DIFFICULTIES IN DETERMINING APPLICATION QUANTITIES FOR RAIL AND WHEEL FLANGE LUBRICATION

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ABSTRACT

The paper discusses the effect of over-heated wheels on attempts to scientifically quantify lubricant consumption by using the coefficient of friction between rail and wheel flange. The economic implications of rail and wheel flange lubrication are also briefly discussed

In an attempt to quantify the skin temperatures generated due to friction in the rail-wheel flange interface, track tests were conducted. The temperatures induced in the rail wear face by passing wheels were measured, as well as the spread of the heat through the rail profile. Unforeseen results pointed to a source of heat, not related to friction, induced into the rail by the passing wheels.

Results of temperature measurements on more than a million wheels were analysed and are presented. The effects of the over-heated wheels on the consumption of lubricants are discussed.

1 A BRIEF HISTORY OF RAIL

As far as we know, the first railways were constructed in Europe. Sebastian Münster illustrated a railroad used in mines at Leberthal, Alsace, on the French-German border, in “Cosmographioe Universalis” in 1550. A mining wagon with flanged wooden wheels and track was used in gold mines in northwestern Transylvania in the mid 16th century and is exhibited in the “Verkehrs und Bau Museum” in Berlin, Germany (Britannica Vol 15 p 478).

The development of railways was a key element in the success of the industrial revolution by providing economical, dependable, high-volume land transportation. The technological advancement of both the locomotive and the rail has formed the basis of the expansion of mainline railway systems since 1830 (Bailey 2005, p 142).

Railway operations are restricted due to trains being limited to running on rail only. Therefore rail transport is not as versatile as road transport, needing complex operating and signalling arrangements for safe crossings and elaborate safe braking and following distances. Rail, however, is ideally suited for the transportation of bulk commodities, like coal or ore, over long distances from a single point of origin to a single point of delivery.

The side of the rail crown is worn by the wheel flanges as the railway wagons are steered through curves. Lateral and centrifugal forces of between 20 and 50 kN are commonly measured in this area due to the steering action, depending on degree of curvature and train speed (Von Gericke, 1984).

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2 RAIL AND WHEEL FLANGE WEAR AND LUBRICATION

Contrary to popular belief, railway rails have a limited life span and the life of rail is determined by fatigue and wear. While all railway vehicles are steered through curves by their wheel flanges, severe metal to metal contact and "scouring" occur in the steering interface, resulting in heavy wear in these contact areas between the wheel flange and the side of the crown of the rail (Fig 1).

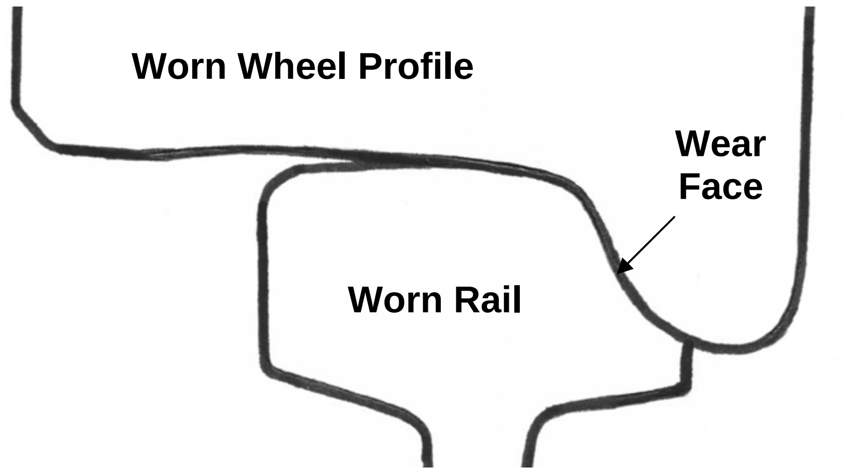

Fig 1. Worn wheel to worn rail contact in a curve: where the wear takes place.

If this wear is not addressed, the rail and wheel flanges are both worn away aggressively and prematurely, costing large amounts of money in maintenance and replacement. However, if the interface is lubricated, dramatic savings are achieved.

Since rail lubrication greatly reduces the side wear on the gauge side of curves on railway track, the reduction of side wear on rails has been measured and quantified. In 1979, the Association of American Railroads started a scientific rail lubrication test program at the "Facility for Accelerated Service Testing" (FAST). Comparing un-lubricated (dry) against very well lubricated rail, reduction in wear of as much as 7800% (78X) has been measured (Reiff, June 1986).

