Title: The Influence of Route Characteristics, Train Design and Maintenance Policy on Wheel Tread Damage, Wheel Life and Costs for Multiple-Unit Trains

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Abstract: In the UK, the use of similar vehicle types by a range of privatised operators gives the opportunity to assess the influence of different route conditions and maintenance practices on wheel tread damage, wheelset life and costs. This paper investigates these influences, using data obtained directly from the train operators and maintainers. By disseminating best practice it is expected that wheelset life can be improved on many fleets, with resultant cost savings.

1. Background:

Through the life of a rail vehicle, the wheelsets are one of the most expensive components. Wheelset manufacturing costs are high (especially when both financial and environmental costs are considered). They require regular maintenance activities [1] including:

- Inspection for safety-critical damage to wheel and axle
- Profile measurement to ensure that flange dimensions remain within standards
- Reprofiling on the wheel lathe (typically about once a year)
- Renewal of wheelset (typically every 4 to 5 years)

These activities have significant labour and material costs, but also require the train to be taken out of service which impacts fleet availability and service provision [2]. Consequently there is a strong demand to reduce the rate of wheel damage, and thereby to extend wheel profiling intervals and wheelset life.

Privatisation of railways in the UK has led to a situation where similar train fleets are operated and maintained by many different organisations around the country. Each operator’s fleet is dedicated to operation on a particular route, and maintained locally. Limited communication between the competing companies means that maintenance practices often differ between fleets. Performance targets and financial pressures often mean that fleets are intensively used; resulting in limited opportunities for reprofiling wheels or undertaking detailed fault-finding and investigation. These constraints can limit the optimisation of wheelset maintenance practices.

2. Methodology:

A wide-ranging survey of wheel tread damage types and maintenance practices has been funded by the Rail Safety and Standards Board (RSSB) and carried out by the Institute of Railway Research at the University of Huddersfield. The work has been supported by other industry organisations, and aimed to investigate the influences of train design, route conditions and maintenance practices on wheel tread damage.

The first stage of this process was a questionnaire review of wheel tread damage and wheelset maintenance on the passenger rolling stock fleets. The questionnaire was designed to be on a single page so that it would appear straightforward to fill in and is reproduced in the Appendix of this paper. Communications through industry colleagues and organisations also encouraged fleet engineers to complete the questionnaire. An excellent response was achieved, covering more than 90% of all the passenger vehicles in the UK. Some useful data was also obtained for freight vehicles and locomotives, although this paper focuses on the passenger diesel multiple-unit (DMU) and electric multiple-unit (EMU) fleets, which total about 10,000 vehicles.

The questionnaire was followed up with visits to many maintenance depots and wheel lathes, enabling detailed discussions and observations of damaged wheels. Telephone conversations were also held where visits were impractical.

Once the responses had been collated and analysed, the results were fed back to all the responders, who were able to check their data and identify any inconsistencies. Because the questionnaire had been completed by different engineers around the country, there may have been different interpretations or variations in sample size or confidence in the data. This stage helped to check that the data was consistent, and led to revisions of some entries and increased confidence in the dataset.

On completion of the analysis, workshops were held at maintenance depots around the country, presenting the results of the work. This provided an opportunity for further discussion and feedback. The authors therefore have good confidence in the data presented and the conclusions drawn; it is possible that some individual figures remain inaccurate but these will not influence the over-all picture presented here.

3. Overview of Results

3.1 Reprofiling Intervals

The typical life of a wheelset on a UK multiple-unit train involves reprofiling 3 or 4 times at approximately annual intervals, followed by renewal of the wheelset when it reaches the minimum permitted diameter. On a few fleets it is necessary to renew axle bearings during this period but the wheel pans and the axle may be re-used.

On some fleets, most reprofiling is carried out as a planned maintenance activity at a given distance interval. Other fleets use automated or manual condition monitoring to determine when the condition of the wheel tread requires reprofiling. The average reprofiling interval can be a useful indicator of the wheel life. This is shown in Figure 1 with the vehicle types grouped by their dominant duty.

