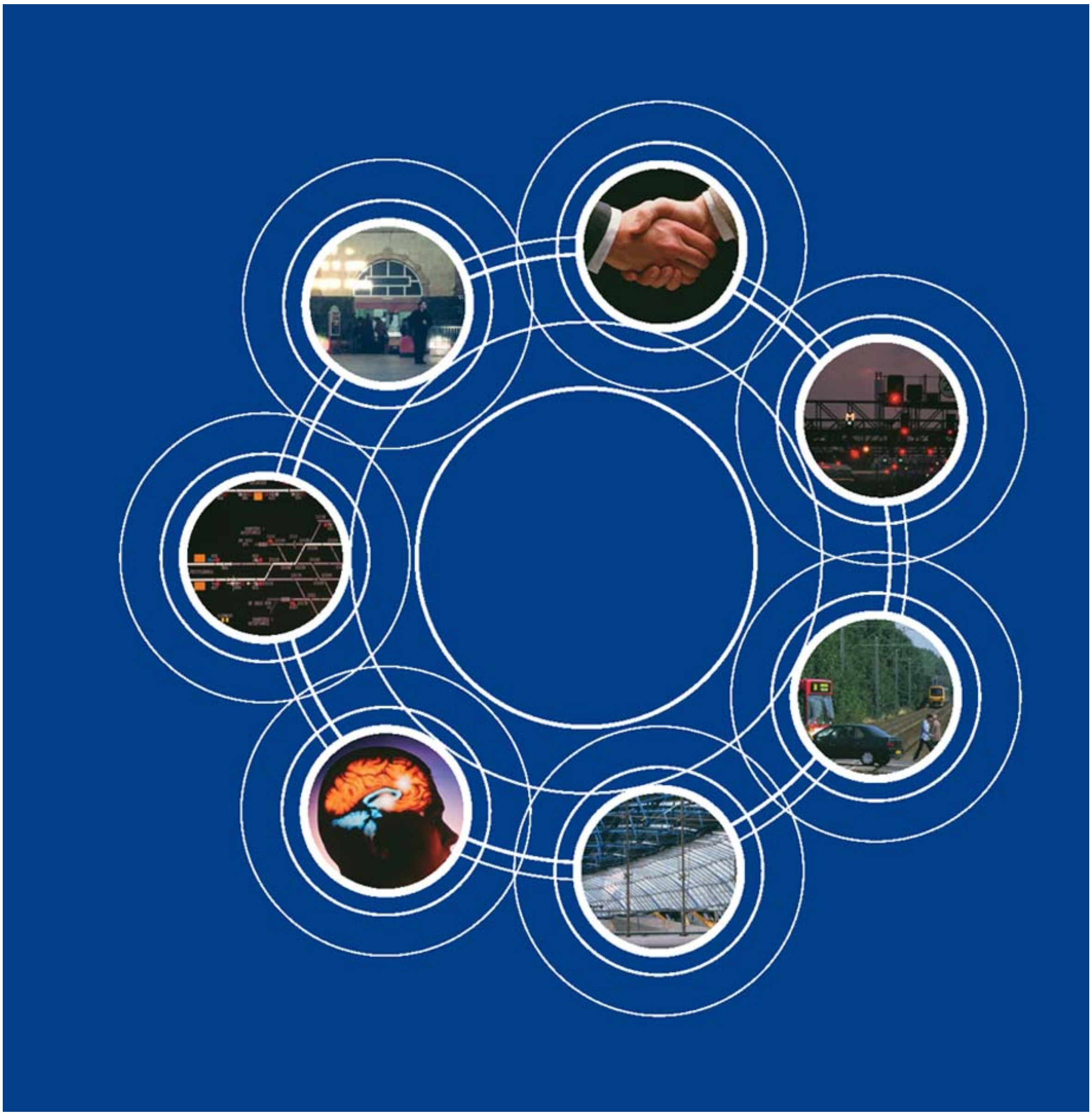
TSAG

RSSB

Research Programme

Strategy Support

Mapping current remote condition monitoring activities to the system reliability framework



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Executive Summary

One of the key themes of the Rail Technical Strategy (RTS) is delivery of a better 'door-to-door' service for passengers, of which a significant part is delivery of an uninterrupted train journey, i.e. one that is not subject to delay.

The Technical Strategy Advisory Group (TSAG), which is facilitating delivery of the RTS, sees Remote Condition Monitoring (RCM) playing a significant part in achieving this ambition. It also recognises that there is already a lot of activity in this area but no overall picture exists.

At the request of a sub-group of TSAG, the Uninterrupted Journey Group (UJG), RSSB commissioned Advanced Rail Technologies (ART) to provide an insight into:

- How far existing capability and planned development within the scope of RCM are improving or are expected to improve reliability in the most significant areas.
- What scope exists for development and application of new and innovative approaches.

ART's work has reviewed 152 existing and emerging RCM activities taking place around the world. By interview, fact finding and experience, ART has identified 52 activities which offer potential to assist in improving reliability. These activities have been mapped against a System Reliability Framework which breaks down the overall system delay by asset and event groups.

The following key conclusions are drawn:

- There is a considerable amount of RCM activity both in Great Britain (GB) and worldwide; maturity being greater on trains than infrastructure.
- 47% of delay minutes relate to hardware failures and, in principle, are amenable to improvement in reliability through the application of RCM. A further 10% may possibly be amenable through monitoring of people and events, leaving 43% unlikely to benefit directly from RCM. However even this 43% may see some benefit indirectly as improved asset reliability is likely to have knock-on benefits and reduce delays from such activities as possessions and track patrols.
- The extent of the overall improvement is likely to be in the range 10-20% which may be lower than industry expectations. These figures need testing with industry stakeholders.
- A considerable amount of development and implementation will be required to achieve these figures.
- To achieve better reductions, there would need to be considerable improvement in the effectiveness of the predictive algorithms currently used in RCM systems.
- Automatic Vehicle Identification (AVI) is not as such remote condition monitoring but it is an essential enabling facility and a common system is needed throughout the GB rail network to enable efficient RCM.
- An industry-wide ontology is required as a basis for integrated communications and data analysis.

Contents

1 Introduction

One of the key themes of the Rail Technical Strategy (RTS) is delivery of a better 'door-to-door' service for passengers, of which a significant part is delivery of an uninterrupted train journey, i.e. one that is not subject to delay.

The Technical Strategy Advisory Group (TSAG), which is facilitating delivery of the RTS, sees Remote Condition Monitoring (RCM) playing a significant part in achieving this ambition. It also recognises that there is already a lot of activity in this area within the domains of both trains and infrastructure; however no overall picture exists, making it difficult to identify gaps, or potential benefits of cross-industry activity.

At the request of a sub-group of TSAG, the Uninterrupted Journey Group (UJG), RSSB commissioned Advanced Rail Technologies (ART) to provide an insight into[1]:

- How far existing capability and planned development within the scope of RCM are improving or are expected to improve reliability in the most significant areas.
- What scope exists for development and application of new and innovative approaches.