Recent in-service experience and measurements on Transnet track suggest that the wear induced in one month of poor or no lubrication on sharp curves (radius less than 300 m) is equal to the wear produced during sixty months (five years) of good lubrication. For medium radius curves between 300 and 800 m radius, the figure gradually reduces to 30 times as the radii of the curves decrease.

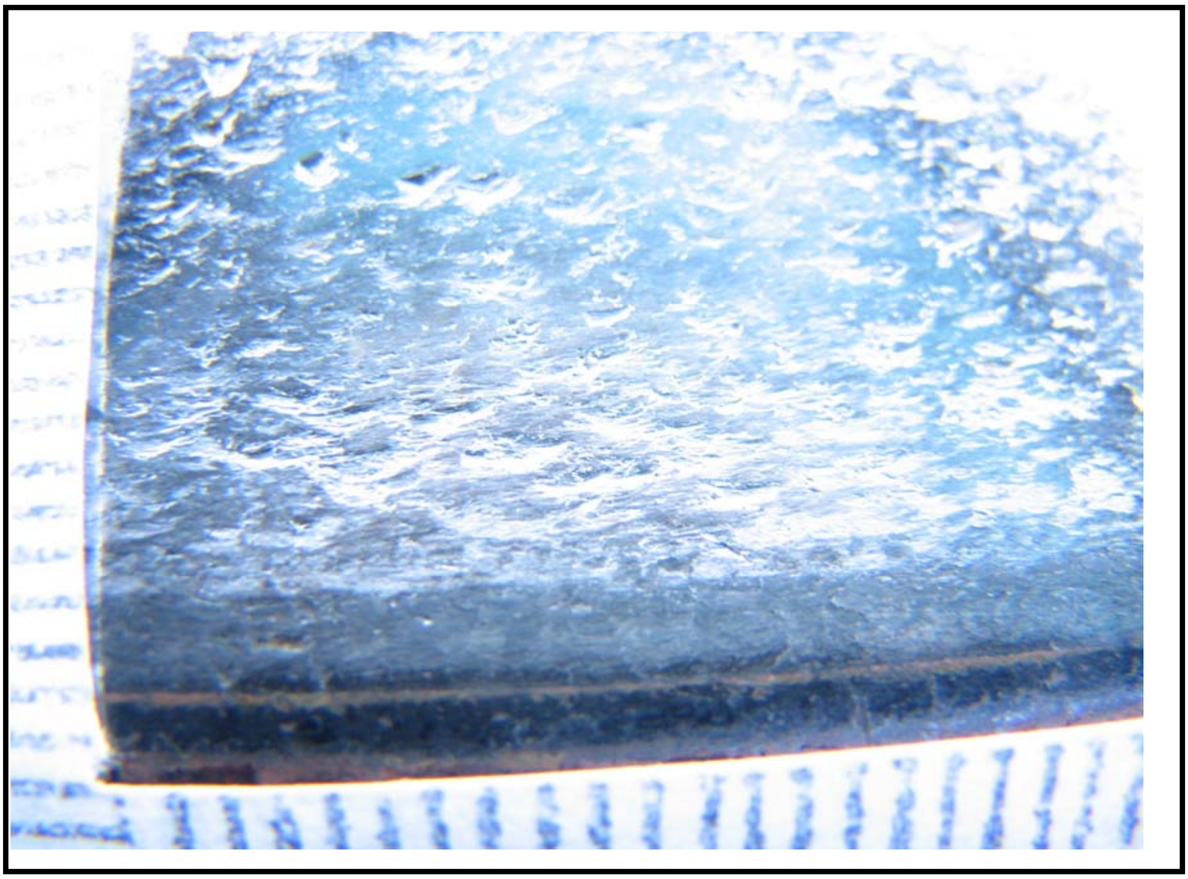

Fig 2. A close-up photograph of side wear on an un-lubricated rail. Note the scouring marks left by passing wheel flanges. The measurement markings at the side and bottom are 1 mm apart.

