- 50 passengers per carriage (peak loading)
- 90 passengers per carriage(crush loading)

3.6 These loadings are marked by the red bars on Figure 8 (the height of the bars is not significant) and the analysis lead us to question whether the nominal loadings ought to be adjusted by increasing the 'night' loading to 5 passengers per carriage and the 'offpeak' loading to 20 passengers per carriage.

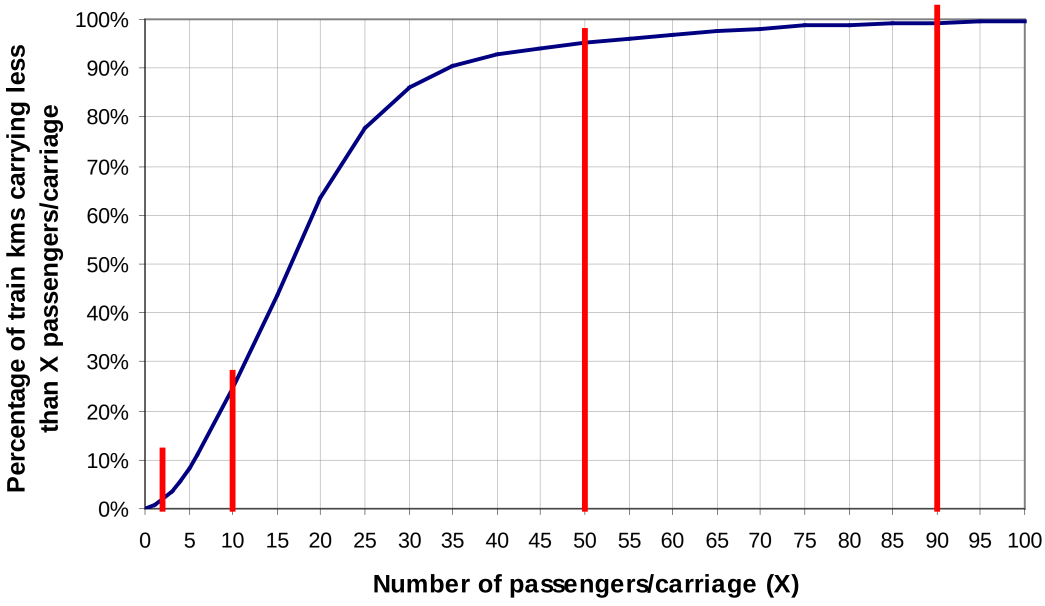

Figure 8: Cumulative distribution of passenger train loadings

3.7 In order to use the loading data in the NMF Safety Model, we had to convert it into an equivalent number of night, offpeak, peak and crush loaded trains (using either the original or revised definitions) on each SRS.

Accuracy of passenger train loadings

3.8 Before considering the effect of the new approaches on the risk, we compared the proportion of trains that are night, offpeak, peak and crush loaded in the SRM to the proportions we had calculated from DeltaRail's data. This showed that overall the proportions of night, offpeak, peak and crush loaded passenger trains was (using the standard loadings) 12%, 64%, 22% and 2% respectively. The assumptions in the SRM are 10%, 72%, 13.5% and 4.5% which are similar but the new analysis shows that a higher proportion of trains are peak loaded with fewer offpeak and crush loaded trains.

3.9 We then compared the number of night, offpeak, peak and crush loaded train kilometres on each SRS when calculated using the current version of the NMF Safety Model and when calculated using Option 1 (i.e. with the same definitions for a night and offpeak loaded train).