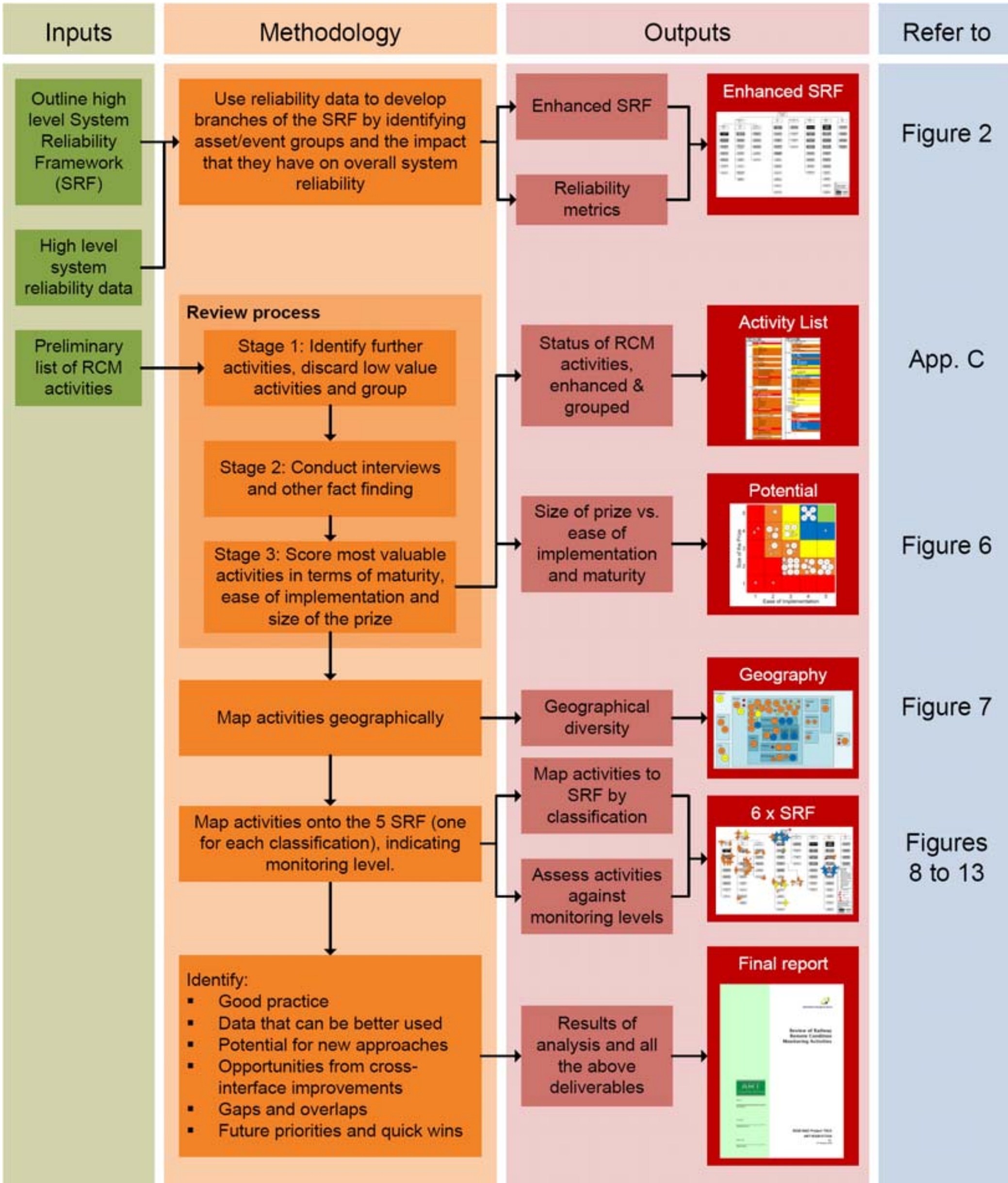
This final report outlines ART's methodology for delivering the work, the results of the study, what can be concluded from them and also suggestions for further work.

[1] UJG's full remit is given in Appendix F.

2 Methodology

Figure 1 below depicts the methodology used to deliver the remit. Further explanation of how the outputs were generated is given in the next section.

Figure 1: High-level methodology



This methodology gave several small enhancements beyond the original remit:

- As well as categorising in terms of their ‘classification’ and ‘monitoring level’ (defined in Appendix F), RCM activities were also categorised according to function: enabling, measurement, transmission, analysis and decision making. Further explanation of this is given in section 3.2.3.

- As well as scoring the most valuable activities according to their 'ease of implementation' and the 'size of the prize', 'maturity' was also included to provide an ability to distinguish between immature activities that have considerable potential and those that have already been proven.
- An additional 'classification' was introduced; infrastructure monitoring the environment, for which a small number of activities were identified.
- The impact on overall system reliability was calculated for each asset/event group on the System Reliability Framework, to establish those that had the greatest impact on overall system reliability.

3 Results

3.1 Enhanced System Reliability Framework (SRF)

The enhanced SRF is shown in figure 2 overleaf and presents graphically the total delay seen across the railway system, breaking down the delay into categories and then into subsidiary asset/event groups. Thus:

- The first level on the SRF at the top of the diagram, 'Uninterrupted Journey', represents the whole system.
- The second level represents the categories, e.g. Infrastructure and Trains.
- The third level represents the asset/event groups within individual categories, e.g. signalling, track circuits, etc.

Asset/event groups with greatest impact on system reliability appear uppermost on the SRF and are in the darkest shaded boxes.

Compared with the original SRF produced by UJG, it has been enhanced in three ways:

- The 'boxes' in the SRF have been established by analysing delay attribution data for the whole railway system.
- This data has then been used to identify how the whole system delay breaks down across the categories and then across the asset/event groups.
- The impact of each asset/event group on system delay has then been established so that the most significant can be clearly identified. This contribution is represented by the grey scale colouring and is defined in the key at the bottom right hand corner. The asset/event groups in each category are listed in order of descending significance with the most significant at the top. Contributions to system delay vary from less than 1% up to a maximum of 6.4% for 'traincrew'.

The data used in this analysis has come from two sources:

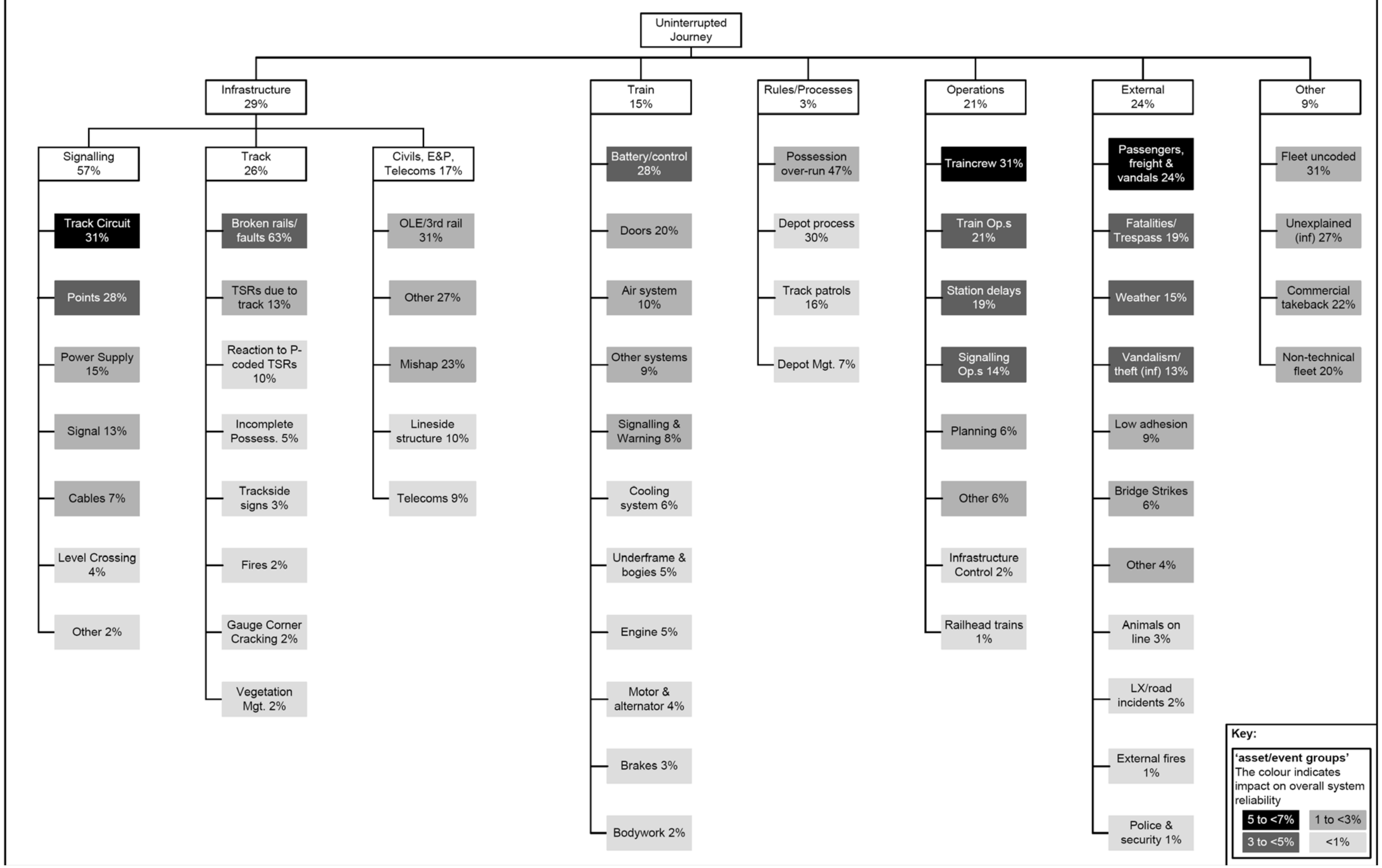
- Infrastructure data is based on periodic delay minutes from Network Rail's 'Industry Performance Period Report Supplement dataset' for the year to P7 2008/09.
- The breakdown of rolling stock delays is based on technical casualty data for 19 (not necessarily representative) fleets over 5 to 13 periods depending on source.