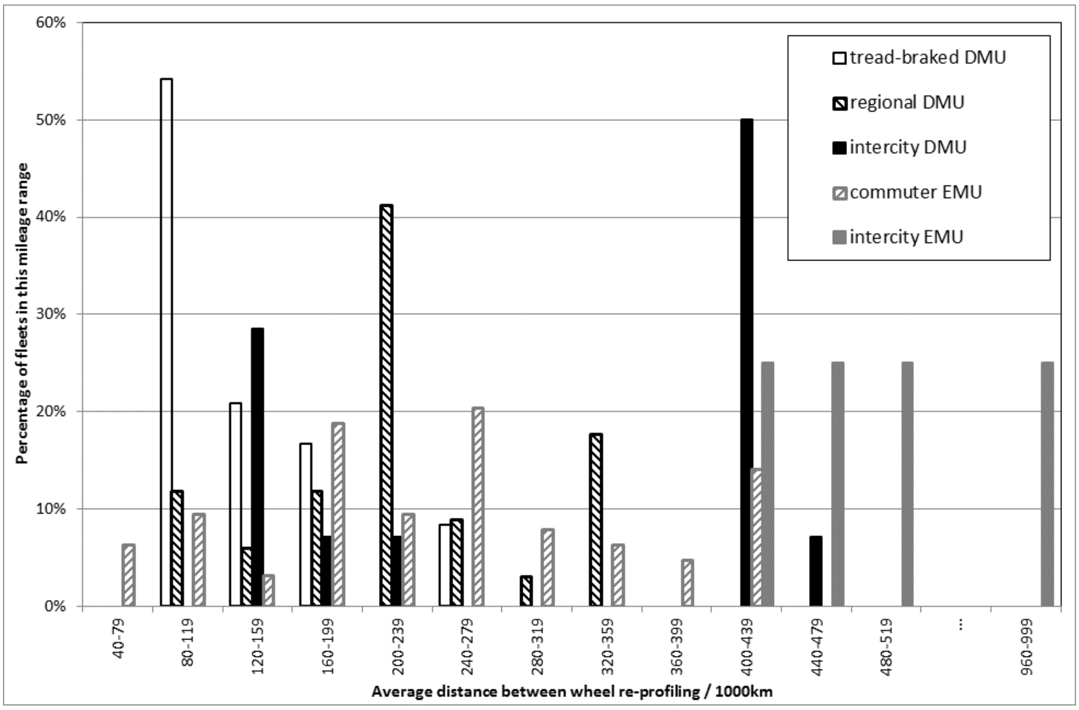

Figure 1: Average Reprofiling Intervals for Various UK Train Types

A number of conclusions can be drawn from this graph. Firstly, there is an order of magnitude difference between best and worst performance. Several intercity (long distance) vehicle types achieve a reprofiling interval over 400,000km, with the best being close to 1,000,000km. However, some intercity DMU vehicles do not perform so well.

Most UK passenger vehicles are now fitted with disc brakes, many also having some form of dynamic brakes. However, some older DMU vehicles remain tread-braked. These generally have shorter reprofiling intervals, driven by the rate of tread wear and limits on flange height and hollow wear on the profile.

Intercity trains typically run on higher-speed routes with straighter alignment, so are potentially less prone to wheel damage related to curving (such as flange wear and rolling contact fatigue). They are also less prone to wheel damage related to braking (such as flats and thermal damage), because they tend to have fewer stops, and often more vehicles in the train so traction and braking is distributed over more axles. Some intercity fleets also use premium wheel steels [3], [4], which offer greater resistance to rolling contact fatigue (RCF) damage, to extend wheelset life.

In contrast, regional and commuter trains have many stop/start cycles and may run on more sharply curved routes. The regional and commuter fleets show a wide range of reprofiling intervals. There are a wide variety of train designs, duties and maintenance practices in this group, which will be discussed in more detail in the next section.

3.2 Reasons for Reprofiling

It is interesting to compare the significant reasons for reprofiling, for each group of train types, and this is shown in Figure 2. Other damage types are relatively rare and tend to occur on individual defective wheels, rather than as a fleet-wide damage mechanism.

For tread-braked vehicles, the tread wear from braking causes an exceedence of the flange height limit, and this drives about 40% of reprofiling. Another 35% of wheels require reprofiling after they have slid during braking, causing flats and cavities. These vehicles are not fitted with any form of wheel slide protection (WSP) system.