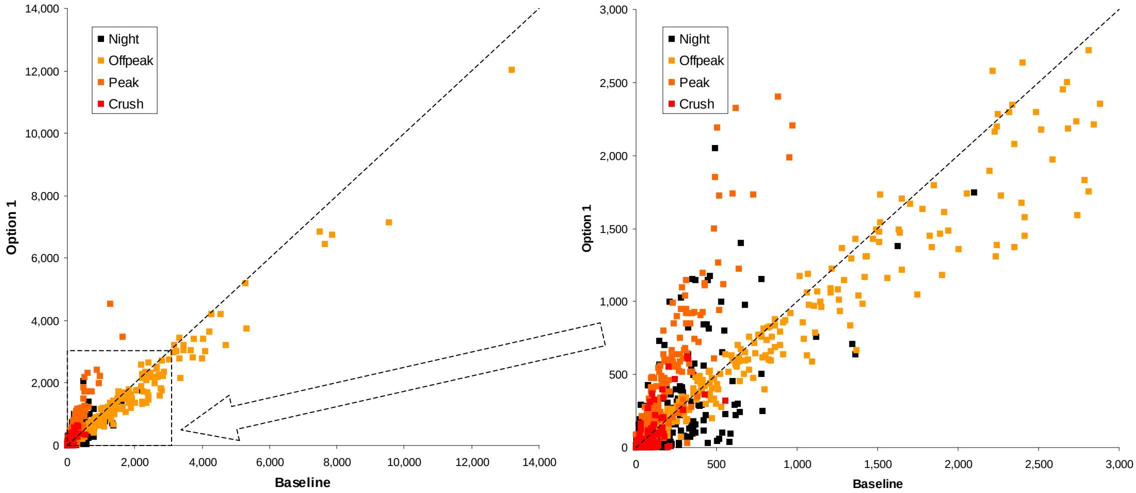

Figure 9: Passenger train kms (1000s) by SRS for Baseline and Option 1

3.10 Figure 9 plots, for each SRS, the passenger train kilometres calculated using the two approaches. The chart on the left shows that offpeak loaded trains show a reasonable correlation, although the distances travelled, for a given SRS, tend to be slightly higher for the Baseline than for Option 1. The chart on the right shows a close up view of the box on the left hand chart and this shows that the correlation is far weaker for night, peak and crush loaded trains. In particular, the existing model significantly underestimates the distances travelled by peak loaded trains.

3.11 This analysis suggests that the current version of the NMF Safety Model is likely, for a given SRS, to underestimate the frequency of train accidents involving peak loaded trains, but overestimate the frequency of accidents involving offpeak loaded trains. Reducing the probability of a peak train being off-peak loaded could reduce the bias but there does not appear to be any systematic bias for night and crush loaded trains. That means that the risk associated with night loaded and (more importantly) crush loaded trains on an individual SRS or specific route is likely to be misleading. However, the numbers of such trains are small so the effect is unlikely to be material compared to the risk from offpeak and peak loaded trains.

Effect on risk profile

3.12 Figure 10 shows the total number of fatalities and weighted injuries for each of the train accident modules, and for each of the three cases. This shows that there is little overall change because the increased risk associated with night loaded services (which have increased in both number and loading for Option 2) is offset by reductions elsewhere. Everything cancels out.

3.13 It is worth noting that, some modules (e.g. HET-04, HET-11 and HET-13), do not calculate the frequency of night loaded etc. trains being involved in a collision so are unaffected by the changes in any case.

3.14 The only module which was materially affected, on some SRSs, was HET-02 (see Figure 11). This is because the module calculates the probability that the non-passenger train collides with a night loaded train (for example) from first principles using the “proportion of offpeak trains that are night loaded”. Modifying this part of the module to use the proportion of trains that are night loaded etc. would have been complicated and served little purpose since, overall, the errors cancel out.

