Management of Rolling Contact Fatigue (RCF) in the UK Rail system: 
A systems solution

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Abstract
For the last 5 years, the UK railway industry has conducted an inter-agency program of research and development focused upon RCF initiation and propagation. The purpose of this enterprise is to identify and manage key system variables in order to reduce RCF levels, thereby allowing safe and economically viable operations.

The initial efforts concentrated upon site specific investigations in order to isolate key variables and to consolidate findings into a general RCF Initiation Hypothesis. Recently, efforts have shifted toward parametric studies wherein key variables are varied in order to quantify the influence each plays in RCF formation and to propose Sustainable Operational Limits (SOLs) that are intended to allow tuning of the system as a whole to reduce damage, prolong asset life and insure long term viability of the system.

At present, the major factors that contribute to both rail and wheel RCF have been isolated and there interaction and SOL values are becoming clear. Trials to evaluate specific ant-RCF operational changes are in their nascent stages. Several new fleet introduction processes are taking recent findings into account. In general, the focus of the anti-RCF effort is shifting from basic inquiry into cost/benefit analysis and the production of tools and methodologies for system level management of the key factors.

1.0 Introduction
RCF in the UK rail system has been documented as far back as 1970 at which time it was relatively rare and not a major cause of rail failure. In retrospect, some rail breaks that were classified as “tache ovale” were most likely RCF breaks since many were found in the high rail of curves where recent findings predict the highest RCF probability.

However, the incidence of RCF increased with time leading Railtrack, the duty holder for railway infrastructure after the 1994 privatization, to increase its inspections and research into RCF, particularly in 1999. In 2000, a RCF rail break at Hatfield on the East Coast Main Line (ECML) led to loss of life and the launching of a major R&D effort that concentrated on the nature and means of managing RCF and that led to the conclusions in this paper.

2.0 Methods
2.1 Project Management and Control
In 2000, the major RCF inquiries were funded and managed by either Railtrack or by the Railway System and Standards Board (RSSB). Initial efforts included both site specific investigations as well as studies to generate prediction algorithms.

In 2002, the Wheel Rail Interface System Authority (WRISA) was chartered to consolidate efforts and to manage the overall UK RCF effort in behalf of the industry stakeholders. Its board was composed of representatives of the major stakeholders who provided the bulk of funds. WRISA launched many studies itself and acted as a coordinator and clearing house for the results of inquiries funded by other agencies. In general, the WRISA field and the RSSB analytical studies were conducted in parallel and lead to, amongst other things, the first RCF General Hypothesis and the Whole Life Rail Model (WLRM) that have formed the basis for the present level of understanding.

WRISA was replaced in 2004 by the Vehicle Track Systems Interface Committee (VT-SIC), one of seven industry wide interface committees which are intended to foster system level optimization by identifying
key interface issues and evolving strategies and tactics to reduce maintenance costs and increase safety, system performance and asset life.

VT-SIC differs from the other committees in that it has a Permanent Project Team (PPG) that promotes the generation of new projects, conducts limited studies on its own and fosters communication throughout the industry. Expert advice to the VT-SIC board is also available from the Technical Advisory Group (TAG) composed of senior technical staff from the supply industry. VT-SIC funding is primarily composed of in-kind contributions from the stakeholders or from RSSB research budgets. Projects funded and executed by individual stakeholders are often reported to VT-SIC and results integrated into the overall RCF effort.

2.2 Site Specific Investigations and WLRM development

Of the various studies conducted by WRISA, the “Great Western RCF Pilot Study” and the “C2C RCF Study” were instrumental in formulating a preliminary list of key RCF initiation factors. In both cases, field observations of the actual RCF conditions (crack surface length, position and orientation) were matched to theoretical predictions produced from established vehicle dynamics simulators, usually Vampire™, the most widely used product in the UK.

The results from the vehicle simulator were used as input to Shakedown Diagrams, a method of predicting surface cracks that uses contact pressure (Po) and the shear force coefficient (contact plane forces normalized by normal load) to predict when conditions were prone to allow crack initiation. This method was successful in predicting the existence of RCF and served as the first technique to isolate key factors and to quantify their interaction.

Detailed analysis of cracked rail profiles did show that significant wear and RCF cracks were often both present. This observation led to the conclusion that a wear function, estimated to increase with the level of force, competed with crack formation. Since Shakedown did not directly predict wear, a function was assumed as depicted in Figure 1.