Appendix D explains how the figures in the SRF have been derived from the available data. It should be noted that this data captures causation from train delays only and not train cancellations. Equally, some delays may have been attributed to where the symptom was seen rather than the root cause. We were unable to verify the accuracy of the source data, but knowledge and experience suggests the relative magnitudes are not unreasonable.

Figure 2: Enhanced System Reliability Framework (SRF)

NOTE: The numbers are given to indicate the relative impact of different groups of assets/events on overall system reliability and are derived from the following data:
- **Infrastructure data based on periodic delay minutes from Network Rail's 'Industry Performance Period Report Supplement dataset' for the year to P7 2008/09.**
- **Rolling stock data based on technical casualties for 19 (not necessarily representative) fleets over 5 to 13 periods depending on source.**

It should be noted that the data captures causation from train delays only and not train cancellations. Equally, some delays may have been attributed to where the symptom was seen rather than the root cause. The project team were unable to verify the accuracy of the source data, but knowledge and experience suggests the relative magnitudes are not unreasonable.



3.2 Activity Review

The activities were reviewed using the following process:

- A further 54 existing and emerging RCM activities were identified beyond the 98 originally provided by UJG, a total of 152 activities in all. Although the search has been international, we do not pretend to have identified even the majority of RCM activities taking place worldwide.
- Stage 1 review: An initial review was performed to establish whether further scrutiny was justified and explain where not justified[2]. 68 activities passed stage 1.

  Note: 13 activities were considered suitable for stage 2 but could not be progressed further due to insufficient information being available in time. They are listed in section 6.6.
- Stage 2 review: Further fact finding was conducted on each of the 68 activities that passed stage 1, where possible interviewing those involved. Interviews were conducted for 42 activities in all; the remaining activities being investigated using conference papers, product information, internet searches and experience. The information obtained was then used to assess the activities in terms of their potential to improve reliability. 52 activities were deemed sufficiently valuable to be assessed under stage 3.
- Stage 3 review: The 52 activities that passed stage 2 were then scored in terms of their 'ease of implementation', the 'size of the prize' and 'maturity' (see section 3.3). These activities are listed in Appendix C.

To pass through to stage 3 and be scored, activities had to pass two tests as a minimum:

- They must contribute to reliability.
- They must involve remote monitoring (i.e. not a ruler/gauge on a depot)[3].

All activities have been assigned a unique 'Activity ID' (given in Appendix C) for ease of reference and this is used in the text and figures of this report.

The stage 2 review involved categorising activities in a number of ways and this is explained in the following.

3.2.1 Function

RCM activities have been categorised by the function that they perform:

- Measurement: Using appropriate sensing equipment to measure condition.
- Transmission: Communicating the measurements to a remote location.

[2] This included a review of 41 activities identified in RSSB R&D project T607 'Identification of existing and new technologies for wheelset condition monitoring' to identify activities worth further consideration. 8 of the 13 activities recommended for further investigation in section 6.6 emanate from T607.

[3] Network Rail trains such as the NMT are regarded as remote condition monitoring (as opposed to local), if the data is being analysed remotely and not on the train, i.e. the people on the train are there to monitor the systems not analyse the data.

- Analysis: Analysing the measurements to turn what can be huge amounts of data into useful information.
- Decision making: Using that information to instigate improvements, whether tactical (e.g. directing a train with an emerging fault to a depot that has the resources to carry out the repair), or more strategic (e.g. improving fault finding mechanisms).
- Enabling: Although not strictly RCM, there are some activities such as Automatic Vehicle Identification which are crucial to the effectiveness of RCM. Such activities have been termed 'enabling'.

The breakdown of stage 3 activities against function is shown in figure 3 below. It can be seen that there is an even presence across all four functions with the few 'enabling' activities reflecting the bias of the work towards RCM. The majority of the 52 activities provide all four RCM functions.

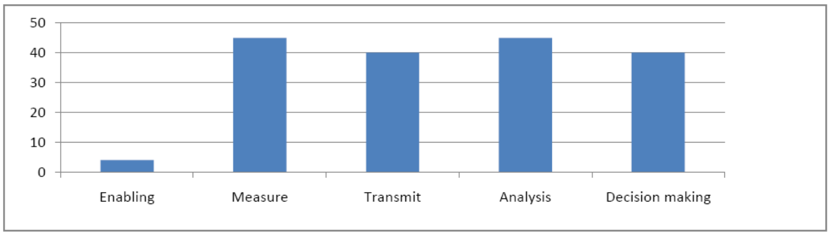
Note:

- Some of the activities are capable of analysis without taking measurements, either because they import measurements from other systems (e.g. Asset View (activity #11)), or they describe analytical methods that need to be deployed (e.g. Predicting points failures (activity #76)).
- The function of 'decision making' covers a wide range of capabilities from providing data to users who can then use it to plan maintenance (e.g. IRIS 320 Train (activity #93)) through to automatic provision of alerts (e.g. Asset View (activity #11)).

Figure 3: Breakdown of activities by function

Number of activities having each function:

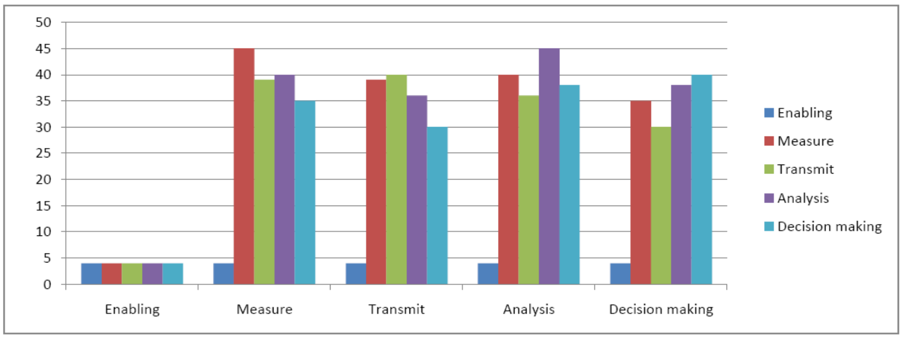
Enabling	Measure	Transmit	Analysis	Decision making
4	45	40	45	40



Cross-correlation (how many activities with each function have another function):

For example: Of the 45 activities emerging from stage 3 that take measurements, 40 of them also analyse the measurements.

	Enabling	Measure	Transmit	Analysis	Decision making
Enabling	4	4	4	4	4
Measure	4	45	39	40	35
Transmit	4	39	40	36	30
Analysis	4	40	36	45	38
Decision making	4	35	30	38	40



3.2.2 Monitoring Classification

As defined in the UJG remit (Appendix F), this categorises the monitoring relationship between infrastructure and train[4]. We have also added the environment to capture RCM activities that monitor the weather.

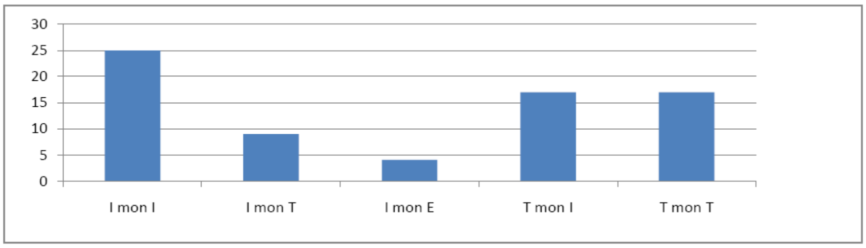
The breakdown of activities against classification is shown in figure 4 below. The majority of the 52 RCM activities within our sample (80%) are carrying out monitoring which is self-contained within the asset type (i.e. trains monitoring trains or infrastructure monitoring infrastructure). But a surprisingly high proportion (60%) of the 52 RCM activities are carrying out ‘cross-asset’ monitoring (i.e. trains monitoring infrastructure, or infrastructure monitoring trains, or infrastructure monitoring the environment)[5].

[4] Network Rail trains such as the NMT are regarded as ‘Trains monitoring the infrastructure’.
[5] These proportions add up to more than 100% because many of the activities are carrying out more than one classification of monitoring (as depicted by the lower chart above).