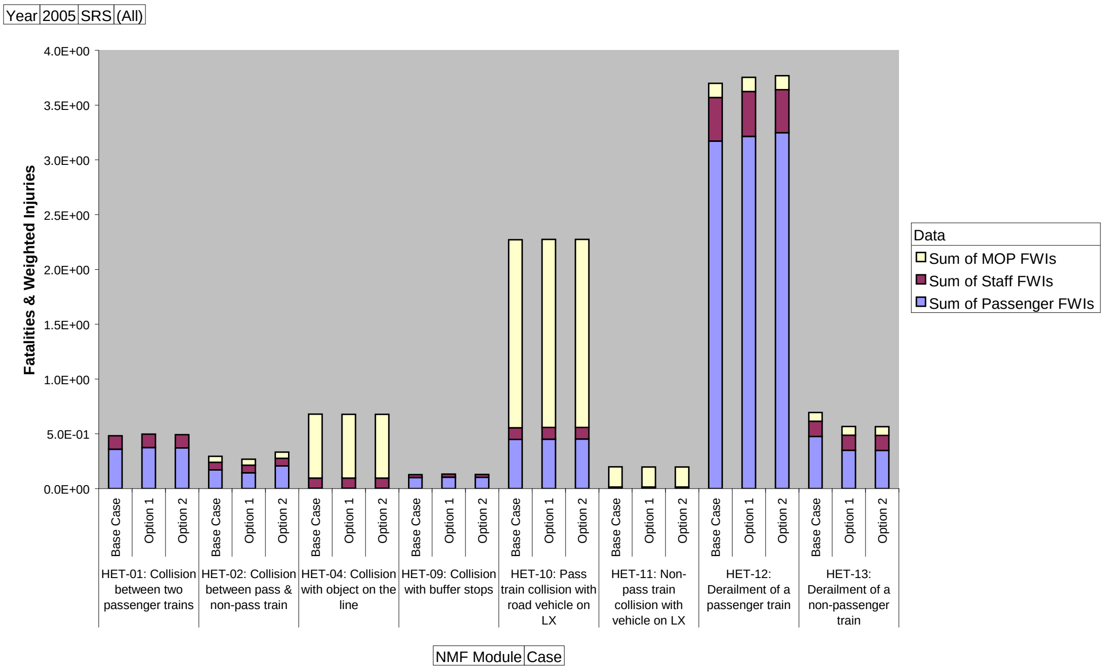

Figure 10: Network Wide Results for 2005

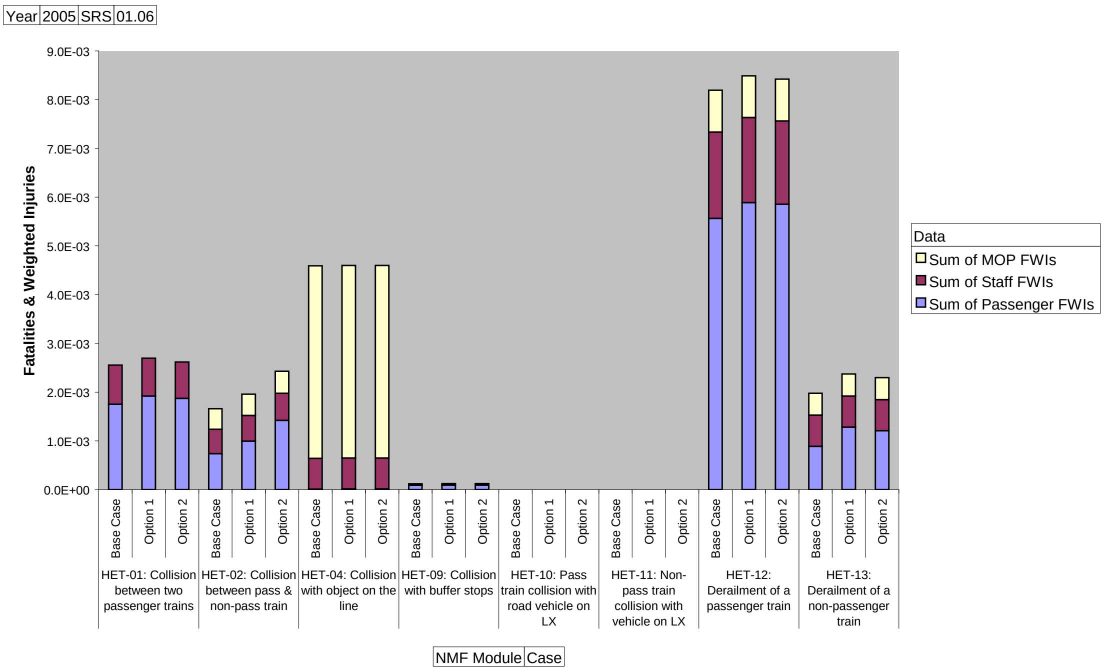

Figure 11: Results for SRS 01.06 (2005 data)

