Paper for WCRR 2011

Determining the benefit of train mass reduction

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1. Introduction

There is general acceptance that significant savings in infrastructure maintenance and energy costs can be made by reducing train mass but there is no agreed value of this benefit which creates great difficulties for those designing or specifying trains. Providing typical figures for the value of mass reduction, accepted across the industry, for representative train fleets is a very considerable step towards developing more cost- and energy-efficient rolling stock.

Research to derive these figures was undertaken by RSSB for the Vehicle-Vehicle System Interface Committee, which includes representation from across the GB rail industry, including the infrastructure manager Network Rail, suppliers and train operating companies. The project was delivered as part of the rail industry’s research and development programme, funded by the UK Department for Transport and managed by RSSB on industry and government’s behalf. Expertise was supplied from RSSB’s own in-house infrastructure and rolling stock specialists.

The objective of this study was to establish a quantified monetary value for reduction in train mass, accepted across the GB industry, for typical fleets of passenger trains. In this study both track maintenance costs and energy costs were assessed for a range of different train mass values and operating scenarios. Whilst GB vehicle types and operating scenarios have been used it is believed that the results are applicable much more widely.

The study assessed both track maintenance costs and energy costs and results are presented as a change in cost for a change in mass where the difference in cost can clearly be either a benefit or a penalty.

2. Selection of scenarios

It was clear from the start of the study that selection of appropriate ‘scenarios’ was a key stage in obtaining meaningful results. This included consideration of factors such as:

- Identification of ‘typical’ fleets and usage patterns
- Spread of route characteristics – geographic and track quality
- Effect of other trains, for example freight
- Implications of train configuration, for example distributed power
- Implications of suspension characteristics

Some of these factors are important for both track and energy costs whilst others are more significant for one than the other.

The appropriate scenarios were selected as combinations of 4 route categories as shown below (with line speed and mean distance between stops):

- Inner Suburban (120 km/h, < 10km)
- Outer Suburban (140 km/h, 10 – 20 km)
- Inter Urban (175 km/h, 20 – 50 km)
- Inter City (200 km/h, >50 km)

and 4 generic vehicles:

- Train A – Inner suburban EMU
- Train B – Outer suburban EMU
- Train C – Inter urban DMU
- Train D – Inter City EMU

These were assessed in the following combinations:

- Inner Suburban - with trains A and B
- Outer Suburban - with trains A, B and C
- Inter Urban - with trains B, C and D
• Inter City - with trains C and D

The reference train mass was the nominal tare mass plus a passenger load with all seats occupied. The passenger load was not changed during the studies. The variations in vehicle mass used were generally +10% to -20% of tare mass from the reference mass with some larger variations included to check linearity.

For each of the route categories, a representative GB route was identified for which detailed calculations were carried out, supported by a number of other routes with similar characteristics to check sensitivity. These routes are shown on the map below.
3. Track degradation studies

Track costs were assessed using the Vehicle Track Interaction Strategic Model (VTISM) which has been developed by RSSB and Network Rail. This model has been used by the UK Department for Transport as an element of their strategy for procuring new trains, by Network Rail to inform track maintenance decisions and was used in the EU FP6 Innotrack research project.

The flow diagram below illustrates the main principles and component parts of this model.

The track degradation studies using VTISM:

- Determined the impact of mass on infrastructure costs over 30 years for each of the four train types on two or more selected routes, as shown above.
- On each route, replaced all vehicles similar to the generic test vehicle, and running over a significant part of the route, with the generic test vehicle.
- Used moderately-worn wheel and moderately-worn rail profiles for all studies.
- Reported most of the results at a financial discount rate of 0% as this is the simplest to interpret but also checked sensitivity to discount rates of 3.5% and 6.5%.

A limited number of additional sensitivity studies were also undertaken to confirm that the main results were representative. These included assessing the effect of mass variations for track degradation both with and without the costs of rolling contact fatigue (RCF) as the effect of mass was expected to be low on the RCF costs compared to the effect on vertical track degradation.