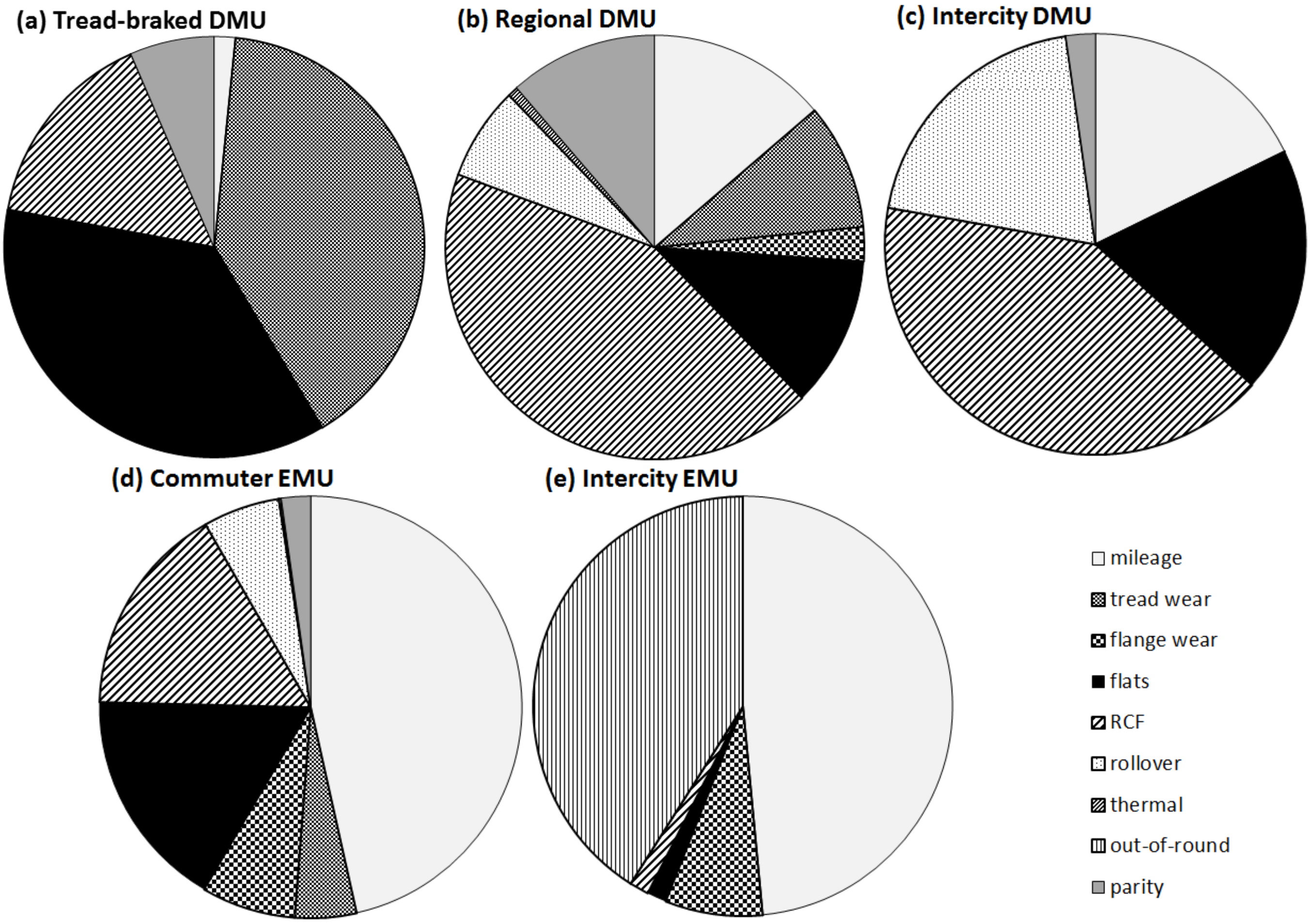

Figure 2: Dominant Reasons for Reprofiling for Various UK Train Types

Most DMU types have driving axles linked by cardan shafts, requiring the wheelsets to be the same diameter. This 'parity' requirement can drive a proportion of wheel reprofiling.

The main reason for reprofiling on the regional and intercity DMU vehicles is RCF. This directly accounts for about 40% of wheels reprofiled, but is also the reason why a mileage (distance) based reprofiling interval is used on some fleets, giving a total of around 60% for each group. Some fleets with poor WSP suffer from flats, while other fleets have problems with tread rollover. Some disc-braked regional DMU fleets are also fitted with 'scrubber brakes' to clean the tread to improve adhesion and train detection, and these can cause some tread wear.

Many commuter EMU fleets are maintained with a mileage (distance) based reprofiling interval, usually to control RCF growth which is a significant reason for reprofiling on these vehicles – together comprising 65% of the total. Some fleets with poor WSP suffer badly from flats. Those operating on sharply curved routes are reprofiled because their flanges have worn down to the minimum thickness, while those on fairly straight routes tend to wear the treads hollow and may be reprofiled for exceeding limits on flange height or tread rollover.

The two large fleets of intercity EMU trains both achieve long reprofiling intervals. On the tilting train fleet, the planned interval is limited by conicity and RCF crack growth, although trials of a new lower conicity wheel profile (P12) and the use of a premium wheel steel (RS8T, Superlos) have shown promise [4] in reducing both problems. On the non-tilting articulated train fleet, the wheels eventually become out-of-round, while some of the leading vehicles suffer from flange wear.

3.3 Diameter Loss

The overall life of a wheel is governed by the loss of diameter. This is influenced by the reprofiling interval, the wear rate when running and the material removed on the lathe when the wheelset is reprofiled. Figure 3 illustrates the average performance for each group of trains, both in terms of the absolute reduction in diameter per reprofiling interval, and in terms of a usage rate per 160,000km.

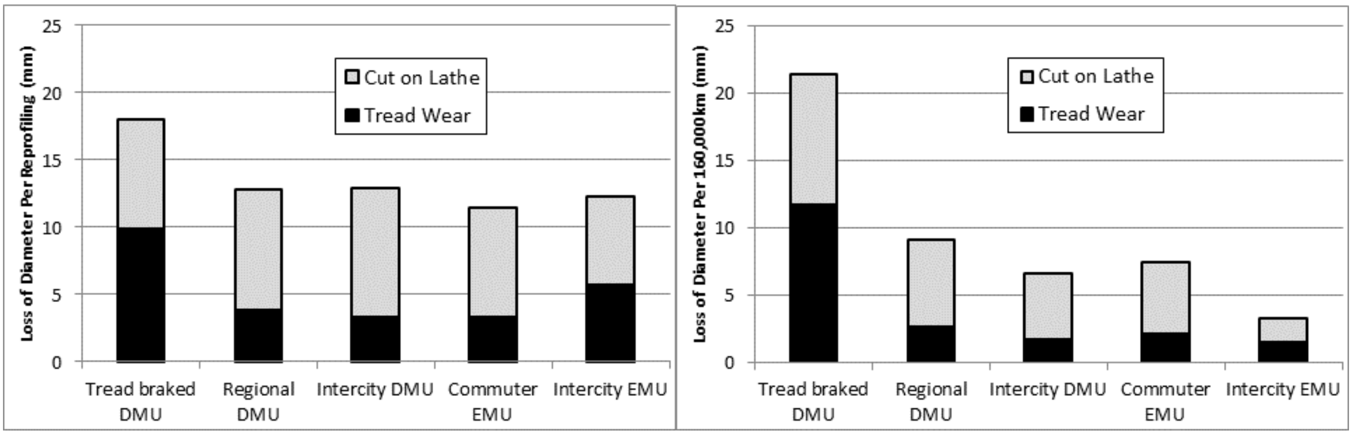

Figure 3: Diameter Loss through Wear and Reprofiling for Various UK Train Types

The tread-braked vehicles have a tread wear rate approximately five times that of the disc-braked vehicles. The average loss of diameter on the lathe is similar on all vehicle types, and for disc-braked vehicles the material removed on the lathe is usually much more than that lost through wear. The intercity EMUs have a longer reprofiling interval than most other groups, and are less prone to flats and RCF so the average material loss on the lathe is slightly lower.