Conclusions

3.15 By comparing the number of night, offpeak, peak and crush loaded passenger train kilometres for the Baseline and Option 1 cases (as shown in Figure 9) we found that:

- The frequency of offpeak loaded services assumed for a particular SRS in the NMF Safety Model tends to be an overestimate
- However, the frequency of peak loaded services tends to be a significant underestimate (i.e. approximately half the correct value)

- There is no correlation between the frequency of night and crush loaded services in the NMF Safety Model and that existing on the network – indicating that the frequency of night and crush loaded services is more random. This reflects the fact that parts of the network experience much higher levels of crowding than others, so deviate from the network averages.

3.16 However, the model results show that the methods used in the current version of the NMF Safety Model to correct for variances between the nominal loading (assumed in the SRM) and actual loadings taken from the NMF are highly effective. The 'error' introduced by using the current simplified approach is negligible.

3.17 We also conclude that modifying the definition of night and offpeak loaded services has negligible effect on the risk analysis. There seems little reason, therefore, to modify the NMF Safety Model to use passenger train loading data for specific SRSs, as was being considered.

3.18 It is worth noting, however, that the current version of the NMF Safety Model assumes a linear relationship between passenger train loading and the number of passenger casualties. If this assumption were changed it may be more important to model the distribution of trains around the network more accurately.

With regard to the SRM, we conclude that:

- The current definitions of night, offpeak, peak and crush-loaded passenger trains do not need to be altered
- The proportion of passenger train kilometres that are night, offpeak, peak and crush loaded should be changed to 12%, 64%, 22% and 2% respectively[10].

[10] The current proportions are 10%, 72%, 13.5% and 4.5% respectively.

4 SENSITIVITY ANALYSIS

4.1 The third area of work was to determine the sensitivity of the safety outcomes to changes in:

- The 126 variables in the safety assumptions file
- The 11 infrastructure parameters
- The 25 train service parameters

4.2 The purpose being to help understand which parameters or relationships may need closer scrutiny when running the model and identify key areas where the model would benefit from further development. Clearly the results would vary depending on the characteristics of the SRS being analysed so the analysis was to be based on national averages for the whole rail network. This meant that the results should be comparable to those for the Safety Risk Model, and the findings should apply to both models.

Identification of most sensitive parameters

4.3 In general we were able to calculate the change in the FWIs predicted for each train accident module as each of the parameters was varied by ±20%. It is worth noting, though, that some variables cannot be varied independently. For example, the proportion of trains carrying hazardous goods that are either flammable or toxic should sum to one. A 20% increase in one must therefore result in a corresponding decrease (although not necessarily by 20%[11]) in the other. Similarly, it is meaningless to increase:

- The probability of a train-train collision being head-on without reducing the probability that it is side-on or rear-end
- The number of tracks without increasing the number of track kilometres
- The proportion of trains that are loco-hauled without reducing the proportion that are multiple units.

4.4 In order to ensure consistency between parameters we created simple ‘rules’ so that a change in one parameter resulted in a logical change in any related parameters.

4.5 Table 3 shows the parameters that each of the train accident modules was most sensitive to, expressed in terms of the percentage change in the number of FWIs per year. Note that, to make the figures easily comparable, the absolute figures are shown for a +20% change in the parameter. The table emphasises the importance of average train speed in the current version of the model.

11 Because more trains are assumed to carry flammable goods, a 20% reduction in the probability that the hazardous goods are toxic corresponds to an 11% increase in the probability that the hazardous goods are flammable.

