Eco-driving: understanding the approaches, benefits and risks


1. Introduction

Like many other industries, the rail industry in Great Britain (GB) is keen to identify and exploit savings that can be made from more efficient use of resources. Eco-driving (or energy efficient driving) presents a real opportunity for railway undertakings – both passenger and freight - to make efficiency savings in both carbon and cost without the need for expensive technological fixes or major changes to current operations.

Eco-driving is the name given to a range of train driving techniques intended to reduce economic and environmental costs. Put simply, it is about driving a train as efficiently as possible, ensuring safe and punctual arrival and departure times but without the excessive use of power and fuel. Rail already has a good environmental image in the public eye, and it accounts for less than 1% of UK carbon emissions [Department for Transport, 2008], but transport altogether is a major source, representing about 22% of the country’s total carbon emissions (Department for Environment and Climate Change, 2009). All transport modes need to play a part in reducing these emissions and contribute to the country’s overall economy-wide targets. However, eco-driving is about more than environmental benefits and cost savings. The focus on the driving task and how it relates to broader company and industry sustainability goals means that it is increasingly treated as part of professional driving.

In December 2009 the experiences of railway undertakings in GB who were introducing eco-driving initiatives were shared at an industry seminar. Following this, a research project was commissioned for the GB rail industry’s Operations Focus Group, to document the its collective understanding of the approaches, benefits and risks presented by efficient driving as well as case studies from individual operators. The project was managed as part of the rail industry’s research and development programme, funded primarily by the UK Department for Transport, and managed by RSSB on industry and government’s behalf. This paper provides a summary of the main findings of the study and highlights areas to consider further.

2. Methodology

The research was split into the following work packages:

- A preliminary hazard assessment of eco-driving techniques not involving the use of train-cab tools or devices such as driver advisory systems
- A statistical analysis of available energy data for both diesel and electric traction
- Case studies demonstrating the approach that eight GB railway undertakings have taken to implement eco-driving

Details on the methodology applied for each of the individual work packages follows.

2.1 Preliminary hazard assessment

A series of qualitative semi-structured interviews with individual railway undertakings and the infrastructure manager (Network Rail) were undertaken to ascertain the main eco-driving techniques currently being employed by operators across GB. Additionally an analysis of the main driving tasks1 expected to be impacted by eco-driving techniques was undertaken by a human factors specialist. The results of the interviews and analysis of the driving task were investigated at a hazard workshop which identified circumstances where an error may be more likely to occur. Subsequently, a high-level Signal Passed At Danger (SPAD) risk ranking exercise to assess the potential consequences (or increased consequences) of a SPAD caused by a distraction or error due to employing eco-driving

1 Normal driving tasks were deemed to be those documented for RSSB research project: Review of current GB driver training programmes and development of leading practice models for the industry - T718 (RSSB, 2009).
techniques was undertaken. This was intended to give an all-round qualitative indication of possible outcomes. Finally, a list of risks and an assessment of their probability of occurring was generated.

2.2 Energy Data Analysis

Data on traction energy consumption was provided by four railway undertakings, covering 15 routes and seven classes of train representing a range of older and newer diesel and electric traction, multiple units and locomotives. The train classes involved included 144, 150, 153, 156, 158 for diesel, and class 90 and 390 (Pendolinos) for electric. The study focused on regional and intercity diesel and electric AC services.

Overall, 226 drives for diesel and 478 drives for electric trains were analysed. Samples for most routes ranged from 20-40 drives, with smaller samples removed from the dataset. The drives provided were all in comparable sets, i.e. having the same journey duration and number of stops over each route, with significantly early or late trains excluded from the analysis. Although not all were available for each sample, the parameters collected included:

- Train class
- Unit number
- Driver number (a unique driver identifier)
- Experience level of driver in years
- Time and date of journey
- Duration of journey
- On-train monitoring recorder (OTMR) data, showing the amount of time spent in each throttle notch position (enabling the calculation of fuel consumption), or amount of time spent in motor demand and electricity consumed in the case of electric trains.
- Average speed of the journey
- Distance covered

Limitations to the analysis

Additional parameters such as temperature, speed over time, gradients, and presence of speed restrictions were also requested, but as this data was not consistently available these additional parameters could not be used in the analysis. The data was collected between April and June 2010, and therefore does not represent variation in climate over different seasons which is known to affect energy consumption significantly.