The influence of these factors on the over-all life of a wheelset is visualised in Figure 4, showing the trend in wheel diameter for an ‘average’ wheel for each group of vehicles. It is assumed that the minimum diameter is 50mm less that the new wheel, which is typical for UK multiple-units. A Weibull frailty analysis [5],[6] or the use of a model such as the Wheelset Management Model [2] would provide a better assessment of variability within a specific fleet. However, this paper is intended to provide a comparison between the different train types and a simple average illustrates that more clearly.

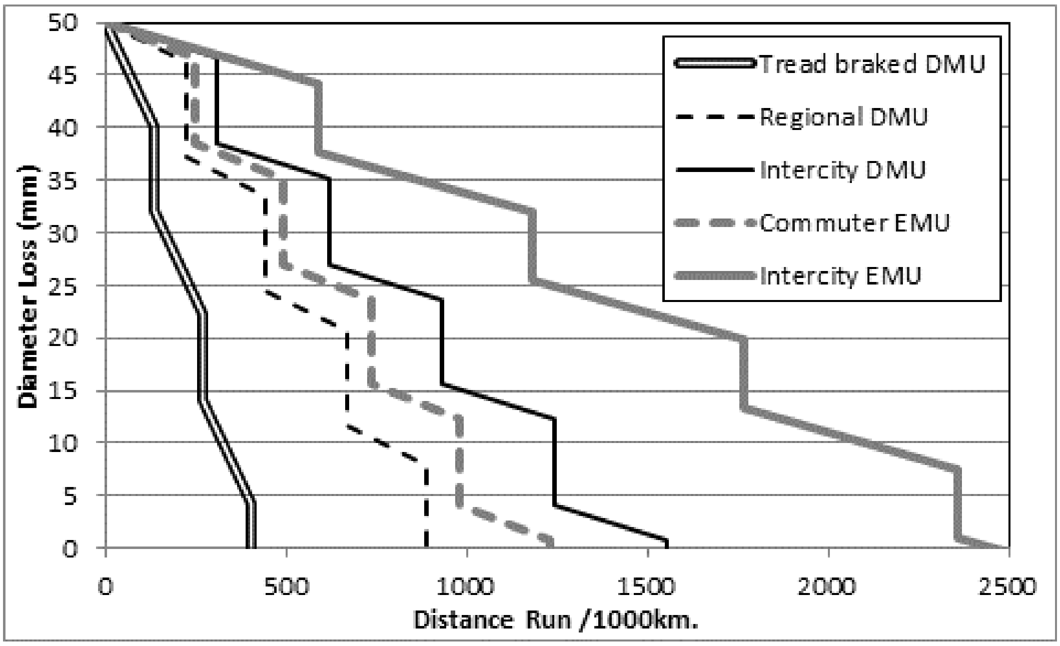

Figure 4: Average Wheel Diameter Trends Through Life of Wheelsets

4. Influence of Route and Maintenance Policy: Mark III EMU Vehicles

4.1 Overview

During the 1980s a series of very similar EMU classes were built using the ‘Mark III’ bodyshell, and these now work in many parts of the country for numerous operators. They provide an interesting illustration of the influence of vehicle type, route characteristics and maintenance practices on wheel damage. These EMUs consist of a heavy power car surrounded by lighter trailer cars, and have quite different bogie types on the two car types. They are disc-braked with an older type of WSP system, and are not fitted with dynamic braking.

The power and trailer cars are usually reprofiled at the same interval, even though the axleload, unsprung mass and primary yaw stiffness of the power cars are nearly double that of the trailer cars. The power cars also have a larger wheel diameter.

4.1 Questionnaire Results and Background

Table 1 gives an overview of the survey results for this type of train, where the dominant damage types and maintenance policies differ significantly between the eleven fleets assessed. These are summarised below; note that distance intervals are quoted in miles, as this is the measure used on these older fleets (1 mile ≈ 1.6km).

Fleet	Reprofiling Policy	Mileage Between Reprofiling	Loss of Dia by Wear	Diameter Removed on Lathe	Dominant Reasons for Reprofiling Percentage of Wheels Reprofiled							
			mm	mm	Mileage	Flats	RCF	Thin Flange	High Flange	Roll-over	Hollow Wear	Parity
1	Mileage	250k	4	5	99		1					
2	Condition	250k	3	5							99	
3	Condition	150k	3	8		40	60					
4	Condition	110k	6	18		6	14	74		2		
5	Condition	160k	5	10		2	7	10		75		6
6	Mileage	120k	3	5	76	12	12					
7	Condition	?	?	6		46	38	6	8	2		
8	Condition	40k	1	6	5	58	33	8	3			
9	Condition	?	?	6		46	40	7	5	2		

Table 1: Dominant Reasons for Reprofiling for MkIII EMUs

For these vehicles, the maintenance constraints have a big influence on the reprofiling interval. The bogie overhaul periodicity is 500,000 miles (800,000km) which is governed by the life of roller bearings and some suspension components. Renewing wheelsets at bogie overhaul is cost-effective, but renewing between overhauls adds considerable expense. When the trains were introduced, wheelsets were intended to be reprofiled 3 times at approximately 125,000 mile intervals, followed by renewal at bogie overhaul.