4. Results for track degradation costs

The following figure shows sample results for the Outer Suburban route for three trains, types A, B and C. The B train type (BmBt) has different masses for motor and trailer vehicles and has also been considered for two different values of suspension primary yaw stiffness (pys). It can be seen that the inclusion of RCF has an effect on the total costs but very little effect on the incremental costs of changes in mass.
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All the track degradation results have been analysed to obtain the incremental value of a change in mass as pence / km / tonne as given in the following table.

<table>
<thead>
<tr>
<th>Route category</th>
<th>Average incremental value including RCF (pence/km/tonne) for track costs</th>
<th>Vehicle Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Vehicle A</td>
</tr>
<tr>
<td>Inter City</td>
<td></td>
<td>0.31</td>
</tr>
<tr>
<td>Inter Urban</td>
<td></td>
<td>0.26</td>
</tr>
<tr>
<td>Outer Suburban</td>
<td></td>
<td>0.17</td>
</tr>
<tr>
<td>Inner Suburban</td>
<td></td>
<td>0.18</td>
</tr>
</tbody>
</table>

The results showed that the value of mass for track costs was in general more sensitive to the route category than to the vehicle type. Thus the average values for each route category have been used in the final results.

Changing the discount rate from 0% to 3.5% or 6.5 % gave a slight reduction in the benefits (pence / km / tonne) for the higher rates but the difference was not significant so the values for the 0% discount rate have been used. Similarly varying the assessed time period from 30 years to 25 or 35 years made small changes to the results but there was no clear trend so the 30 year values have been used.

5. Energy studies

Energy costs were assessed using RSSB software and a number of comparisons with other available data (operational timings and measured energy consumption) were undertaken to give confidence in the validity of the model. While it is clearly evident that a lightweight train will consume less energy for a given duty, the relationship between train mass and energy consumed is complex due to a range of
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factors such as route characteristics, installed power, maximum permissible train speed and aerodynamic drag.

The characteristics of each of the core routes were obtained and the following figures show the line speeds and gradients for the core Inter Urban route as an example.

To represent typical operational conditions, a number of assumptions were made in undertaking the energy assessment including:

- A traction power setting of ¾ of maximum
- A constant brake force corresponding to 6% g
- Only input traction energy is considered (fuel consumption is not computed for diesel trains)
- Coasting was not generally included

A comprehensive set of train performance calculations was undertaken for the selected routes and service patterns using the generic trains. These trains are representative of the range of services operated in GB and current rolling stock types. Each train was modelled with a range of tare masses to build up a matrix of results in terms of traction energy consumption and other relevant data. As for the track costs it was found that the effect of mass on energy costs was more sensitive to the route
category than to the vehicle type so average results for each route category, across the relevant vehicle types, are used.

Some additional calculations were undertaken to study the effects of regenerative braking and of targeted coasting as both of these can further reduce energy consumption. This work showed that it was acceptable to consider the effects separately and hence the mass benefits given here do not take either regenerative braking or coasting into account.

6. Results for energy costs

The results were synthesised to give traction energy versus mass relationships for groups of services and routes as kWh/km.

For each core route the results were tested against equivalent groups of train services (classified as overlap and support) as a sensitivity check and the following figure shows these results for the InterCity routes.

For the Inner Suburban routes an initial analysis suggested it would be useful to split this group into two sub-groups, a ‘commuter’ group with a mean distance between stops in the range 5 to 10 km and a ‘metro’ group where the mean distance between stops is less than 5 km. Results for the ‘metro sub-group are given below. This demonstrates that there is some variability in the required energy but that it is realistic to take an average result for the slope of the lines, to represent the effect of mass reduction.
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The key to the station codes is:

<table>
<thead>
<tr>
<th>Station Code</th>
<th>Station Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHM</td>
<td>Birmingham New Street</td>
</tr>
<tr>
<td>COV</td>
<td>Coventry</td>
</tr>
<tr>
<td>EUS</td>
<td>London Euston</td>
</tr>
<tr>
<td>HFN</td>
<td>Hertford North</td>
</tr>
<tr>
<td>LET</td>
<td>Letchworth</td>
</tr>
<tr>
<td>LTV</td>
<td>Lichfield Trent Valley</td>
</tr>
<tr>
<td>MOG</td>
<td>Moorgate</td>
</tr>
<tr>
<td>RDC</td>
<td>Reddich</td>
</tr>
<tr>
<td>WAT</td>
<td>London Waterloo</td>
</tr>
<tr>
<td>WFJ</td>
<td>Watford Junction</td>
</tr>
<tr>
<td>WGC</td>
<td>Welwyn Garden City</td>
</tr>
<tr>
<td>WOK</td>
<td>Woking</td>
</tr>
<tr>
<td>WVH</td>
<td>Wolverhampton</td>
</tr>
</tbody>
</table>

From these figures, the values of mass in terms of traction energy have been derived for the different route categories. Taking an average electricity price of 9.2 cents (€0.092) per kWh these can be converted to cents/km/tonne as shown below.

<table>
<thead>
<tr>
<th>Route category</th>
<th>kWh/km/tonne</th>
<th>Electricity value cents/km/tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter City</td>
<td>0.012</td>
<td>0.11</td>
</tr>
<tr>
<td>Inter Urban</td>
<td>0.016</td>
<td>0.15</td>
</tr>
<tr>
<td>Outer Suburban</td>
<td>0.021</td>
<td>0.19</td>
</tr>
<tr>
<td>Inner Suburban</td>
<td>0.027</td>
<td>0.25</td>
</tr>
<tr>
<td>Metro</td>
<td>0.035</td>
<td>0.32</td>
</tr>
</tbody>
</table>

The values of traction energy/mass slope confirm that the sensitivity per km of traction energy cost to vehicle mass is highest for metro or commuter routes and lowest for high speed Inter City routes where energy used overcoming aerodynamic drag becomes predominant.

7. Summary and conclusions

The values of mass from the energy and track results are combined in the following table (the track results have been converted from sterling to the euro using a rate of £1.00 = €1.10):
The proportion of the total cost savings from the two different areas changes with the route category. For the Inter City routes the track cost savings are dominant whilst for the Metro routes the energy cost savings are dominant. This is a result of the differing line speeds and stopping patterns inherent in the different operations. However the total cost savings per km (at the assumed energy price) are of a similar magnitude for all route categories. The results are shown graphically below.

Taking the combined cost saving figures above and fleet mileages from data supplied by the GB Association of Train Operating Companies (ATOC), for the applicable train types for the route categories, example annual cost savings/tonne can be established:

<table>
<thead>
<tr>
<th>Route Category</th>
<th>Cents / km /tonne</th>
<th>Average mileage km/unit/annum</th>
<th>Annual cost /tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter City</td>
<td>0.48</td>
<td>508,800</td>
<td>€ 2,440</td>
</tr>
<tr>
<td>Inter Urban</td>
<td>0.45</td>
<td>451,200</td>
<td>€ 2,030</td>
</tr>
<tr>
<td>Outer Suburban</td>
<td>0.41</td>
<td>168,000</td>
<td>€ 690</td>
</tr>
</tbody>
</table>
The introduction of typical average mileages illustrates how the relative ranking of the route categories changes and shows that for any given application it is important to establish the likely usage (for example the predicted annual mileage, operating speeds and service patterns) of the rolling stock in order to determine the most appropriate values of mass to be used. Clearly this will vary with different fleet operations and figures should be derived on a case by case basis. From the annual costs, lifetime costs can then be estimated to allow a comparison between the cost savings, for example resulting from a weight saving re-design, and the costs of achieving it.

It is recommended that:
- The values determined by this study should be used in future procurement projects to assess the benefits of mass reduction
- The overall average values should be used unless data is required for a specific route and service pattern in which case it is recommended that bespoke calculations are undertaken
- The values should also be considered during major overhaul or refurbishment to consider whether worthwhile mass savings can be achieved

8. Acknowledgement

The authors would like to thank RSSB for permission to publish this paper and the GB rail industry, particularly the members of the Vehicle-Vehicle System Interface Committee, for their support and advice during the work described.