At the time of undertaking this study none of the participating railway undertakings had fuel meters on their diesel units. To enable some form of diesel fuel consumption analysis to be undertaken the study used estimated fuel consumption data derived from a tool developed by one of the railway undertakings (Arriva Trains Wales) using data from the OTMR of the time spent in each throttle-notch position which was translated into litres of fuel based on theoretical flow rates from engine specifications for each throttle notch position. This fuel calculator had not been validated at the time of the study, which needs to be borne in mind when reviewing the findings; therefore results from the diesel analysis should be taken as a proxy for potential savings rather than actual savings.

Furthermore, whereas data on which drivers would be deemed eco-drivers versus non-eco-drivers was provided by some railway undertakings the sample sizes were limited. Therefore as the data provided for the study did not allow for the construction of a clear eco-driving sample versus a control group, ‘real drive’ data was used which meant that a straightforward analysis of whether ‘eco-drives’ are more fuel efficient than other drives could not be undertaken. Therefore an alternative approach to the analysis was employed which examined the variance in energy consumption over a route and investigated a number of parameters such as the percentage of time spent in high throttle-notches or motor demand, slack time available in the route timetable, train units, driver experience and time of travel (i.e. peak, off-peak, night services) to assess if the extent that these have a direct correlation with energy savings.

For each route in the sample the mean traction energy consumption and the standard deviation around the mean were calculated. The analysis then focused on three target levels for investigating consumption: the conservative target (the mean +1 standard deviation), the mean target (the mean itself), and the optimistic target (-1 standard deviation from the mean):
Challenge A: A more and more energy efficient railway

- Conservative target: What savings could be gained if all the unusually high fuel consumptions were brought to within one standard deviation above the mean?

- Mean target: What savings could be gained if all the above mean consumptions were brought down to the mean level?

- Optimistic target: What savings could be gained if all the consumptions were brought to within one standard deviation below the mean?

Furthermore the coefficient of variation (the standard deviation divided by the mean fuel consumption for the route) was calculated which allows the extent of the variance of the fuel consumption around the mean to be compared between routes. Finally the coefficient of determination $r^2$ was used to investigate the strength of relationships between variables such as the effect of driver experience or a specific train unit against fuel consumption.

2.3 Case Studies
The qualitative, semi-structured interviews with operations managers and drivers from eight different railway undertakings and the infrastructure manager from the risk work package were expanded to gather case study data around the topic of eco-driving. The interviews lasted an hour and explored different aspects of eco-driving initiatives including approach, cost, use of incentives, whether specific communications resources were produced and lessons learnt.

3. Findings
The idea of efficient driving is not new to the industry. In the days of steam locomotives, the cost of coal – coupled with the physical ability of the fireman and (later) the Clean Air Act – meant that the railway was strongly motivated to avoid unnecessary fuel consumption. Eco-driving was once considered part and parcel of professional driving, and in GB at least there is a clear appetite to rediscover these skills. The main eco-driving techniques currently being employed by GB operators include:

- Selective use of the power lever for acceleration (with differing techniques for electric and diesel traction)
- Coasting (reducing or shutting off the power)
- Use of gradients – shutting off power at or just before the crests of hills to benefit from falling gradients
- Avoiding unnecessary use of the brake to avoid the loss of kinetic energy that has been gained

For diesel traction, the focus is on avoiding using the higher notches unless absolutely necessary, which helps reduce fuel consumption. For electric traction, the focus is on driving up to speed as soon as possible and then using coasting to reduce the amount of electricity consumed, although on some traction types which run above 100mph (eg the Pendolino), operators have also seen potential benefits from avoiding running at maximum speed except where necessary to make up lost time.