It is accepted that the fatigue life of standard 280 to 290 HB hardness rail on South African railway tangent track is about 800 MGT (Million Gross Tons). This figure is also accepted for curves with a radius larger than 800 metres. However, the wear life on curves between 300 and 800 m radius is accepted to be only around 350 MGT under local conditions, due to side wear. The wear life of curves of less than 300 m radius is accepted, also due to severe side wear, to be only 150 MGT. Without rail lubrication, the rail life would be between 13 and 27 MGT. This figure is substantiated by actual experience during the early days of the Richards Bay Coal Line, around 1977.

The effect of lubrication can be improved by well managed maintenance of the lubrication equipment and process. It is estimated that good management of the lubrication process could increase the expected wear life of rails on sharp curves below 300 m radius from 150 to 200 MGT (30%) and rails on 300 to 800 m radius (medium) curves from 350 to 400 MGT (14.3%). A railway system similar to Transnet is calculated to be able to thereby annually save 22 000 metres of rail on sharp curves and 34 000 metres of rail on medium curves, a total of 56 000 metres of rail by this moderate increase in wear life. At a cost of R15 000 / ton and an additional R110 / m installation cost, this saving comes to R 56.6 million / annum.

3 LUBRICATION OF RAIL

Little mention was made of wheel and rail wear on early railways, mostly because axle loads and speed were relatively low. However, as heavier locomotives were introduced and loading and speed increased, the rail-wheel flange wear problem grew exponentially. The wear rate of wheel flanges and rail crown increases as the radius of the curve decreases and speed or axle load increases. The sharper the curves and the more rigid the vehicles, the more side wear will take place on the contact surfaces at the head of the rail in the curve (Borup and Åström, 1981).

Most wear situations known to tribologists have the same surfaces in contact in a repeated sequence and a reservoir of lubricant surrounding it. The wheel and rail situation, however, has different wheels passing any specific point on the rail, making it difficult to keep the wheel-rail interface lubricated since there is no reservoir of lubricant from where the lubrication process is constantly replenished. The rail is out in the open, subject to extreme weather and temperature conditions like frost, snow, heat, dust, dirt and rain. Apart from these factors, a number of additional traffic and track factors influence the consumption of lubricant in this interface, like curve length and radius, track gauge and super-elevation, train speed and axle load, as well as wheel and rail profile, to mention but a few. To have efficient lubrication, the lubricant has to be replenished at regular intervals, or enough lubricant has to be applied to enable a reservoir layer to build up on the rail.

On railway systems internationally, locomotive-mounted lubrication systems, purpose-built lubrication wagons, trackside systems, as well as dedicated road-rail (or hi-rail) lubrication vehicles are used to apply lubricant to combat rail and wheel flange wear. Trackside lubrication used to be the only rail-wheel lubrication system practised locally by Transnet until the end of 2002, although a number of other systems had been evaluated over many years and were found to be unsuitable for local conditions.

No reliable and practical method to quantify grease consumption quantities is described in international scientific literature. Lubricant quantities are usually determined by applying grease until a sufficient coating can be maintained by railway maintenance staff.

4 MEASUREMENT OF RAIL TEMPERATURE

In an attempt to quantify the amount of grease to be applied to the rail on a once-a-day basis by hi-rail lubrication on the Richards Bay Coal Export Line, all aspects that influence grease consumption were reviewed critically. Earlier research into grease spread was revisited with the aim to ascertain if the theories applied for spacing of trackside lubrication machines could be applied to application by hi-rail vehicle.

After much consultation, it was decided to measure the temperature in the rail-wheel interface as close to the surface as possible. It was reasoned that the rise in temperature in the rail wear face induced by a passing train should be equitable to the coefficient of friction measured on this face, and that this figure should in some way correspond to the quantity of grease consumed. A very small thermocouple was glued into a shallow groove filed into the high rail gauge face of the rail on a curve as close to the rail-wheel interface as possible. The aim was to measure the rise of temperature during the passage of a two hundred truck coal train. The lateral forces exerted by each passing wheel were also measured.