Table 3: Summary of most sensitive parameters

Parameter	HET-01	HET-02	HET-04	HET-09	HET-10	HET-11	HET-12	HET-13
Infrastructure								
Length of section and number of tracks								9%
Number of user worked crossings					10%	10%		
Train Service								
Average number of carriages per train (peak)	10%			10%			11%	
Average train speed (kph)	22%	21%	20%	20%	21%	20%	35%	29%
Freight/parcels trains per hour (night)						7%		
Freight/parcels trains per hour (off-peak)		10%				8%		9%
Number of hours per working day (night)		8%	7%		8%	9%		
Number of hours per working day (off-peak)		27%	9%		11%	9%		17%
Passenger kms per weekday	15%	8%		15%			16%	
Passenger trains per hour (off-peak)			7%		7%			
Passenger trains per hour (peak)			9%		10%		11%	
Proportion of passenger trains (Mk3 MU)	29%			23%				
Safety Assumptions								
Probability of collision.. At a junction with TPWS not effective	9%							
Probability of collision being high speed (TPWS not effective).. Other	12%							
Probability of collision with.. Road vehicle on the line (accident)			18%					
Probability of buffer stop collision.. At high speed (no TPWS)				6%				
Probability of buffer stop collision.. At high speed (with TPWS)				13%				
Probability of collision with road vehicle on.. UWC excl suicide					9%			
Probability of collision with road vehicle on.. UWC excl suicide						10%		
Probability of passenger train derailment.. On open track at high speed due to other causes							14%	

4.6 'Tornado diagrams' were produced for each module, examples of which are shown below for the HET-12 module (passenger train derailment).