Apart from the more direct benefits of fuel and energy savings, the infrastructure manager reports that eco-driving provides indirect cost savings through decreased wear and tear on traction and infrastructure equipment. Train operating companies have found that it results in a better customer experience through a smoother ride while still arriving on time. More assertive driving styles can result in trains arriving too early and having to wait outside terminal stations, encountering more adverse signal aspects, as well as consuming more energy, driving up energy costs and carbon emissions.

3.1 Risk Findings
In essence, the preliminary hazard assessment sought to determine whether eco-driving inadvertently compromises safety in return for fuel economy. The hazard assessment found that the main precursor to hazards due to eco-driving is distraction.
The two main hazards identified from the workshop included:

- Failure to control the train speed (over-speeding)
- Failure to see a sign or an obstruction on the line ahead

The various potential consequences of these hazards were also assessed; specifically SPADs, derailments, and striking objects or people on the line-side.

It was determined that there is a commonly understood priority list for driving: safety over performance and performance over eco-driving. Eco-driving would not be implemented under any type of degraded working or emergency. It was agreed that the railway industry should continue to ensure that this priority list is maintained and emphasised to drivers.

In conclusion, the potential seriousness and consequences of a category A SPAD due to eco-driving appear to be low, as it is likely to be a temporary distraction leading to an over-speed with time to recover before encountering a conflict point, and in many cases Train Protection and Warning System (TPWS) will stop the train before the conflict point.

The effect of incentives and monitoring should be carefully considered before implementing any such programmes in relation to eco-driving. If the programmes are designed to affect a driver’s attitude to driving techniques, they should continue to promote safety as a priority.

The following issues were found to be worthy of further consideration:

- Driver forgets to sound the warning horn due to eco-driving when approaching track workers or level crossings
- Driver misjudges the speed of a DC train (third rail) in icy conditions due to eco-driving: this is unlikely as eco-driving should not be implemented during adverse weather conditions. Even if eco-driving were undertaken in this situation, with the driver unaware of the adverse conditions, it should quickly become clear that conditions were dangerous and a different driving style would be adopted.

Railway undertakings have been encouraged to be aware of these two risks when implementing their eco-driving policies in order to mitigate them. The research also suggests that during driver training the industry should continue to raise awareness of the potential for distraction while eco-driving.

The use of route cards and in-cab displays such as driver advisory systems for eco-driving is not yet prevalent in the GB rail industry, but the research found that they may represent potential distractions to drivers once introduced. In GB each operating company is responsible for undertaking their own risk assessments before future implementation of such tools.

### 3.2 Energy Analysis Findings

In discussing traction energy consumption this analysis will refer to litres of fuel used by diesel trains, and kilowatt-hours (kWh) of electricity used by electric trains.

#### 3.2.1 Diesel traction analysis

Table 1 presents the results from the diesel traction analysis, illustrating the range of potential savings available on each route.

<table>
<thead>
<tr>
<th>Route</th>
<th># of drives</th>
<th>Fuel consumption (litres)</th>
<th>Potential saving</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Std deviation</td>
</tr>
<tr>
<td>Cardiff to Ebbw Vale</td>
<td>40</td>
<td>16.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Manchester Victoria to Bradford</td>
<td>6</td>
<td>18.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Cardiff to Cheltenham</td>
<td>34</td>
<td>50.7</td>
<td>4.1</td>
</tr>
<tr>
<td>Norwich to Sheringham</td>
<td>22</td>
<td>14.9</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Challenge A: A more and more energy efficient railway

<table>
<thead>
<tr>
<th>Route</th>
<th># of drives</th>
<th>Energy used (kWh)</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>Yarmouth to Norwich</td>
<td>21</td>
<td>8.9</td>
<td>1.1</td>
</tr>
<tr>
<td>Huddersfield to Leeds</td>
<td>14</td>
<td>7.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Lowestoft to Norwich</td>
<td>19</td>
<td>10.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Sheringham to Norwich</td>
<td>24</td>
<td>13.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Norwich to Yarmouth</td>
<td>21</td>
<td>8.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Norwich to Lowestoft</td>
<td>23</td>
<td>9.8</td>
<td>1.6</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>12.3%</strong></td>
<td><strong>4.4%</strong></td>
</tr>
</tbody>
</table>

For the diesel routes analysed, the potential energy savings were between approximately 1% and 12.3%, with a mean target savings level of 4.4%.