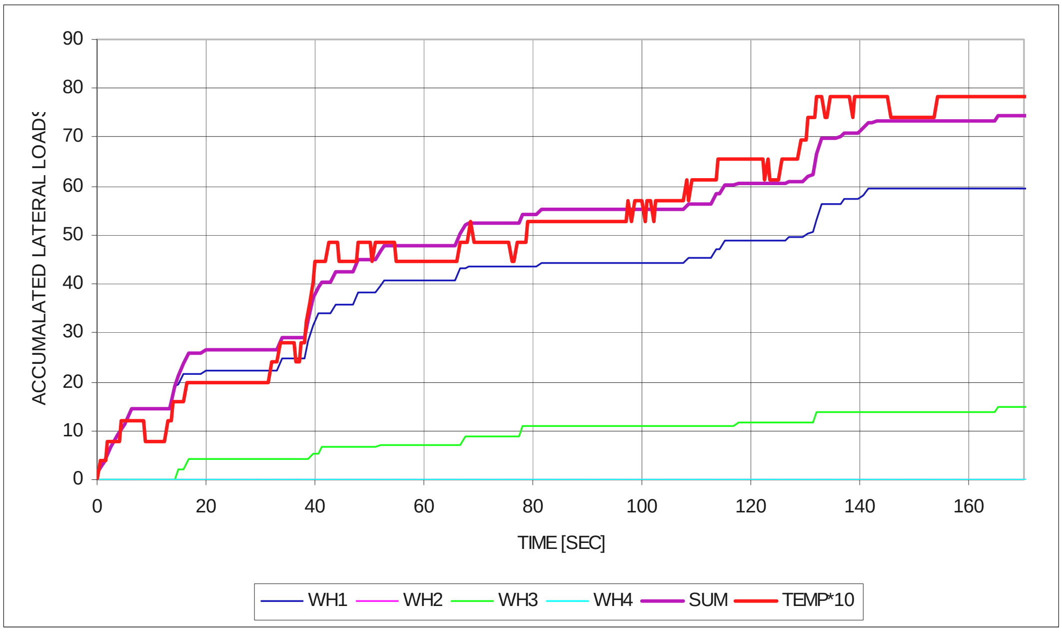

Fig 3. Results of a test measuring the temperature rise in the rail and the lateral forces exerted by the wheels under a 200 truck coal export train travelling at 52 km/h, shown graphically.

A good correlation was found between the lateral forces exerted by the passing train and the rise in temperature in the rail. On average, about 8º to 10º Centigrade rise in temperature was recorded for a passing two hundred truck coal train at about 50 to 55 km/h. An example of one of the tests is presented in graph form herewith. The cumulative lateral force exerted by wheel 1 and wheel 3 seemed to give a good correlation to the cumulative rise in temperature in the rail when plotted to axis.

The coefficient of friction (COF = μ) was also measured since it was planned to correlate the results with this factor. No meaningful relationship was found and it was ascribed to the fact that, although lubrication was stopped for a number of days on the section 20 km before the train would reach the test site, the rail could not be worn clear of lubricant due to contamination by unusual deviation of “up” trains onto the “down” line. The temperature rise under “dry” un-lubricated conditions could therefore not be measured. Since the 8º to 10ºC temperature rise was unexpectedly high under conditions of μ=0.2 to 0.36, it was surmised that a much higher temperature could be expected when the rail is dry and μ= 0.55.

It was reasoned that if the temperature rise under COF value μ = 0.25 was 10°C it could be expected that the rise under μ = 0.55 would be around 20º. If this was the case, it would have serious consequences for the continuous welding of rail on that line, since this welding is done under very strictly controlled conditions and within a tight temperature envelope.

5 MORE IN-TRACK TEMPERATURE MEASUREMENTS: THE SECOND TEST SERIES

Because of this concern, it was decided that a second series of tests would be done. It was the specific aim to measure the temperature rise under various conditions of lubrication, including dry, un-lubricated conditions, and to simultaneously measure the spread of the friction-induced heat throughout the rail. It was arranged that the track would not be lubricated so that the approaching trains would traverse a distance of 60 km on un-lubricated track before reaching the evaluation site. The same site was used for the first and second tests, on a 604 m radius curve at kilometre 59/9 between Vryheid and Ulundi on the coal export line (Frohling, De Koker and Amade, 2009).

Fig 4. A view of the test site showing the positions of the thermo-couples to measure the spread of heat in the rail profile, and strain gauges to measure forces exerted by the passing train wheels.

The measurements listed here were recorded:

- The vertical and lateral forces and loads were determined by measuring the shear strain in the rail by strain gauges applied at the neutral axis of the rail.
- The temperature measurements were done by temperature probes (thermo-couples) attached to the rail surface, and on contact surfaces glued in grooves cut in the running surface and gauge face of the high leg rail.
- One thermo-couple was stuck in a groove cut into the running surface of both the high leg and low leg rails of the track.
- A hand-operated tribometer manufactured by Salient Systems was used to measure the coefficient of friction on the side wear surface of the rail.
- Ambient temperature and train speed were recorded.
- Traffic data was sourced from the central traffic control office at Vryheid.