Simultaneously, the RSSB funded WLRM was pursuing a methodology that could account for the various stages of crack growth from the early surface initiation, the intermediate “shallow growth” phase and the final vertical growth that is present in broken rails. An important early outcome of this method was the evolution of a crack initiation algorithm that was based upon the concept of Contact Patch Energy i.e. both RCF and wear were functions of Energy (T-Gamma or T-γ), each having a distinct threshold value and rate of accumulation, as shown in Figure 2.

Although both the Shakedown and WLRM approaches are capable of predicting the existence of rail RCF, the latter has proven to be the most accurate and useful method, since it directly accounts for both RCF and wear, has an unambiguous numeric output and its Damage Index is relatable to fatigue life. Therefore the results presented in this paper are based upon WLRM analysis.
2.3 The RCF Hypothesis and RCF initiation modes

As a result of the early site investigations and the evolution of the successful use of both Shakedown and WLRM-based crack predictions, a general RCF Initiation Hypothesis was formulated to describe the circumstances that lead to RCF in the UK system. The hypothesis was always envisioned as a working document, intended to focus debate, isolate key factors, evolve with new findings and aid in defining future work streams. It has served these purposes.

The hypothesis identified excess contact patch shear forces as the primary cause of RCF initiation. Although contact patch pressure could rise under some crack-prone circumstances, both Shakedown and WLRM-based analysis demonstrated that high shear force levels were the dominant factor during crack formation. These high force levels were a result of excess Rolling Radius Difference (RRD) and Angle-of-Attack (AOA), both attributes of wheelsets as they negotiate curves or track geometric anomalies.

The hypotheses proposed that RCF initiation could be placed in three modes that lead to crack formation and that lent themselves to different remediation tactics. Figure 3 depicts the modes in terms of the operating point of the wheel/rail relative to the Shakedown Limit. In each mode, the steady-state condition is depicted as the large oval on the Shakedown diagram and transient states by the smaller excursions across the Shakedown Limit.

Although excessive shear forces (or $T-\gamma$) are the prime reasons for RCF initiation in all three modes, the operating conditions are quite distinct:
• During Mode 0 RCF initiation, the combination of curve radius and bogey Primary Yaw Stiffness (PYS) is sufficient to create a steady state condition over the Shakedown Limit resulting in persistent cracks throughout the body of the curve.

• Mode 1 initiation occurs when the wheel/rail contact conditions are consistently near the Shakedown limit and small variations, even changes in rail profile at welds, cause sudden short lived excursions across the limit. In some cases, consistent oscillations in the contact position have been observed.

• Mode 2 initiation occurs when normal non-RCF wheel/rail contact that is distant from the Shakedown Limit is driven by combinations of track geometric variations and vehicle steering responses to cause occasional excursions across the limit. The rail and wheel, from the interface point of view, are seen to “converge”, usually in response to 20-25m lateral alignment or gauge changes. This mode dominates shallow curve and Switch and Crossing (S&C) RCF.

In all Modes, PYS is a major contributing factor because it dictates the level of force required to deflect the axles relative to the bogey body so that they remain perpendicular to the running rail while curving. This orientation means that the axles must move from parallel and assume an angle proportional to the degree of curvature. As the curvature or PYS rise, so do the forces and contact patch energies, resulting in an increase in RCF initiation.

Discussions held amongst the industry stakeholders have resulted in recognition of PYS as a key RCF initiation factor, but not as a system design parameter to reduce the probability of RCF. Instead, $T-\gamma$ itself has been generally accepted as a design guideline with some new fleet specifications including limits, usually depicted as a function of curvature.

The early RCF studies also identified the complex interaction between key factors that lead to non-linear RCF probabilities. Figure 4 shows the interaction between two key factors – track irregularity and wheel conicity - and demonstrates the need for parametric studies rather than analysis based upon a single key variable.

Figure 4: Interaction of track quality and wheel condition leading to various levels of RCF
3.0 Parametric studies and the clarification of key variable interaction

3.1 The use of a Generic Passenger Vehicle model

Many of the early RCF modelling exercises were conducted with precise vehicle models and focused on specific RCF track sites. Although this method is essential to validate the general approach, isolate key variables and generate RCF prediction algorithms, it does not lend itself to broad parametric studies intended to clarify key factor limits in a universal sense. VT-SIC therefore promoted the generation of a ‘generic model’ that is intended to represent the wheel/rail interaction of typical UK H-frame passenger stock.