According to the data, routes from Cardiff have the lowest potential savings levels and are also the only ones that use class 150 rolling stock. Routes to and from Norwich are generally characterised by having a higher level of potential savings, and all use class 156s. The route from Manchester Victoria to Bradford shows moderate potential savings levels using class 158s, while the route from Huddersfield to Leeds has potential savings comparable to the routes from Norwich, and uses class 144s. While there is likely to be a relationship between train class and energy consumption, potential savings are driven by a combination of factors. A significantly larger dataset would be required in order to truly understand the effects of each variable (such as route characteristics, gradients, linespeeds, stops, temperature and the maintenance of the unit itself (amongst other variables) directly on energy consumption.

### 3.2.2 Electric Traction Analysis

Combining and comparing the results for the Norwich to Liverpool Street route and the Manchester Piccadilly to Euston route, table 2 shows that the former route has a significantly greater coefficient of variation, thus greater potential for savings.

#### Table 2: Electricity savings for Norwich / Liverpool Street and Manchester Piccadilly / Euston

<table>
<thead>
<tr>
<th>Route</th>
<th># of drives</th>
<th>Energy used (kWh)</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>Norwich to Liverpool Street</td>
<td>227</td>
<td>3059</td>
<td>497</td>
</tr>
<tr>
<td>Liverpool Street to Norwich</td>
<td>205</td>
<td>3321</td>
<td>416</td>
</tr>
<tr>
<td><strong>Average for Norwich / Liverpool Street</strong></td>
<td></td>
<td><strong>3190</strong></td>
<td><strong>513</strong></td>
</tr>
<tr>
<td>Manchester Piccadilly to Euston</td>
<td>25</td>
<td>4489</td>
<td>289</td>
</tr>
<tr>
<td>Euston to Manchester Piccadilly</td>
<td>24</td>
<td>4514</td>
<td>229</td>
</tr>
<tr>
<td><strong>Average for Manchester Piccadilly / Euston</strong></td>
<td></td>
<td><strong>4502.5</strong></td>
<td><strong>307.5</strong></td>
</tr>
</tbody>
</table>

For the two electric routes analysed, the potential savings levels were between 0.6-15.4% for Norwich to Liverpool Street and 0.3-6.3% for Euston to Manchester Piccadilly, with mean target savings levels of 5.2% and 2.3% respectively.

There are a number of factors that could contribute to this difference in consumption. First, the Manchester Piccadilly route uses Pendolinos, which are much newer than the class 90s being used on the Norwich to Liverpool route. Norwich is a 100 mph route, with more stops and opportunities for coasting than the Manchester route. The Pendolinos on the Manchester route travel at 125 mph and can tilt around curves, whereas class 90s would have to restrict their speed.

Another possible reason is that trains on the Manchester Piccadilly / Euston route have comparatively little slack in their timetables compared to the Norwich to Liverpool Street route. This may have resulted in all drivers driving assertively and to similar consumptions in order to comply with their timetable and in doing so has led to a comparatively small variance between their mean fuel consumption levels and potential range of savings. These factors could make the Manchester Piccadilly drives comparably more efficient and uniform in terms of fuel consumption, giving rise to
less variance and leaving less room for potential savings. Again however, a significantly larger dataset would be required in order to truly understand the effects of each variable.

3.3 Case Study Findings

Eight case studies were developed covering suburban, regional, intercity and freight services and both diesel and electric (AC and DC) traction reflecting a broad spectrum of experiences and perspectives on implementing eco-driving. The case studies reveal the different techniques employed reflecting the capabilities and scope for individual routes with varying types of rolling stock as well as different approaches for encouraging eco-driving.