From the results of this series of tests, it was seen that the running surface of the low leg rail was heating up to unexpected high temperatures, roughly around 80% and more of that of the surface temperature measured on the high leg rail. This was unexpected since lateral forces and friction did not induce high temperatures on the low leg rail.

These results can be seen comparing the plot for probe 3 and probe 12, both in red in Figure 5. The logical deduction from this therefore is, although friction, speed and lateral forces might contribute to the temperature rise in the high leg rail, the low leg also is heated by a source of heat not related to friction, speed or lateral force. Further investigation and measurement proved that the wheels running on both the rails were hot and therefore induced heat into the rails.

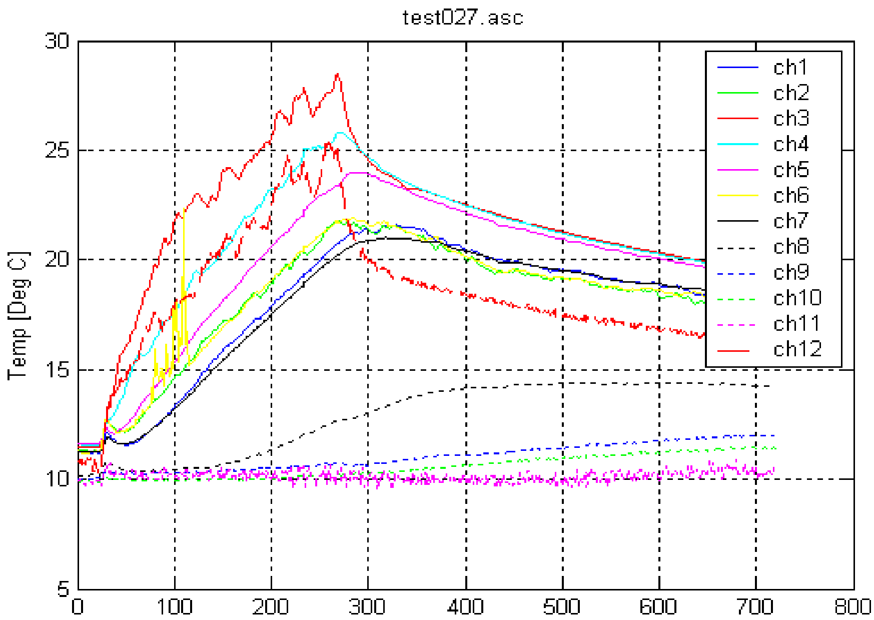

Fig 5. Temperature measurements against time showing the rise in temperature and the spread of heat in the rail due to, and after the passing, of a 200 truck coal train.

6 THE SOURCE OF HEAT IN THE PASSING WHEELS

Two factors would usually cause the wheels on railway wagons to overheat. The one instance would be when the bearing on which the axle runs, malfunctions and overheats, and the second would be when the friction brakes that are applied to the wheel treads, malfunction and do not release. Both these cases of malfunction can cause serious damage and, in extreme cases of overheating, derailment of the train. For this reason, Transnet has installed temperature sensors along the track. These devices measure the temperature of the passing train wheels and it is recorded by the ancillary equipment. The sensors can be aimed to measure either the temperature at the periphery or tire of the wheel or alternatively at the centre bearing area.

The temperatures for the wheels of about 1 500 trains that passed the brake temperature sensor situated at Intshamanzi near Vryheid between February and May 2008 were analysed, and it was found that 64% of the wheels were running at temperatures between 130ºC and 190ºC. This explained why the rail heated up without application of lateral forces or friction between wheel flange and rail. The temperature distribution is shown in Figure 6 below.