The development of the generic model was done in stages and included blind study comparison of generic to vehicle specific model outputs. Results indicated that contact patch variables including creep forces and T-γ were sufficiently close to represent the range of PYS and vehicle masses common in the UK system. The generic model is not presently used to study broader issues such as ride quality or car body clearance. Figure 5 depicts the WLRM Damage Index values for a PYS range that encompasses the most soft to the stiffest found in the UK system.

![Figure 5: WLRM Damage Indexes for a range of PYS simulated at a cant equilibrium condition](image)

Figure 5 indicates a general finding: all bogies have a curvature where they have a maximum probability of generating RCF. As the PYS increases, the maximum damage curvature moves from sharp to shallow curves and the breadth of curvature affected becomes wider, implying a greater system RCF risk. Particular bogey designs range from low to high RCF risk:

- The damage curve labelled “old slam door” is indicative of the recently retired MKI & MKII rolling stock that generally did not create RCF until its low conicity wheels became heavily worn.
- The “MK3 coach” curve describes the moderate RCF potential of the current HST fleet coaches in use on several UK main lines. These 125mph vehicles are approaching the end of their life expectancy but do represent a relatively high speed bogey design with a very reasonable PYS and resulting RCF damage profile.
- The “MK4 coach” curve does represent a high speed coach in use on the East Coast Main Line (ECML) and is also indicative of several new 125mph trains that have recently entered UK service.

In general, PYS in the UK passenger fleet is increasing. As operational speeds have increased, PYS has risen to ensure high speed vehicle stability. But some bogies have PYS values higher than stability requires. A variety of reasons exist for these high levels such as the longevity of stiff bushings. In any case, the trend partly explains the increase in both wheel and rail RCF that has occurred in the UK system in the last decade.
3.2 The anti-RCF effect of high Cant Deficiency

Studies have shown that generally all combinations of installed cant and operating speed that yield the same cant deficiency will in fact produce the same contact patch forces and energies. Generic model RCF studies therefore explore the effects of cant deficiency without documentation of the specific cant-speed combination used. (None the less, the combinations used are realistic).

The WLRM Damage curve in Figure 5 was generated by simulating a cant equilibrium condition. Figure 6 depicts the same range of PYS and curvature but at a cant deficiency of 150mm, the practical limit for non-active tilt passenger stock in the UK. Cant deficiency causes a shift of the damage peaks from shallow to tight curvature with the most dramatic effect on high PYS bogies. This finding suggests that for shallow curves dominated by high PYS bogies, RCF risk may be minimized by increasing cant deficiency. Clearly other system attributes such as ride quality and track strength must be taken into account.

The beneficial effect of cant deficiency upon RCF initiation can be explained by the change in net lateral force between the cant equilibrium and deficiency cases. As cant deficiency increases, the net lateral force in the direction opposite the curve centre must increase to accommodate the increased centrifugal forces. Since the leading axle lateral forces are in “the wrong direction”, the trailing axle must supply the increase by shifting toward the high rail and assuming a leading AOA that produces outward lateral forces. This effectively rotates the bogey, reducing the lead axle AOA and inward lateral forces. The lead axle T-γ is thereby reduced, as is the RCF propensity.

Figure 6: WLRM Damage Indexes for the 150mm cant deficiency condition.

Figure 7: Boggy orientation at cant equilibrium and at high cant deficiency with load sharing between lead and trial axles in the latter condition
3.3 The RCF effects of weight and Cant Deficiency

The generic model was used to investigate the effects of weight on the generation of RCF.

- A base case was simulated with a nominal weight of 38 tonnes, typical for EMU stock introduced in the past decade.
- An increased weight of 47 tonnes represented the heavy condition and corresponds to some of the newer stock recently introduced in the UK.
- A vehicle of 29 tonnes was used for the light case and corresponds to the lightest of older coaching stock.

The heavier weight increased RCF initiation for high PYS vehicles, in shallow curves under low cant deficiency conditions. Figure 8 demonstrates how the RCF probability of the heavy vehicle is roughly twice that of the light vehicle at 1500m for bogies over 16MN-M/Rad PYS. This finding contributes to the explanation of the increase in RCF on those UK routes where light low PYS vehicles have been replaced recently with newer high PYS heavy vehicles.

When the same comparison was made at a cant deficiency of 80mm, the effects of weight were greatly reduced as shown in figure 9. As cant deficiency increases, the difference between light and heavy vehicles continuous to diminish. These findings reinforce the suggestion that high cant deficiency should be considered as an anti-RCF tactic.