Figure 4: Breakdown of activities by monitoring classification

Number of activities having each monitoring classification:

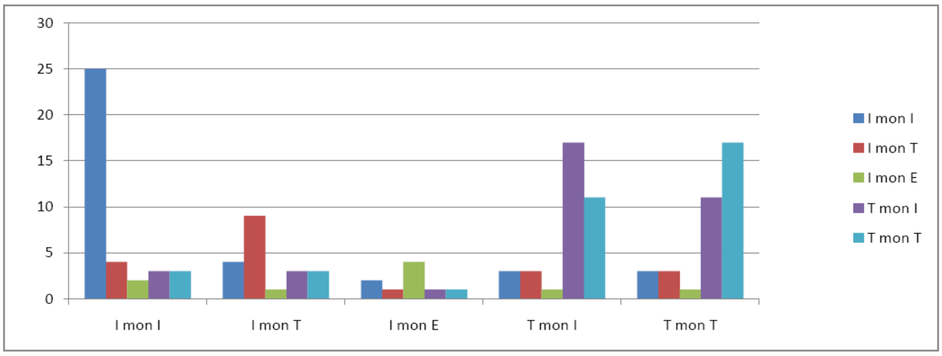
I mon I	I mon T	I mon E	T mon I	T mon T
25	9	4	17	17



Cross-correlation (how many activities with each classification are also in another classification):

For example: Of the 25 infrastructure activities monitoring the infrastructure, 4 are also able to monitor trains and 2 the environment.

	I mon I	I mon T	I mon E	T mon I	T mon T
I mon I	25	4	2	3	3
I mon T	4	9	1	3	3
I mon E	2	1	4	1	1
T mon I	3	3	1	17	11
T mon T	3	3	1	11	17



3.2.3 Monitoring Level

As defined in the UJG remit (Appendix F) this categorises how RCM activity delivers value in accordance with the following four levels:

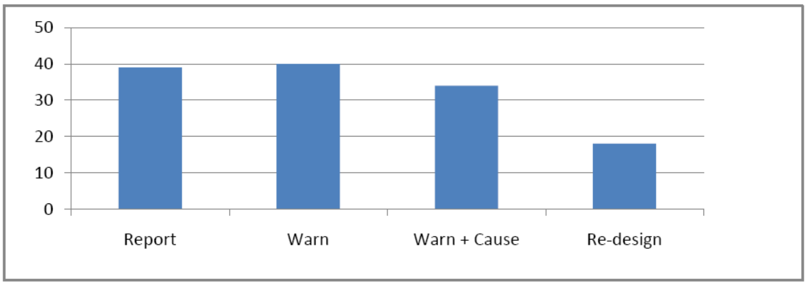
- Report a failure
- Warn of a future impending failure
- Warn with cause identified
- Provision of data to facilitate designing out a future failure

The breakdown of activities against monitoring level is shown in figure 5 below. It can be seen that there is a reasonably even spread across the first three levels, but fewer activities are able to provide data to facilitate design improvements. The majority of the 52 activities are monitoring in at least the first three of the four levels (as depicted by the lower chart below).

Figure 5: Breakdown of activities by monitoring level

Number of activities in each monitoring level:

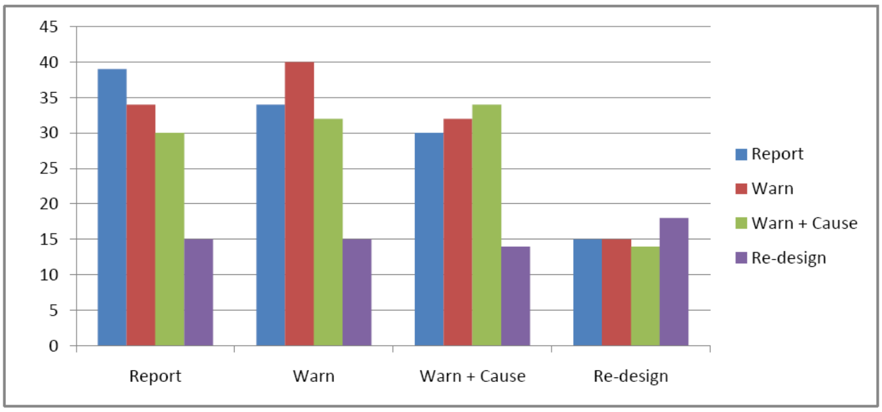
Report	Warn	Warn + Cause	Re-design
39	40	34	18



Cross-correlation (how many activities in each level also belong to another level):

For example: Of the 39 activities that can report faults, 34 of them can also warn of the fault.

	Report	Warn	Warn + Cause	Re-design
Report	39	34	30	15
Warn	34	40	32	15
Warn + Cause	30	32	34	14
Re-design	15	15	14	18



3.3 Potential value

The 52 activities that passed through to stage 3 are graphically presented in figure 6 overleaf. Activities with the most potential *immediate* value are those in large circles in the top right of the grid. Those with the most potential *future* value are those in medium or small circles in the top right of the grid.

Note that at this stage of the analysis, value is considered in the context of the asset only, not the system as a whole, i.e. value has been considered in terms of the potential impact on the asset's reliability and not overall system reliability. To understand the potential impact an activity has on the system, the contribution of the monitored asset's unreliability to system delay has to be considered as well; this is dealt with by mapping the activities onto the SRF in section 3.5.

A more detailed understanding of figure 6 can be gained from the following:

- The numbers shown in the circles refer to 'Activity ID' in the activity list given in Appendix C.
- Three parameters are represented using the x, y coordinates and the size of the circle as follows:

Level of maturity	Size of prize (at asset level)		Ease of implementation	
Low (small circle) Concept or academic paper, or demonstration / prototype available; or obsolete technology (whilst mature, it now has little value)	1	Nil or negligible benefit	1	Major hardware cost and organisational implications
	2	Some benefit to small number of asset classes/train systems	2	Major cost, many individual assets/train systems to be instrumented
Medium (medium circle) Production system available	3	Some benefit to large number of asset classes/train systems or big benefit to small number of asset classes/train systems	3	Medium cost, relatively few assets/train systems to be instrumented
High (large circle) Production system available, established, and proven in service	4	Big benefit to large number of asset classes/train systems	4	Low cost, no technical issues to resolve
	5	Step change in reliability over all asset classes/train systems	5	Quick and easy implementation

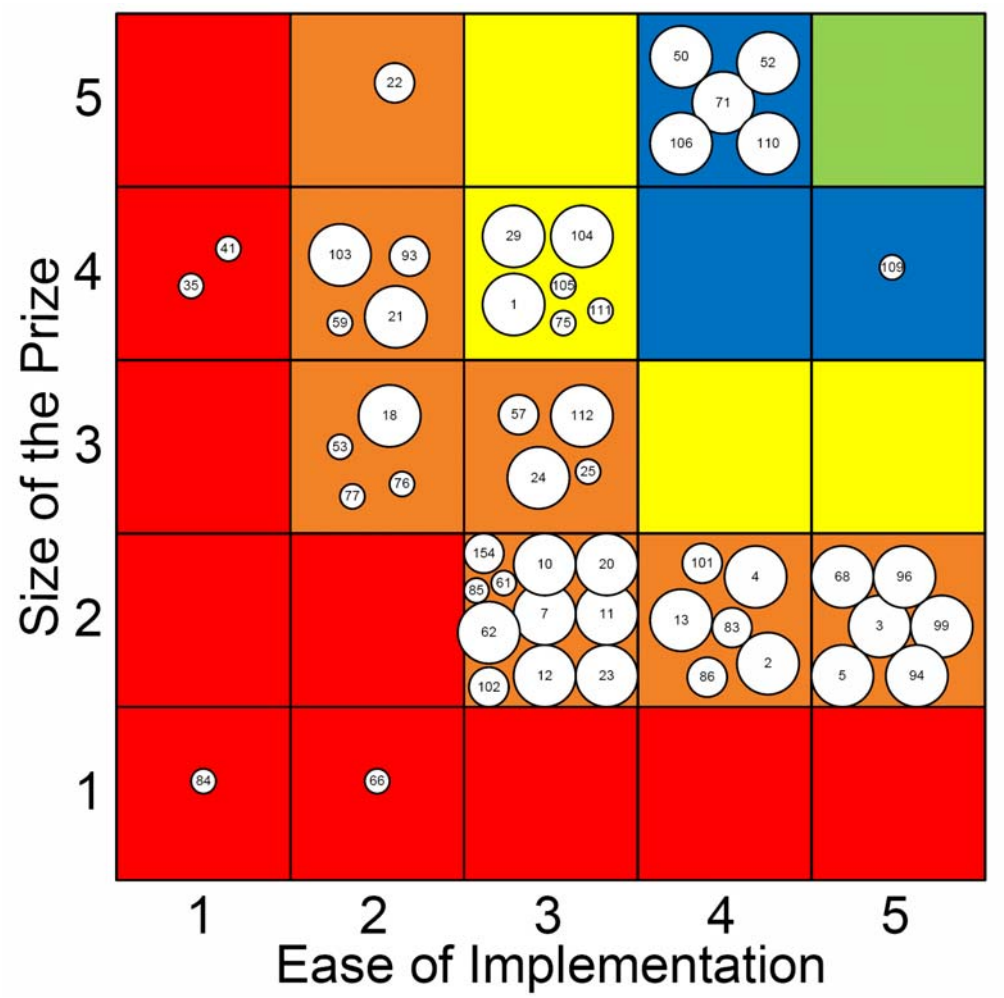
The colour of the square in which the activity is shown indicates the potential value of the activity; for example, activities in blue squares have more potential than those in the yellow, etc. The five regions of colour have been established according to the product of the 'size of prize' and 'ease of implementation' as follows:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

The colour along with the size of the circle is used in other mapping to indicate potential value. Note the colour 'red' does not necessarily mean that an activity should not be done. For example Integrail (activity #35) has high 'size of the prize' but will not be simple to implement, hence it scores low on 'ease of implementation' and appears in the red region.