4.2 Analysis and Review of Post-Questionnaire Discussions

Fleet 1 operates a fairly straight, flat route, and did have major problems with flats in poor adhesion conditions owing to an unreliable WSP. The fleet maintainers initiated a rigorous policy of WSP fault-finding and in the process found several wiring faults that had been present since the trains were built. Correcting these faults and insisting that any train having its wheels reprofiled for flats should not re-enter service until the fault has been found and corrected has largely eliminated flats as a source of damage on this fleet [7]. This has enabled wheelset reprofiling to be managed on a planned basis with a 250,000 mile interval, to prevent the onset of RCF, allowing the wheels to be re-used at bogie overhaul for a total mileage of 1,000,000 miles. This doubling of the useful wheel life gives significant maintenance cost savings.

The average trend in wheel diameter (shown as the remaining useful diameter above the minimum permitted) is shown in Figure 5. Even after a million miles, fleet 1 has significant diameter remaining and some wheels might be re-used for a third bogie overhaul interval. This graph shows the average performance: in reality there is a range of wheel diameters across the fleet and the decision on whether to re-use wheels at bogie overhaul is based on their diameter at that time.

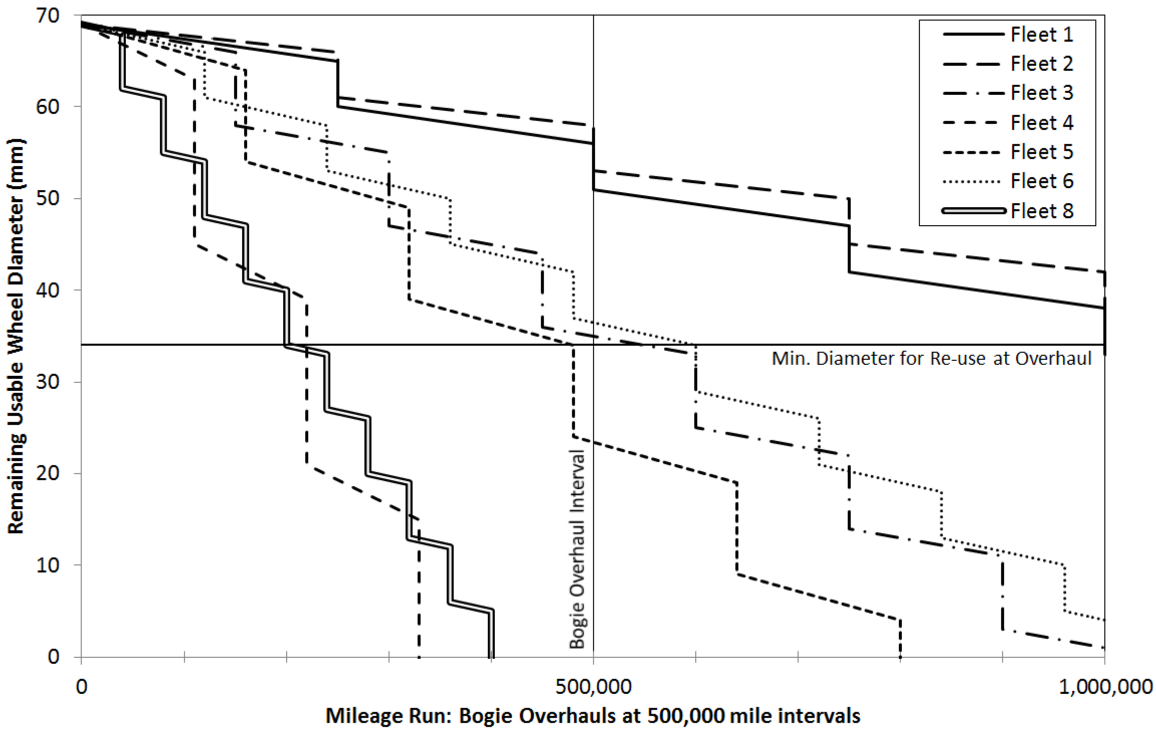

Figure 5: Average Wheel Diameter Trends Through Life of Wheelsets: MarkIII EMUs

Fleet 2 operates similar routes to fleet 1; these are late-build units with an improved WSP performance. Their maintenance is based at a different depot and they are reprofiled on a condition basis; however they achieve the same reprofiling interval as fleet 1.

Fleet 3 works routes with a mixture of straights and moderate curves. The dominant damage is RCF, and this is probably influenced by the route characteristics [8]. However, flats are also a major problem, and although the ‘average’ trend just achieves two bogie overhaul cycles, it is likely that many wheelsets do not. Attention to the WSP system and the introduction of a mileage-based preventive reprofiling policy to control RCF might significantly increase the proportion of wheelsets that can be re-used at bogie overhaul.