Despite some variety in approach a great deal of commonality was found between what makes for successful implementation of eco-driving, including:

- Senior management commitment
- Embedding eco-driving policies
- Understanding opportunities for eco-driving on a particular route
- How to measure success (what data to use)
- An eco-driving champion winning hearts and minds
- Briefing and training
- Modifications to in-cab controls
- Coasting boards
- Having a clearly defined roll-out plan
- Incentives (whilst maintaining the safety over performance and performance over eco-driving hierarchy)
- Working with the infrastructure manager (Network Rail)
- Supporting good public relations
- Understanding a company’s position on the ‘eco-driving continuum’

However key challenges to eco-driving were found to include:

- A lack of slack in the timetable for a particular route. To keep to time it may be necessary to drive more assertively, make full use of the traction’s capability and avoid coasting.
- The topography of a route may mean that gradients are not suited to coasting or reduced power.
- In addition, there may be a need to commit time and resources to the task of implementing eco-driving which may not be readily available.

4. Discussion

The implementation of eco-driving initiatives is moving rapidly across GB as energy and cost savings are being realised by railway undertakings that are considering what the eco-driving opportunity means for them in terms of reputational benefits and how it may support their applications for future franchises. Introducing and encouraging eco-driving calls for a methodical approach by the individual train operating company concerned. At present there is no nationally agreed guidance for eco-driving, each operator has adopted its own approach and is creating its own set of guidance concerning these techniques. To some extent this approach is entirely appropriate as much will depend on the specific characteristics of the route and traction used for each railway undertaking.

However, whilst operators need to develop their own implementation methods this research has provided some general underpinning information to an industry-wide understanding of the high-level risks and potential benefits to be gained from eco-driving. It also shares lessons learnt by a number of operators who are implementing eco-driving across their operations.

The preliminary hazard assessment identified the main precursors to hazards due to eco-driving. In conclusion it identified two main hazards: failure to control the train speed (over-speeding) and failure to see a sign or an obstruction on the line ahead. In addition a number of issues were highlighted as being found to be worthy of further consideration by train and freight operators in developing plans to mitigate potential risks. A clear message is that the industry should continue to re-emphasise the
prioritisation of safety over performance and performance over eco-driving and continue to raise awareness of the potential for distraction while eco-driving during driver training.

A range of energy savings are available on all routes investigated in the analysis, although the scale of savings is dependent upon a large number of interrelated factors, and while there are acknowledged difficulties in gathering even basic data such as accurate fuel consumption levels, many other parameters are not easily available or are simply not recorded. In order to be able to statistically prove that eco-driving resulted in the savings found in this study a similar analysis would need to be performed but with much larger datasets for each route, as well as additional routes controlling for variables in order to improve the statistical significance of the results. Any analysis of this type is faced with the difficult question of what actually constitutes eco driving, whether a control group could feasibly be formed, and how to establish such a control group. Whilst tools can be built to estimate consumption of fuel on diesel units, the installation of energy meters is strongly encouraged to ensure that accurate data is available to understand potential margins for savings on each route and in developing targets for realistic savings available in the future. For any operating company considering implementing or strengthening their eco-driving initiatives, this analysis could provide an outline methodology for determining the potential for energy savings and evaluating the impact and challenges once eco-driving has been introduced.

Where only a handful of train and freight operators confirmed that they were eco-driving at an industry seminar held in December 2009, virtually all train and freight operators in Great Britain (GB) are reported to be implementing eco-driving now. This research was indicative of a point in time in the development of eco-driving in terms of both the knowledge and technology available in GB to support the concept but also in terms of its priority with regards to a company’s wider business objectives. Since this report was written at least three train operators have begun the process of having meters fitted to diesel units which will soon result in much more accurate data being available for more rigorous analysis of the potential energy and cost savings that may be directly attributed to eco-driving.

The findings of this research demonstrate that there is potential on all routes analysed for energy savings to be made, however due to all of the reasons noted above the results of the diesel data analysis in particular should be treated as indicative or proxy results and not as conclusive actual savings.

5. References

Department for Transport, May 2008, Rail transport submission to the Committee on Climate Change.


RSSB, (2009), Review of current GB driver training programmes and development of leading practice models for the industry (T718), RSSB.

6. Thanks

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