It is notable that no activities appear in the green region. It is also notable that all the activities in the blue region relate to trains, whereas the infrastructure activity with the most potential is in the yellow region. This reflects the greater maturity and success of train RCM solutions compared to infrastructure.

Figure 6: Potential value of RCM activities



3.4 Geographical spread

The geographical spread of the activities that passed through to stage 3 is shown in figure 7 overleaf. It was originally intended to mark activities on a map of Great Britain; however it became clear that this was inappropriate for the following reasons:

- Many of the activities were being used outside of Great Britain.
- Some of the activities were geographically located in many different locations, while some were specific to a particular route or individual site.

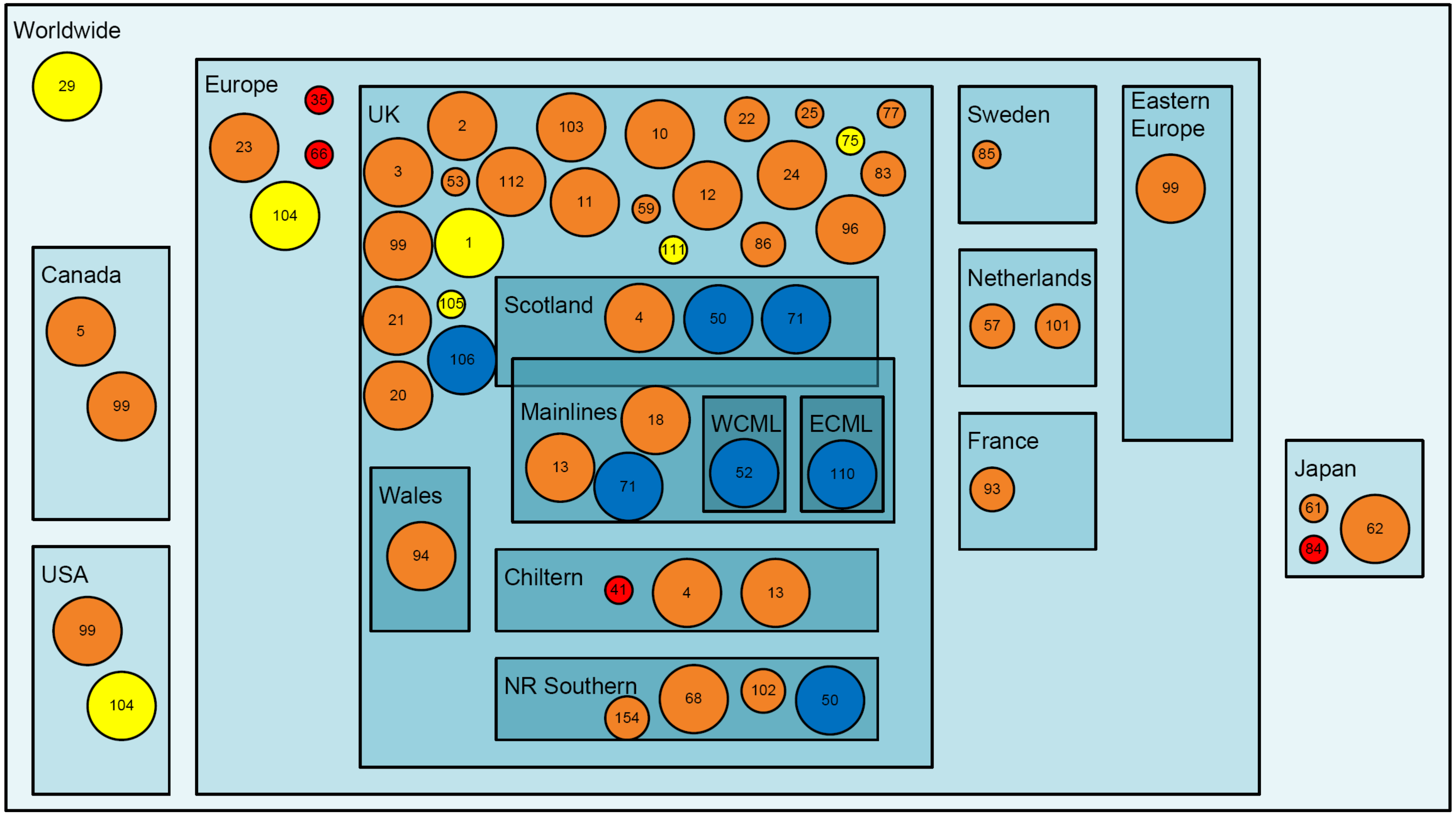
A graphical representation of the world has therefore been chosen using Venn diagram principles. Thus boxes fit within boxes to signify countries fitting within larger regions and activities shown in a particular box are geographically located in the number of regions to which the box pertains. For instance, activity #29 which from the activity list in Appendix C is RAILBAM is located throughout the world, whereas ICEALERT (activity #99) is in use in Canada, the United Kingdom (UK), the USA and Eastern Europe. Again the colour along with the size of the circle indicates potential value (see section 3.3).

The diagram illustrates that the sample covered activities that span a wide geographical area. There is a significant concentration of activities in the UK reflecting the locus of the review and our knowledge, although it may also be due to the UK putting significant effort into RCM[6]. Aside from the UK, there does not appear to be any other particular country which has an unusually high concentration of RCM activities in the sample.

More detailed information on existing Network Rail RCM installations is given in Appendix B.

[6] Some informed opinions are that in many respects the UK leads Europe in RCM.

Figure 7: Geographical spread of activities reviewed



3.5 Mapping onto SRF

Figures 8 to 13 map each of the activities which passed through to stage 3 to the asset/event groups that they monitor. The activities of greatest value appear uppermost on the SRF; colour coding of the activities and the SRF boxes are as previously described in section 3.3 and 3.1 respectively. Blue is the most valuable, followed by yellow, orange and red in that order, and the darker the box on which they sit, the greater the potential impact on reliability. Activities with the largest circles are likely to be of more immediate benefit than those with medium sized and small circles.

The preponderance of large blue circles around trains is testament to the number of mature systems that have demonstrated significant improvements in reliability at modest additional cost when they are based on a data recording system that has been fitted to serve other purposes, e.g. train management and driver advice.

A more detailed understanding of figures 8 to 13 can be gained from the following:

- Again the colour along with the size of the circle indicates potential value (see section 3.3).
- Each figure covers one monitoring relationship:
    - All activities (figure 8)
    - Infrastructure monitoring infrastructure (figure 9)
    - Infrastructure monitoring trains (figure 10)
    - Infrastructure monitoring the environment (figure 11)
    - Trains monitoring infrastructure (figure 12)
    - Trains monitoring trains (figure 13)
- The monitoring level (see section 3.2.3) is depicted for each activity using a series of arrows as shown in the key.

Note:

- Activities shown against categories apply to at least two of the subsidiary asset/event groups. For instance, Orbita (activity #71) is shown against the 'train' asset/event group box and is able to monitor the condition of many train systems.
- There was so much commonality between activities that applied to asset/event groups 'TSRs due to track' and 'Reaction to P-coded TSRs'[7], a dashed box drawn around both boxes indicates that activities within the dashed box apply to both asset/event groups. One Bridge monitoring (activity #94) is shown outside the dashed box and against the lower of the two asset/groups because it applies only to 'Reaction to P-coded TSRs'.

[7] A Temporary Speed Restriction (TSR) is P coded when it does not attract delay minutes because it is within the route allowances. If it stays on too long or is more severe then delay minutes will be incurred and coded as a 'Reaction to P-coded TSRs'.