Fleets 4 and 5 both work on routes with a high proportion of sharp curves, and see higher levels of tread wear during curving than fleets 1 to 3. Fleet 5 has vehicle-mounted flange lubrication and a slightly softer suspension yaw stiffness than fleet 4. The effect of this is clear in Figure 5: fleet 4 is reprofiled frequently for flange wear and a heavy cut depth is needed to restore the flange shape. These wheels do not usually last a full bogie overhaul interval and require costly mid-life replacement. In contrast, fleet 5 is reprofiled less frequently and with a shallower cut depth on the lathe. The dominant damage mechanism is tread rollover, largely a consequence of the heavier tread wear which tends to move the wheel/rail contact on the inner rail of curves toward the field side of the wheel tread. Fitting flange lubrication to fleet 4 could improve its performance to match fleet 5, and this might halve wheelset costs. It is unlikely that the wheel life on fleets 4 and 5 could be extended to 1,000,000 miles. The additional cost of renewing wheelsets mid-way between bogie overhaul outweighs the saving in reduced wheelset consumption which might be achieved with (say) a 750,000 mile wheel life.

Fleet 6 is managed on a mileage-based reprofiling interval, largely as was originally intended for this type of unit, with most wheelsets achieving the bogie overhaul periodicity. This is considered satisfactory by the operator/maintainer, as their lease for these trains includes new wheelsets at bogie overhaul so there is little financial benefit to them in further extending the wheel life.

Fleet 8 operates curved suburban routes with very frequent stops. Data for fleets 7 and 9 is incomplete but otherwise similar to fleet 8, so the latter is considered as representative of these three fleets which work on similar duties for different operators. These trains have limited access to a wheel lathe as they are often out-based at smaller depots and sidings, so the reprofiling policy and intervals are highly constrained by operational requirements. The reasons for reprofiling are dominated by flats and RCF, and these fleets have a shorter bogie overhaul periodicity (375,000 miles rather than 500,000 miles) which enables most wheelsets to last the interval. It seems likely that attention to the WSP systems could improve average wheel life on these trains, as seen on fleet 1. However, in privatised commercial operations it can be difficult to keep a train out of service long enough to diagnose the fault – too often a train comes in with flats, is reprofiled, goes back into service without repairing the WSP fault, and the problem recurs soon afterwards.

4.3 Validation of Questionnaire Results

The average trends presented in Figure 5 show some wide differences in wheelset life between similar fleets. To confirm that these trends represent reality, wheel reprofiling records for arbitrarily selected motor and trailer vehicles from three of the fleets were analysed and compared to the average trends from the questionnaires. These are shown in Figures 6, 7 and 8 for fleets 1, 3 and 8 respectively.

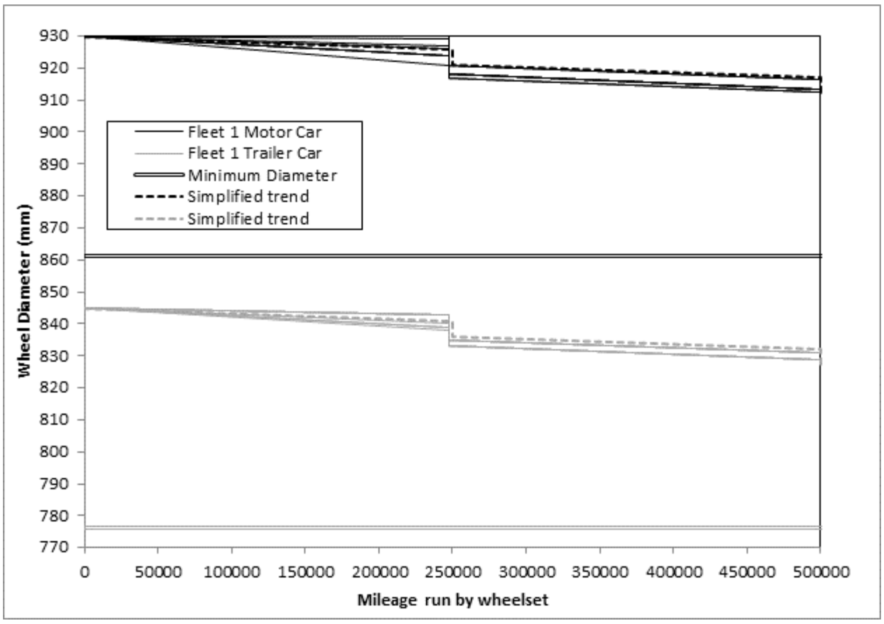

Figure 6: Actual Selected Wheel Diameter Trends: Fleet 1

For fleet 1, the selected data is from the period after the resolution of the WSP problems. Both motor and trailer vehicles are in line with the simplified trend from the questionnaire response, although the diameter removed on the lathe is slightly higher in practice.