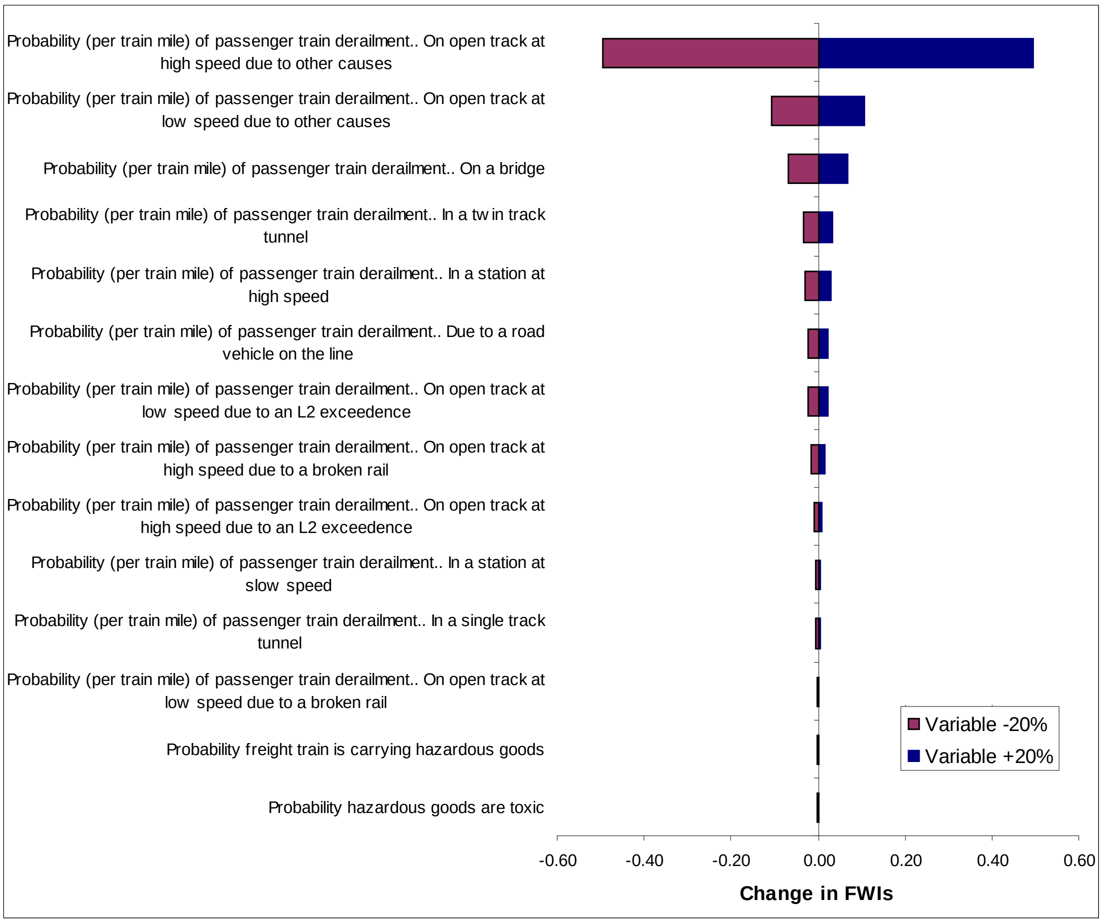

Figure 12: HET-12 sensitivity to safety assumption paameters

4.7 Figure 12 shows that HET-12 risk is particularly sensitive to one safety assumption: the probability of passenger train derailment on open track at high speed due to 'other causes' (i.e. this excludes track faults but includes obstructions on the track, rolling stock faults and overspeeding). A 20% change in this parameter results in a 12% change in overall HET-12 risk (i.e. a change 0.5 FWIs per year).

4.8 HET-12 risk is dominated by the consequences of a peak or crush-loaded passenger train derailing so it is not surprising that Figure 13 shows that the key train service parameters are:

- Average train speed
- The carriage loading, derived from the number of passenger kilometres per day and average number of carriages per train
- The number of peak trains, derived from the frequency of passenger trains in the peak and duration of the peak period (i.e. when it is NOT the night or off-peak period)

4.9 It is worth noting that, of all the train accident modules, HET-12 is the most sensitive to changes in average train speed: a 20% increase in speed resulted in a 35% increase in risk and a 20% reduction in speed resulted in a 30% reduction in risk.