Figure 8: All activities mapped onto the SRF

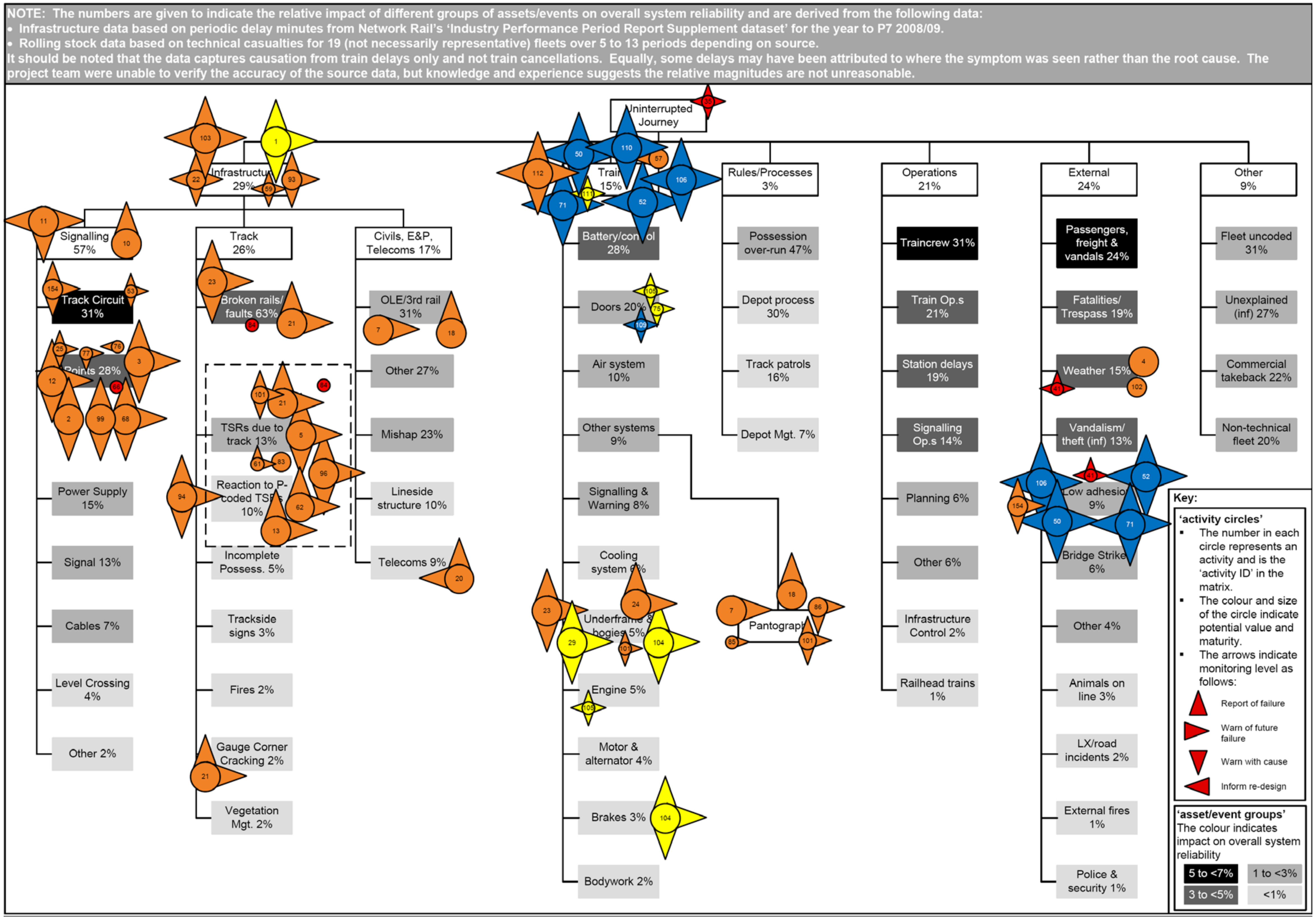


Figure 9: Infrastructure activities monitoring the infrastructure mapped onto the SRF