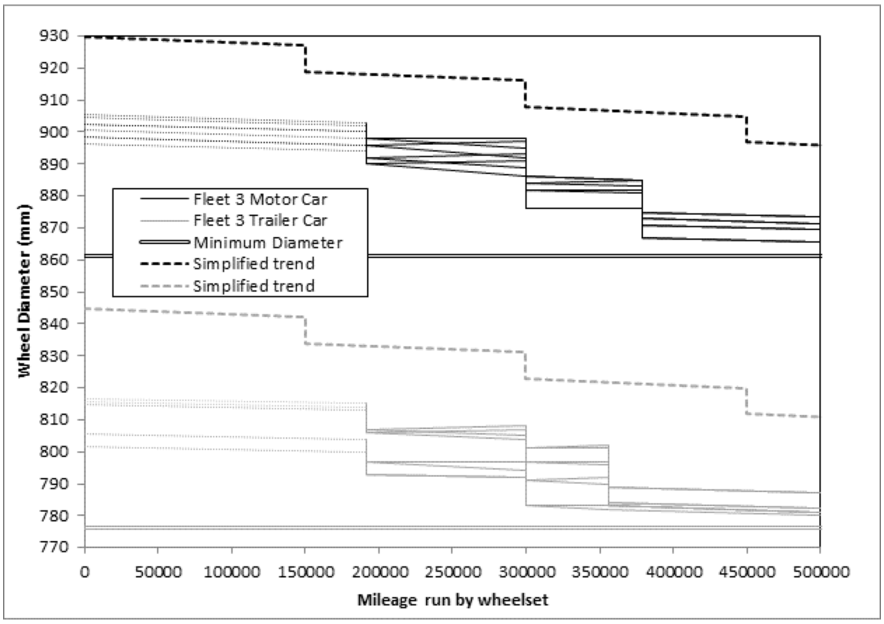

Figure 7: Actual Selected Wheel Diameter Trends: Fleet 3

For fleet 3, in this case both the selected vehicles have been fitted with part-worn wheelsets at bogie overhaul, so the starting diameters are less than for new wheels. However, the wear rates, cut depths and reprofiling intervals are broadly in line with the simplified trend for both vehicle types.

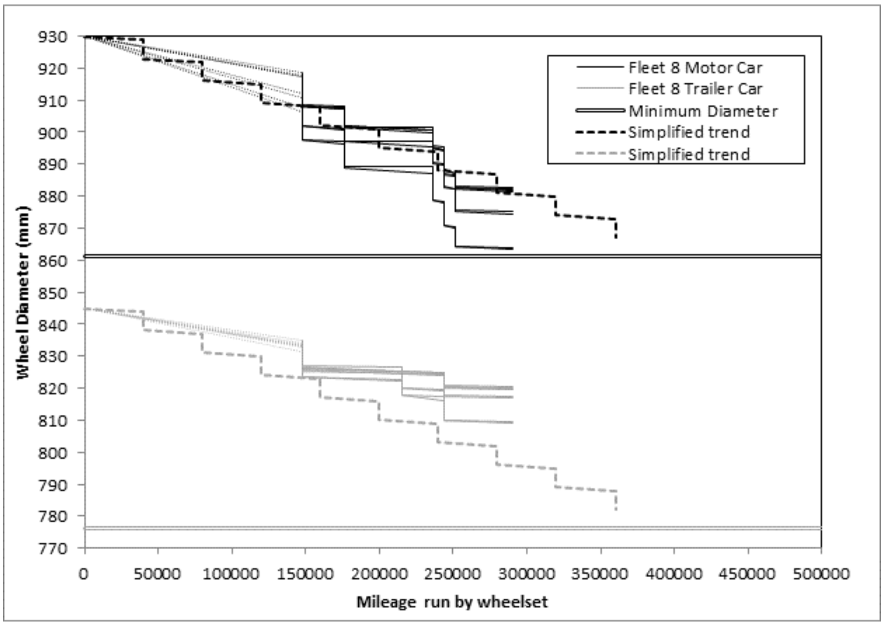

Figure 8: Actual Selected Wheel Diameter Trends: Fleet 8

For fleet 8, the available data only covered the latter part of the wheelset life and it is likely that there were also reprofiling operations in the first 140,000 miles. It is notable that the motor vehicle is turned repeatedly for flats within a short period, and that one wheelset is reduced to near-minimum diameter after only 250,000 miles. The simplified trend is perhaps pessimistic for the selected trailer car, but is optimistic for the motor car.

This data indicates that, for the selected fleets, the simplified trends provided in the questionnaire (and in some cases revised after further discussion) are reasonably representative of a typical performance of vehicles in those fleets. It is therefore valid to use this data to illustrate the large differences in wheelset life on similar trains working on different routes and maintained in different ways. It is intended to carry out a more rigorous statistical analysis of the reprofiling intervals and reasons on these fleets in due course.

4.4 Discussion

Route characteristics and maintenance practices have been shown to have a very large influence on wheelset life on UK multiple-unit trains. This may be more significant than the design parameters of the train (such as distribution of weight, traction and braking) although maintenance constraints resulting from design aspects are also important (such as bearing life, bogie overhaul periodicity and wheelset parity limits).

It was observed that maintainers who kept detailed wheel condition and maintenance records, and actively managed and optimised their maintenance practices, achieved significantly better wheel life than those who did not. The costs of these initiatives were quickly paid back by reduced wheelset costs. However, the privatised rail industry in the UK meant that in some cases the costs were borne by one company while the savings were realised by another; this discouraged initiatives that could provide a clear net benefit.

Analysis of the example fleets illustrated that there are significant benefits to be gained from solving problems associated with WSP systems to prevent flats, or by the provision of effective flange lubrication to reduce flange wear on curves. Applying best practice at the wheel lathe to optimise cut depths was also cited by some maintainers as providing a significant benefit. These appear to be obvious ‘quick wins’ but may be difficult to achieve in practice.