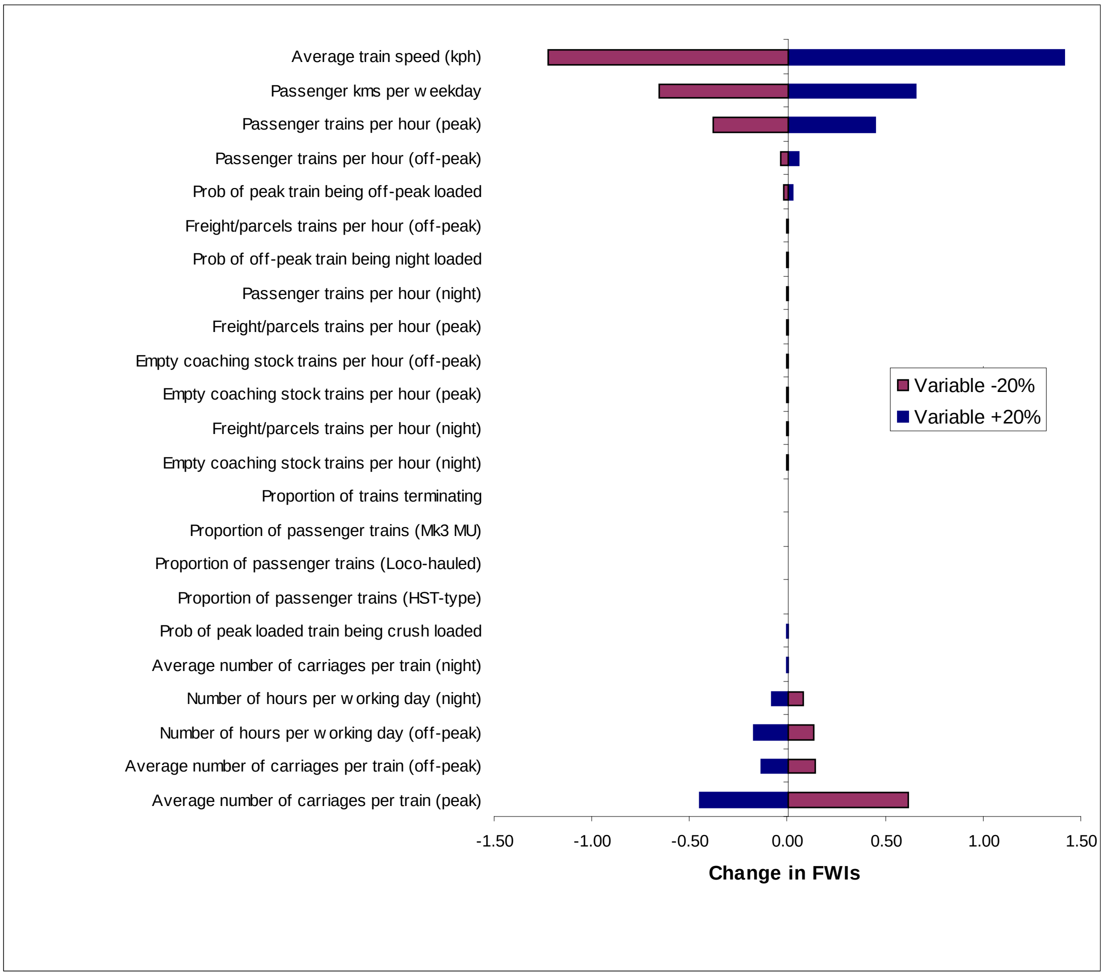

Figure 13: HET-12 sensitivity to train service parameters

Effect of average train speed

4.10 As Table 3 shows, all of the train accident modules are highly sensitive to average train speed. Since the consequences of a train collision (for passengers, staff and members of the public) is directly proportional to the average train speed, we would expect to see a 20% change in risk for a 20% change in speed unless speed had other effects on the risk. The table shows that some modules are indeed more sensitive than this and that the two derailment modules, HET-12 and HET-13, are particularly sensitive – mainly because the probability of a secondary collision is also a function of train speed.

4.11 However, the picture is different in terms of their effect on the overall risk. Figure 14 shows that HET-10 and HET-12 account for a high proportion of the total risk so parameters that these modules are sensitive to have a more significant effect on the overall risk.