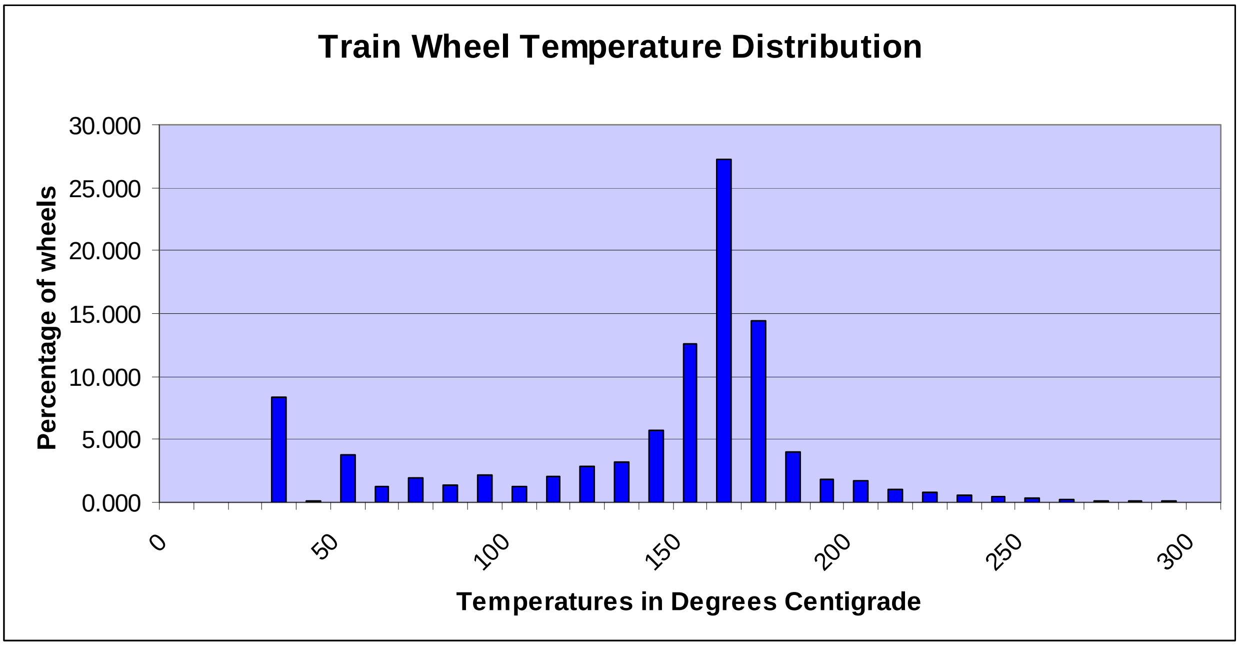

Fig 6. Temperature distribution on 1.2 million wheels on the Richardsbay Coal Line.

About 2% of the wheels were running at above 225ºC which is the flashpoint of the grease used for lubricating the rail. Extreme temperature evaporates the oil out of the grease soap base and damages the lubrication properties of the grease, in some cases actually burning the oil in the grease. This accelerates the need to replenish the grease on the rail, resulting in an abnormally high usage of grease to lubricate the line effectively.

7 CONCLUSION

Due to the fact that extreme temperatures in wheels occur in haphazard fashion, it nullifies efforts to quantify the grease consumption based on coefficient of friction or lateral forces measured on the rail.

Prescribing quantities for grease application in the rail-wheel interface is generally considered to be a matter of trial and error, with subjective guidelines and personal “feel” and experience being the dominant prescriptors. Adding to this is the phenomenon of hot wheels burning off the newly applied grease. Further complicating factors are the difficulty to measure the coefficient of friction with real accuracy on the rail over the vast distances involved, as well as the different characteristics of various greases. Accurate, scientific determination of grease application guidelines therefore becomes virtually impossible.

8 FUTURE DEVELOPMENTS

Factors used to determine the distance between trackside rail lubricators, like length and degree of curvature, train speed and axle load, cannot be used for determination of frequency and quantity of application for on-board or “Hi-Rail” applicators. The application cycle has to fit in with the train schedule. The application quantity is controlled by intermittent application as the applicator traverses through the curve and limited by the tendency of the grease to creep onto the running surface of the rail. .

A less scientific guideline is presently being considered where a number of factors could be incorporated, each being assigned an indicator rather than an exact measurement. The factors involved should include, inter alia, the radius of curvature on the line, the axle load and speed, the type of bogie, and the type of grease. Furthermore, rail-wheel profile fit, track geometry and condition of rolling stock each plays a large role, but these factors are extremely difficult to quantify and are even more difficult to measure in practice. Ways are sought to quantify and incorporate these factors.

It is hoped that some useful guideline will see the light soon.

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