Other studies have found that for low PYS vehicles on tight curves, increased weight has a minor beneficial effect. By comparing the Damage Index for the 12MN-m/rad case at 750m, the effect can be observed. However, at 600m, the effect is reduced. The net beneficial effect of increased weight is therefore very limited and of small consequence.
3.4 The RCF effects of Track Quality

All of the WLRM Damage Index plots presented in previous sections were formed from the average T-γ while the vehicle traversed the main body of each simulated curve. The values therefore represent “steady state curving” and do not directly reflect the influence of local track geometry variations.

From the track engineers point of view, this is not indicative of the RCF threat to the rails since track quality variations can cause localized increase in the Damage Index leading to RCF clusters well before the average RCF condition is attained. This aspect of fatigue is demonstrated in figure 10 that proposes that a curve with a fixed Damage Index profile that is examined at three successive intervals will yield three different RCF states, each more pronounced than its predecessor.

In order to interpret the effects of Track Quality variations, therefore, the generic model T-γ outputs obtained while negotiating the main body of each simulated curve were tabulated using the 95th Percentile values rather than the average. This approach indicates the probability of RCF clusters forming in an intermittent fashion.

Figure 10: Local Track Quality variations producing early clusters of RCF which with increasing MGT eventually expand in distance and severity.

Figure 11: Generic Model WLRM Damage Index output tabulated by average and by 95th percentile. The latter reflects the influence of local Track Geometry variations.

Figure 11 indicated that for nominal weight vehicles with high PYS at cant equilibrium, the effect of Track Geometry variations is very pronounced in shallow curves with the probability of cluster formation essentially uniform from curves from 1000m to 2250m. This trend has been validated by further study.
using multiple sets of Track Geometry taken from typical UK main line curves. The 95th percentile results do vary from set to set but the trends are the same.

The data set used to form Figure 11 was also used to study the effect of Cant Deficiency on Track Geometry variations. Figure 12 demonstrates how the 95th Percentile Damage Indexes are reduced as cant Deficiency increases. This finding again reinforces the notion that high Cant Deficiency curves have a reduced propensity for RCF initiation, even in the presence of track geometry variations.

Studies currently underway are exploring the role of Track Geometry variations in more detail by scaling different Track Geometry sets to match standard deviation (SD) maintenance limits used by Network Rail and tabulated in Line Standard NR/SP/TRK001 table 10. Four levels are defined for both vertical and alignment. Early results indicate that the beneficial effect of increased cant deficiency depicted in Figures 11 and 12 remains valid but only to a point: SD values approaching the 4th level, the mandatory intervention value, can not be negated by increased cant deficiency. The threshold SD values beyond which cant deficiency compensation fails to work will be determined in the near future.

These findings suggest that to decrease the probability of RCF in curves, particularly shallow curves that are dominated by heavy high PYS vehicles, track quality requires higher standards than straight track and that cant deficiency in such curves should be adjusted to the highest cant deficiency that is practical.

3.5 Anti-RCF wheel shapes

Previous studies have indicated that the lower a wheel/rail sets effective conicity in the curving configuration, the lower the propensity to initiate rail RCF. This effect is due to the lack of conformity or sameness of slope of the rail gauge-shoulder and the wheel flange-root. This dissimilarity precludes contact on the gauge-shoulder which is the most RCF prone portion of the rail.

Network Rail exploits the effect of slope mismatch by grinding the gauge-shoulder area of the high rail in curves in order to preclude contact and thereby reduce the probability of RCF. This practice effectively transforms single point gauge-shoulder/root-flange contact to 2 point contact on the top-of-rail and on the rail gauge-face as shown in Figure 13. The top-of-rail contact generates T-γ that is below the RCF damage threshold and the gauge-face T-γ is high enough to create wear, not RCF.
Network Rail Line Standard NR/SP/TRK/001 section 23.2 requires rail lubrication on any curves with a radius of 1500m or less or any curves with significant rates of sidewear. Part of the logic supporting this standard is to preserve the ground profile by negating the increased gauge-face contact that grinding produces.

Rail Grinding is a complex and obtrusive process requiring constant attention to grinding machinery and the presence of slow moving grinding trains on a high speed network. WRISA, therefore, sponsored the creation of an anti-RCF wheel shape – the WRISA2 profile – that has slightly less conicity than the present UK standard, the P8 profile. Like the existing UK RD9 profile, the WRISA2 has an area of “relief” in the flange-root that reduces gauge-shoulder contact but, unlike the RD9, has been designed to preserve its anti-RCF properties by reducing contact stresses at the edges of the relief area.