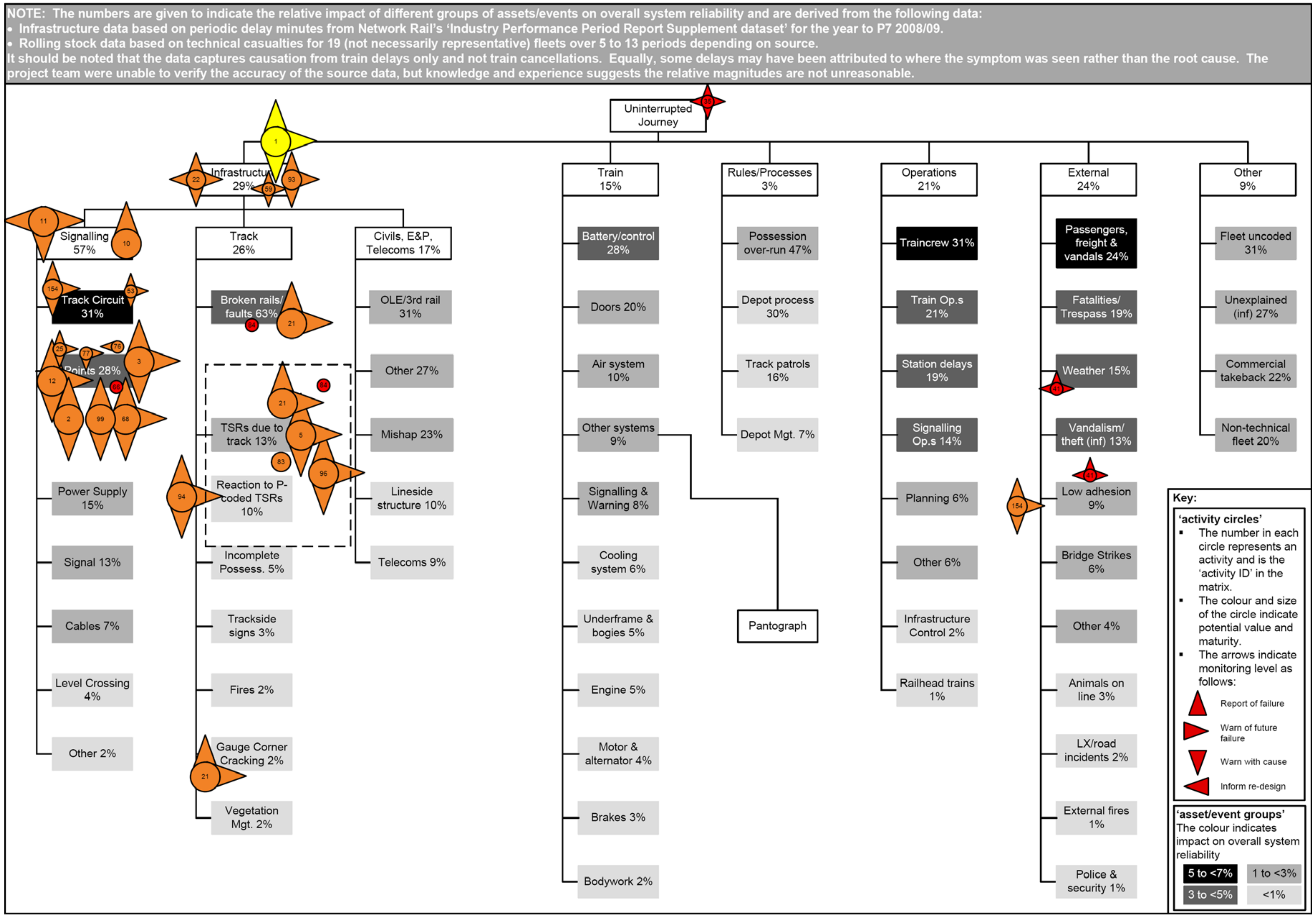


Figure 10: Infrastructure activities monitoring trains mapped onto the SRF

NOTE: The numbers are given to indicate the relative impact of different groups of assets/events on overall system reliability and are derived from the following data:
- Infrastructure data based on periodic delay minutes from Network Rail's 'Industry Performance Period Report Supplement dataset' for the year to P7 2008/09.
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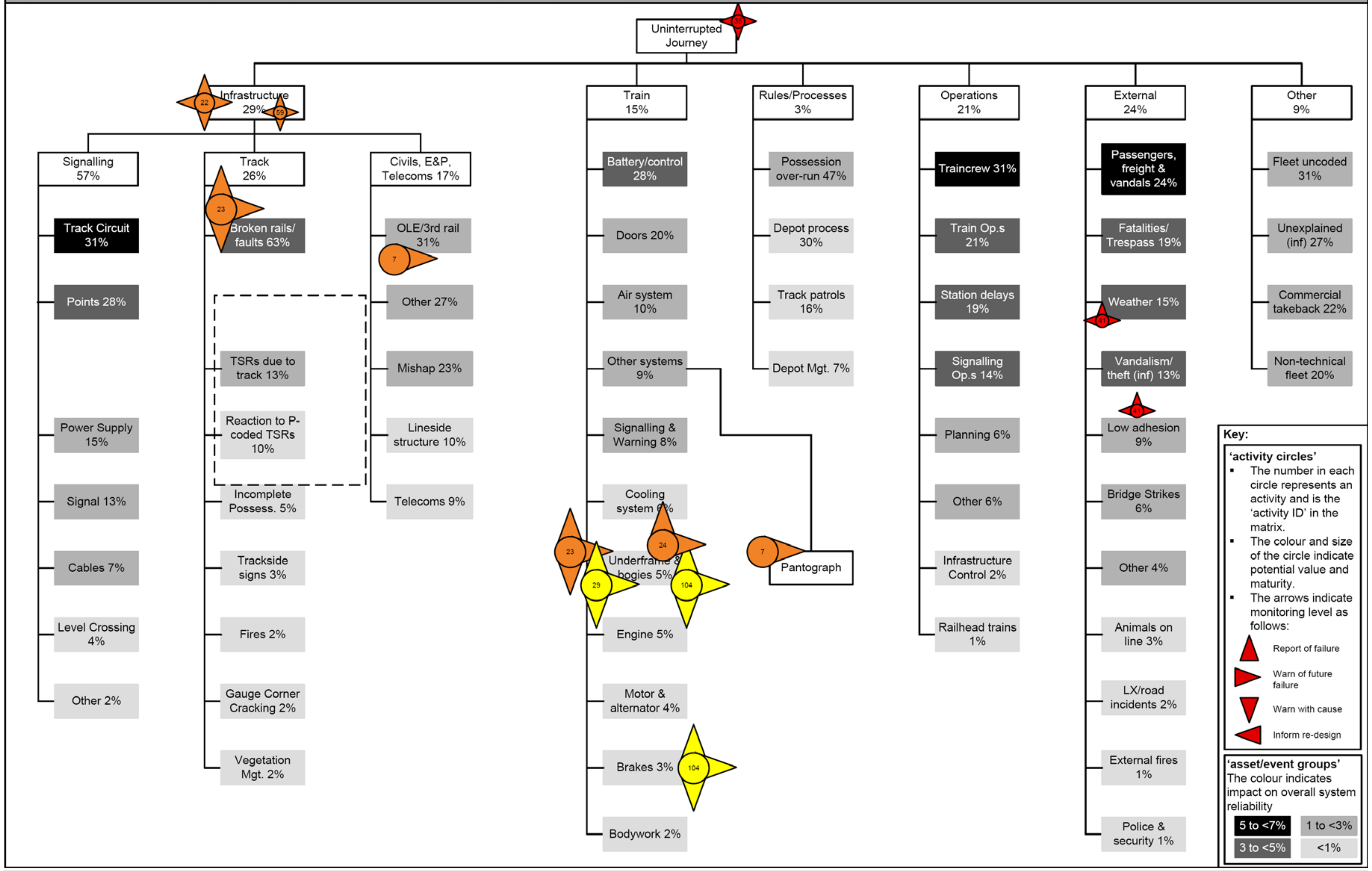
It should be noted that the data captures causation from train delays only and not train cancellations. Equally, some delays may have been attributed to where the symptom was seen rather than the root cause. The project team were unable to verify the accuracy of the source data, but knowledge and experience suggests the relative magnitudes are not unreasonable.



<u>Figure 11: Infrastructure activities monitoring the environment mapped onto the SRF</u>

NOTE: The numbers are given to indicate the relative impact of different groups of assets/events on overall system reliability and are derived from the following data:
- **Infrastructure data based on periodic delay minutes from Network Rail's 'Industry Performance Period Report Supplement dataset' for the year to P7 2008/09.**
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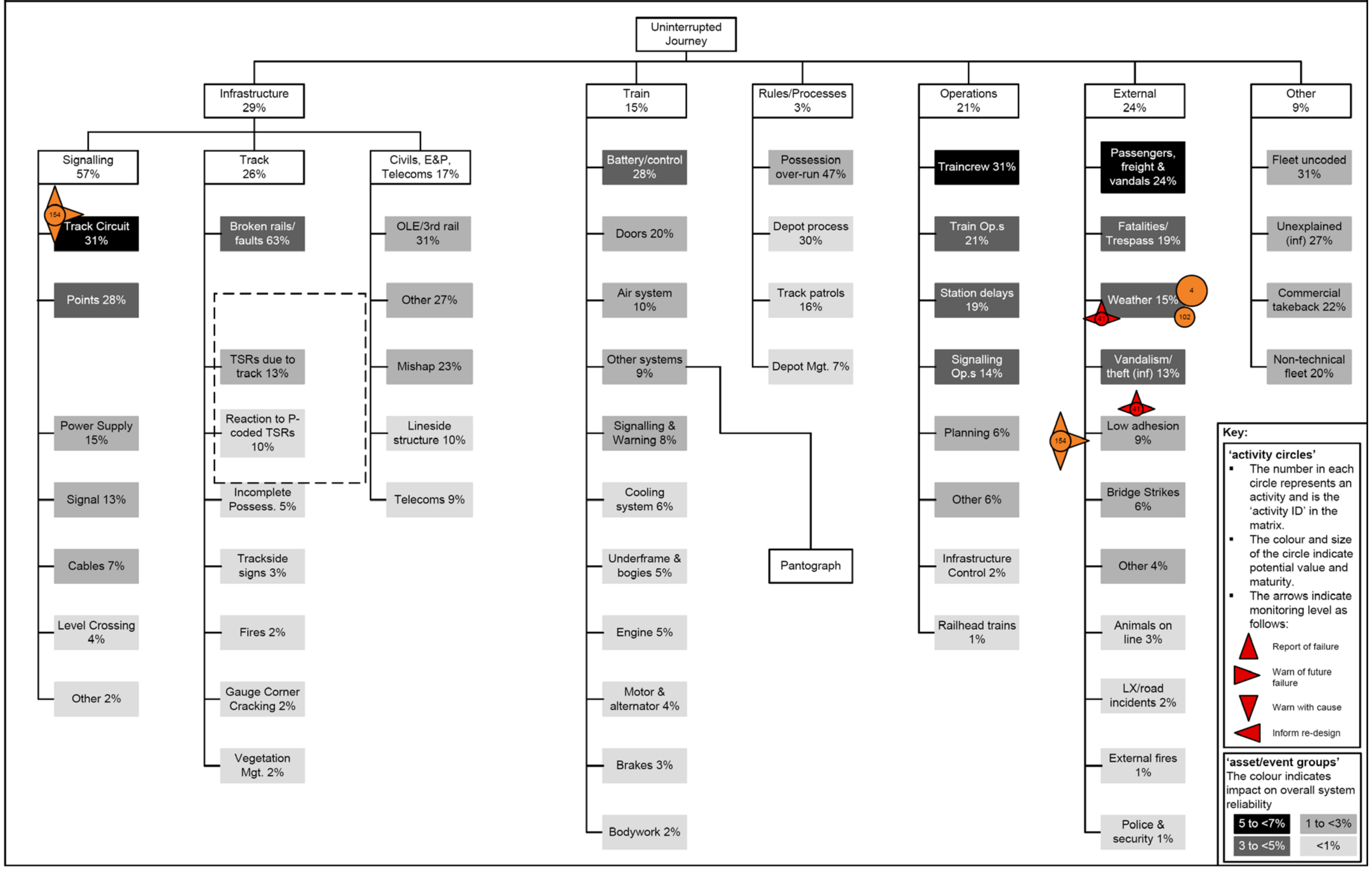