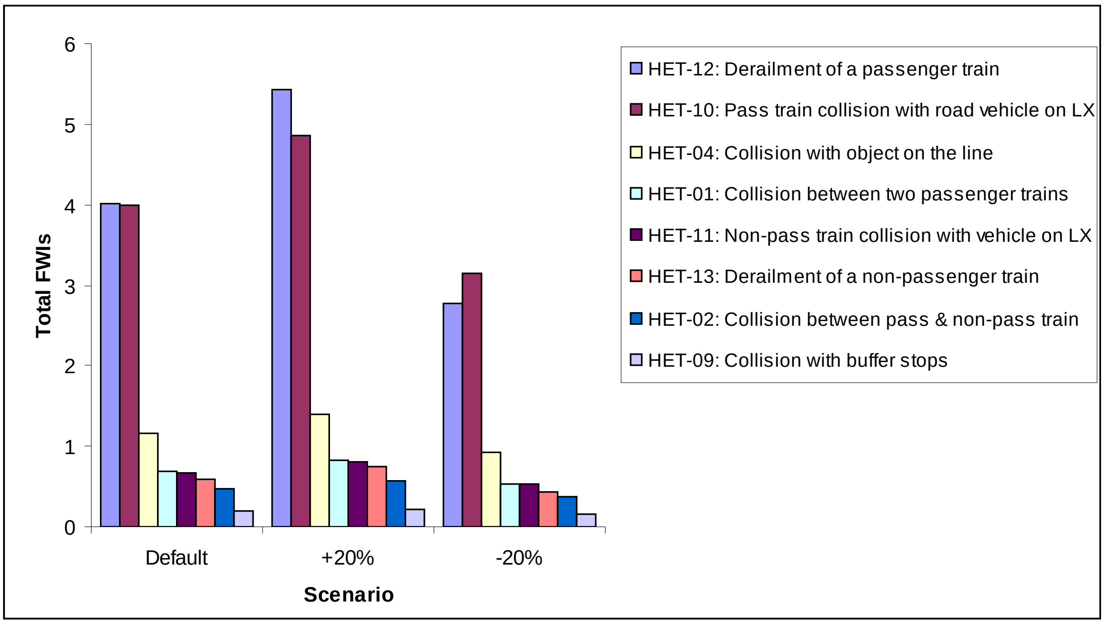

Figure 14: Effect of Average Train Speed on Total FWIs

4.12 It is important to note that the number of FWIs calculated by the NMF Safety Model is approximately 30% to 40% higher than the figures calculated by the SRM for a number of good reasons (as documented in earlier reports). While there is a difference in the absolute numbers, the models are based on the same principles and the findings of the sensitivity analysis should also be valid for the SRM.

4.13 To complete the speed analysis, we identified (for each train accident module) all of the calculations that are a function of train speed and considered whether the relationships were valid and, if not, how they should be changed. This resulted in a number of conclusions.

Conclusions

4.14 The sensitivity analysis identified a number of parameters that affect multiple modules, and which may benefit from greater scrutiny for future versions of the SRM and NMF Safety Model. The most critical parameter is, not surprisingly, average train speed. Having examined all the speed-related parameters in the NMF Safety Model we conclude that:

- The speed (and hence consequences) of collisions and derailments is currently assumed to be proportionate to average train speed. This is inappropriate for low speed collisions and derailments and may also be invalid for high speed incidents.
- If the average speed of high speed derailments is related to average train speed, then relationships should be developed between the probability of trains not maintaining clearances, hitting lineside structures, etc. and average train speed where these do not already exist.
- The current linear relationship between average train speed and the consequences of an accident may overstate the consequences on low speed lines and understate them on high speed lines[12].

---

[12] It has been suggested that the consequences from an accident should be a function of the kinetic energy of the train and, therefore, should be proportional to the square of the train speed.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 These studies have demonstrated that the NMF Safety Model is a flexible tool that can be used to:

- Project changes in risk based on planned changes to passenger and freight services and, crucially, identify the possible safety implications of increasing passenger train loadings.
- Test the effect of changes to the SRM, whether they are the sensitivity of individual parameters or the benefits of alternative calculation methods, before going to the expense of modifying the SRM itself.

5.2 The analysis has also confirmed that the current approach to calculating passenger train loadings is highly effective overall, although it will introduce errors on specific SRSs, and has provided revised figures for the proportion of trains that are night, offpeak, peak or crush loaded for the SRM.

5.3 Finally, the analysis has provided:

- projections for passenger kilometres, passenger train kilometres and freight train kilometres until 2030, and
- baseline safety predictions over this period for train accidents, movement accidents and non-movement accidents.

5.4 The low rate of growth of passenger train kilometres, compared with passenger kilometres, has had a significant effect on the risk from train accidents and, indirectly, on the normalised risk from non-movement accidents.

5.5 In terms of future development of the NMF Safety Model, our recommendations are that.

- There is little immediate benefit to modifying the NMF Safety Model to use passenger loading data held in the NMF, although we now know that this could be done by automating the process we used.
- RSSB should review a number of relationships in the SRM and NMF Safety Model to decide whether they should be related to average train speed and, if so, how.
- The probability of train-train collisions in HET-01 and HET-02 should be a function of train frequency instead of using national averages from the SRM.
- The cost and delay minutes attributable to train accidents needs to be completed so that the model quantifies all of the costs associated with safety incidents.