Studies just completed have shown that the anti-RCF properties of the WRISA2 are likely to last in UK operations for about 60kmiles before the shape reverts to a worn P8 profile. (This does not imply that wheel turning is needed at this point since the worn P8 shape will be well within current standards). Since the anti-RCF properties are not likely to last the entire interval until wheel turning is necessary, the WRISA2 lends itself to a “light and frequent” wheel turning regime that is used by some fleet operators in the UK.
3.6 Combining anti-RCF tactics: the Ideal Reduced RCF State

In previous sections, the RCF potential of PYS, vehicle weight, track geometry, cant deficiency and wheel/rail profiles have been explored. The PPG has conducted a limited study of combining these effects and has produced an "Ideal Reduced RCF State" that is a product of:

- Weight reduced to 32 tonnes
- Cant deficiency of 150mm
- Use of the WRISA2 anti-RCF wheel shape

Figure 15 shows that in the steady state case (use of the average $T_\gamma$ not the 95th percentile), the propensity to produce RCF above 1000m is essentially eliminated. This result is based upon the same generic model that produced the results in earlier sections of this report but has been verified by use of vehicle specific models that produce essentially the same results.

The Ideal Reduced RCF State demonstrates that if several system parameters are each adjusted into the anti-RCF portions of their operational range, then in principle the RCF propensity of the system can be greatly reduced from current levels. This is a hypothetical finding and the challenge to industry is to determine to what extent weight, cant deficiency and wheel conicity can be adjusted in actual practice:

- Of the 3 parameters that were varied, weight represents the largest challenge as trends in UK passenger stock are toward heavier not lighter vehicles.
- At this time, cant deficiency design limits exist but actual site specific design values are subject to variation and engineering discretion
- The WRISA2 wheel profile will begin trials in the near future. Some operators are also investigating the use of the existing RD9 profile as well.

Figure 15 and the interplay of cant deficiency and track quality reported in section 3.4 of this report both indicate that a review of current track geometry standards for curves as well as cant deficiency design practice should be conducted to explore the practical implications to both track and rolling stock.

PPG has defined a remit to explore the implication of higher levels of cant deficiency on ride quality as many current passenger bogies are likely to ride against the lateral bump stops leading to reduced passenger comfort. Higher cant deficiency is not likely to lead to higher flange or gauge face wear as the leading axle generally moves away from the high rail as explained in section 3.2 of this report.
4.0 Anti-RCF tactics

4.1 Present Tactics
At present, RCF suppression tactics in the UK have several main components:

- **Rail Grinding** is used to reduce gauge shoulder contact on RCF prone curves and S&C as described in section 3.5 of this report. Network Rail has invested heavily in large 64 stone grinding trains that focus on main lines as well as several smaller machines that grind short segments and S&C.
- **Ultra-sonic inspection capabilities** have been enhanced across the network so that incipient cracks that are growing under the gauge shoulder area may be detected in their early growth stages. Inspection schedules are coupled to surface crack length and are intended to reduce the incidents of sudden unscheduled rail replacement and to allow for long term planning of rail renewal.
- **Increased training** of area track engineers has focused upon identifying track geometric “RCF Triggers” such as 20m mid-cord offsets that can lead to RCF cluster formation. In general, track quality has improved in the last several years and, along with grinding and increased inspections, has contributes to a major reduction in RCF rail breaks.

In spite of these efforts, total network RCF costs remain substantial since grinding and inspections are intrusive and require special equipment and skills. Wheel RCF costs are also significant to some operators. In the long run, tactics are needed to reduce the likely-hood of RCF initiation in the first place.

4.2 Future tactics and tools
Control tactics such as ultra-sonic inspections are fundamental to RCF management but do not reduce or eliminate the circumstances that lead to critical T-γ levels. Grinding does directly influence T-γ by manipulating contact patch locations, but it requires repeated intervention since rail wear reduces its effectiveness. Future tactics, on the other hand, will concentrate on directly managing the key factors leading to high T-γ in the first place.