With these problems solved, RCF is often the limiting damage mechanism: this can be managed by introducing preventive reprofiling at an optimised interval, or reduced by the use of an alternative wheel profile, suspension characteristic or premium wheel steel [2]. By adopting best practice it may be possible to increase the wheel life on all these train types to approach the 1,000,000 miles achieved by fleets 1 and 2.

The trains with the highest reprofiling intervals in Figure 1 are limited by tread wear affecting profile shape. Hollow wear can generate a high conicity, which may lead to stability problems, and can also promote tread roll-over driven by more frequent contact near the wheel chamfer. On other fleets, the wear is not evenly distributed and eventually leads to problems with out-of-round wheels. On disc-braked multiple-units these problems usually occur before tread wear causes an exceedence of the maximum flange height limit. To some extent wear is beneficial as it can remove damaged material faster than RCF cracks propagate, so it may not be desirable to reduce tread wear rates.

One comment made by several maintainers was that comparing the results of the questionnaires was very worthwhile, as it put the performance of their fleet in perspective. This highlighted the potential benefits that could be realised by improved management and maintenance of wheelsets, and made fleet engineers think about what they could do better to become best in class.

5. Conclusions:

The paper has investigated the influence of different route conditions and maintenance practices on wheel tread damage, wheelset life and costs using data obtained directly from train operators and maintainers.

On most fleets, wheel reprofiling intervals are driven by one or two dominant wheel damage types; this has a significant influence on wheelset life and whole-life costs. However, the dominant types of wheel tread damage can differ significantly on similar vehicles running on different routes. The wheel damage type can also influence the cut depth on the lathe to restore the wheel profile and remove damaged material.

Some fleets are maintained with a preventive (mileage-based) lathe reprofiling interval, while others use monitoring techniques to schedule reprofiling based on wheelset condition. Both methods can be effective; mileage-based reprofiling tends to be carried out more frequently but may remove less material on the lathe.

The maintenance policies for some fleets are constrained by wheel lathe capacity or train availability requirements. The links between wheel tread maintenance and other wheelset and bogie maintenance schedules also vary and can have a significant influence.

The benefits of managing and analysing wheel condition and maintenance records have been demonstrated. These can be used to assist with the planning of wheelset maintenance and optimisation of reprofiling interval to reduce wheelset costs.

By disseminating best practice it is expected that wheelset life can be improved on many fleets, with resultant cost savings. Whilst it may be possible to increase wheel life on many fleets to match existing best practice, there may be limitations for extending wheel life further.

RSSB research project T963-01 [9] has developed a guidance document to assist fleet operators in optimising wheelset life. This guide provides a common basis for categorising wheel tread damage, and recommends methodologies for managing wheel damage and minimising maintenance costs. The contents of the guide have also been disseminated to fleet operators through a series of industry workshops.

Acknowledgements

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The GB Vehicle/Track System Interface Committee and the train operating companies/vehicle maintainers who supplied data to the project are acknowledged for their support during the research work.

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Appendix: Wheel Damage Questionnaire

Wheel Damage Questionnaire: Project T963

Please complete a column of data in the table for each class of vehicle you maintain. Some answer options are suggested – if one or more of these are applicable please write in the initial letter.

If damage types or maintenance practices differ between wheelset types (e.g. motor, trailer, leading axles), please indicate data for each type where possible. Please continue on a separate sheet if necessary.

Vehicle Class:						
Operator:						
Maintainer:						
Location:						
Wheel Profile:						
Wheel Material:						
Route Type:	Intercity, Commuter, Regional					
Brake Types Used:	Tread, Disc, RHeostatic, REgenerative, Hydrodynamic					
Sander Type:	Manual, Automatic, 1-shot, None					
Flange Lube:	STick / SPray / None					
Turning Policy:	Mileage-Based, Condition-Based, Other (specify)					
Typical wheelset mileage between turning:						
Typical loss of diameter through wear *between turnings* (Φ mm):						
Typical diameter removed on the lathe *at each turning* (Φ mm):						
Roughly, what percentage of wheels are turned for these reasons:	Mileage					
	RCF Cavities Shelling					
	Flats					
	High Flange					
	Thin Flange					
	Parity					
	Other______________					

Is wheel turning and renewal scheduling heavily influenced by other maintenance schedules (e.g. bogie/bearing overhaul, access to lathe etc) or is it usually independent? ____

Condition Monitoring: which of the following do you use routinely [R], or occasionally [O]:

Visual [ ], Roundchex [ ], Wheelchex [ ], Gotcha [ ], TreadView [ ], MiniProf [ ], Gauges [ ],
Other [ ] (specify) _____________________________________

Are wheelsets usually turned on an under-floor wheel lathe? [Y/N] ________

Do you experience more damage on smaller wheels? [Y/N] __________

Do you experience more damage on leading wheelsets? [Y/N] __________

Do you have an existing guide to wheel damage terminology and actions - Please could we have a copy?

Do you have any photographs of tread damage on your fleet - Please could we have copies?

Who should we contact to discuss this data or get further information?

Name: ____________________ Phone: ____________________ Email: _________________________________

Thank you very much for your time. Please return the completed questionnaire to:

Feel free to get in touch with either of us if you have any questions.