- **The Simplified Whole Life Rail Model (SWLRM):** This evolving software package creates an estimate of RCF risk on a route for the fleet that runs upon it. The SWLRM uses tables of T-γ similar to the plots in this report to create average energy levels and resultant WLRM Damage Index for individual curves and for routes as a whole. It is intended to:
  - Assess the RCF risk of present or envisioned fleets by matching fleet T-γ characteristics to route curvature and cant deficiency.
  - To prioritize all curves on a route by their RCF risk as a function of the fleet composition at each curve.
  - Produce an aggregate wheel RCF risk for the different fleet components and to identify which curves pose the highest wheel RCF risk.

- **Track-Ex software:** This software package is both a test bed for algorithms that identify RCF prone track locations as well as a prototype tool for RCF risk assessment by track engineers. At present, great reliance is placed upon 1/8th mile SD reports that often do not highlight the local track features that increase RCF risk. Track-Ex will:
  - Produce 20m mid cord track quality reports for straight and curved track segments
  - Curve RCF risk reports
  - S&C risk reports
  - SWLRM damage estimates
  - Custom plots of specific site track geometry
  - Other damage reports such as bridge dynamic load estimates

- **Advance RCF Sensors:** At present, an Instrumented Torque Axle is under trial that is intended to identify track locations of sudden changes in longitudinal steering forces that are often associated with RCF clusters. If successful, the device will also be examined to see if can assess S&C track quality and to identify straight track sites likely to induce excess vehicle hunting.
• Cant deficiency adjustments: Significant engineering discretion is available to track engineers in the selection of cant deficiency. Trials will be conducted at selected sites to increase cant deficiency but remain within current design upper and lower limits. If RCF reduction is significant, other performance factors are tolerable (such as ride quality) and the cost/benefits are favourable, new design guidelines will be considered.

• Curve Specific Track Quality standards: Studies focused upon the role of Track Quality on RCF initiation in curves will be extended to determine draft RCF specific intervention levels. Once verified by trials, the creation of Curve Specific Track Quality standards will be subject to cost/benefit analysis and, if favourable, be considered for application.

• Alternative Metallurgy: Resistance to crack initiation increases with metal hardness. Recent Network Rail rail procurement contracts call for an increase from 220 to 260, the European standard. In addition, trials of MHH premium rails in selected RCF and wear prone curves will commence this year. Recent cost/benefit analysis has shown that site specific rather than universal use of premium rails is financially practical.

• Use of anti-RCF wheel profiles: The WRISA2 profile will soon be undergoing field trials and, once certified for general use, efforts will be made to place it in service, especially in fleet operations that utilize “light & frequent” wheel turning tactics.

• Modified PYS vehicles: Attempts to match bogie curving performance to intended routes will address both new and existing fleets. (T-\(\gamma\) will likely remain the control parameter rather than PYS itself):
  o New fleets will be specified so that their PYS values are suitable for stable operations at line speed but that are otherwise tuned to the intended route to minimize wheel and rail RCF probability.
  o Existing fleets will be reviewed to see if reductions in PYS are technically and financially viable.

• VTSIC will cooperate with other interface committees who are investigating vehicle weight. Since weight affects other damage modes as well as energy consumption, the present trend for heavier vehicles requires a system level review and the tradeoffs between weight and other system performance indexes clearly understood.

5.0 Conclusions
The early RCF research efforts conducted in the UK were successful in identifying methods of predicting RCF as well as isolating most of the key factors that contribute to crack initiation. Recently, the parametric studies have created greater insight into the interaction of the factors and have pointed out that the wheel/rail system must be “tuned” in order to reduce maintenance and prolong asset life. Bogie characteristics, track cant deficiency, wheel and rail shapes, track quality and vehicle weight all interact to create the circumstances prone to RCF. To achieve a sustainable and cost/effective reduction in RCF, they must be adjusted in concert, not in isolation.
As the technical issues become clear, the need for cost/benefit analysis increases. At present, RCF trials have already identified how expenditures by one stakeholder create significant benefit for others. The need, therefore, for universal understanding of the technical and financial issues is becoming increasingly clear as is the need for a straightforward means to balance cost and benefit amongst the different stakeholders.

WRISA had proposed that the industry adopt the concept of Sustainable Operational Limits (SOLs) that would constrain system key variables to a domain within safety limits and would allow for increased system performance in a financially viable manner. Figure 16 depicts the concept for 2 key factors that could represent bogy PYS and track quality that could only be “tuned” with the cooperation of different stakeholders.

The concept of SOLs remains valid and can be used to assess the costs and benefits to move the system from its present RCF state to an optimal system configuration: the Ideal Reduced RCF State. The technical issues are clear. It is now a matter of getting down to business.

6.0 References
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