Figure 12: Train activities monitoring the infrastructure mapped onto the SRF

NOTE: The numbers are given to indicate the relative impact of different groups of assets/events on overall system reliability and are derived from the following data:
- **Infrastructure data based on periodic delay minutes from Network Rail's 'Industry Performance Period Report Supplement dataset' for the year to P7 2008/09.**
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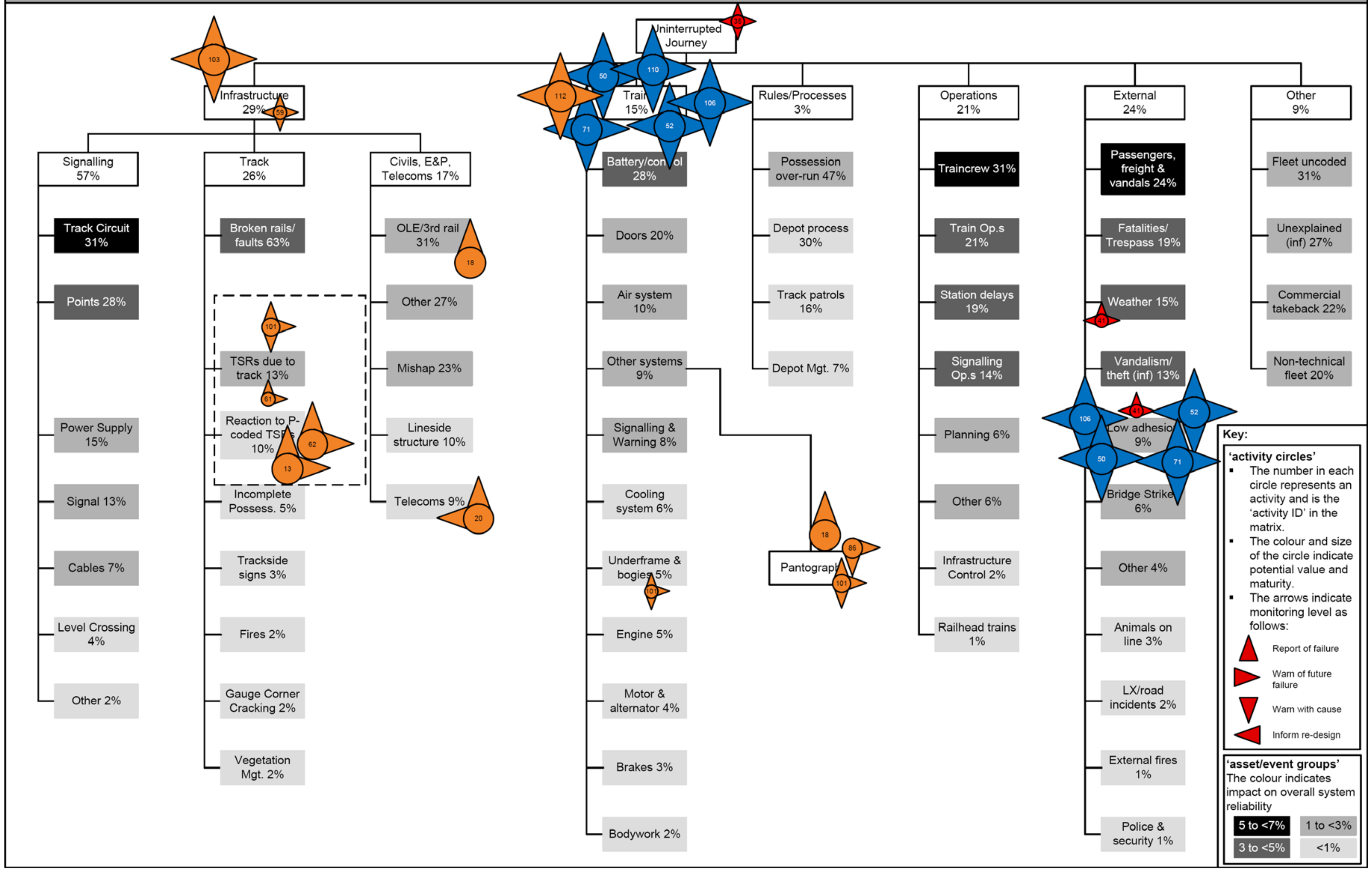

Figure 13: Train activities monitoring trains mapped onto the SRF

NOTE: The numbers are given to indicate the relative impact of different groups of assets/events on overall system reliability and are derived from the following data:
- **Infrastructure data based on periodic delay minutes from Network Rail's 'Industry Performance Period Report Supplement dataset' for the year to P7 2008/09.**
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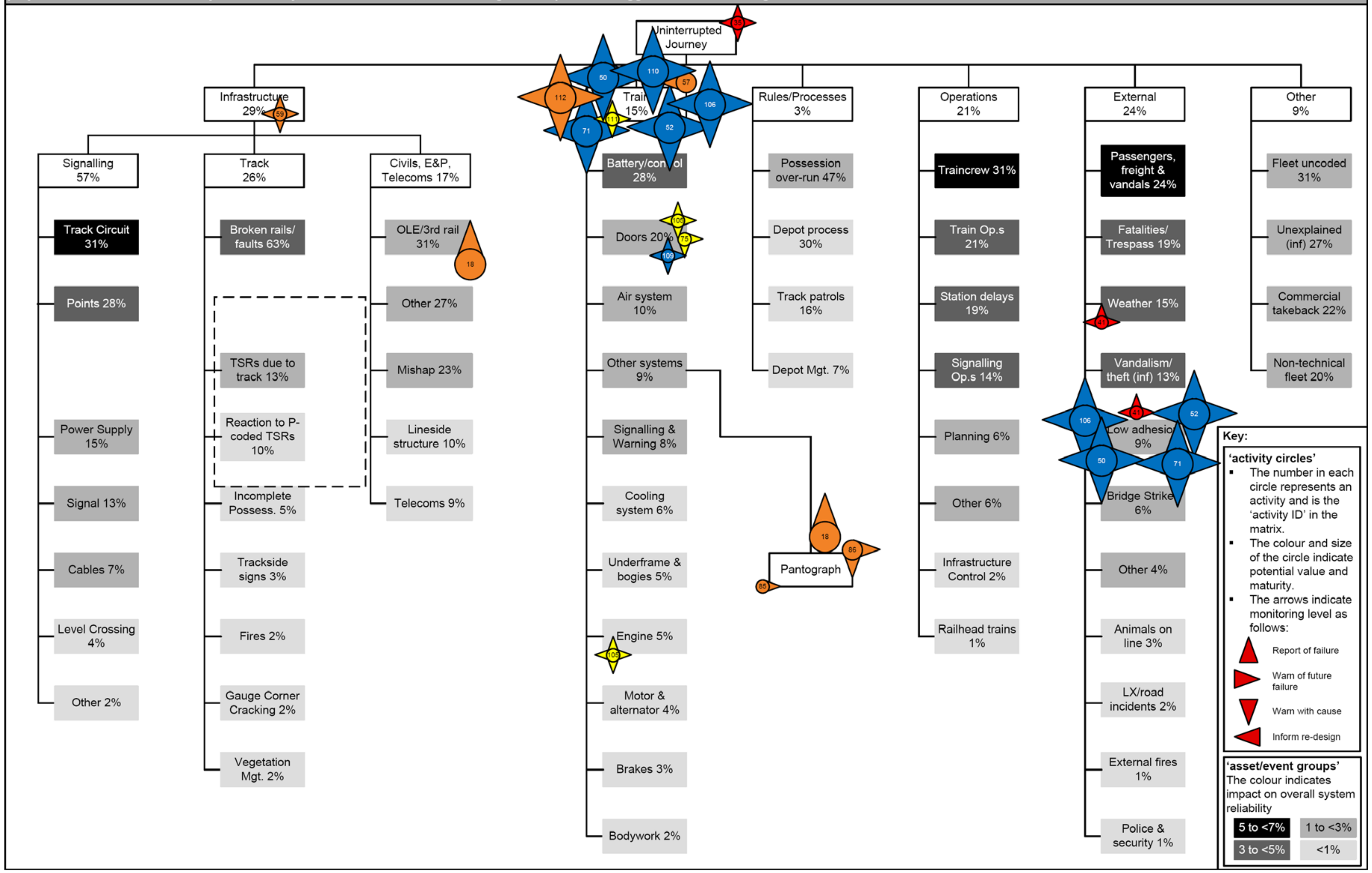

4 What the results tell us

The analysis below is based on a consideration of the activities reviewed looked at in the context of the make-up of train delays given in the SRF. It is set out in sections 4.1 to 4.6 below in the same order in which the SRF is structured. Section 4.7 then considers opportunities across interfaces.

4.1 Infrastructure

4.1.1 Signalling

Within this generic category, the asset groups which contribute most to overall train delays are:

- track circuits (5.1%)
- points (4.6%)
- signalling power supplies (2.5%).

Indeed, Network Rail's view is that these three categories represent the top three causes of train delay across all infrastructure, not just signalling. The train delay figures do not entirely support this view, since broken rails/track faults rank slightly higher than points failures[8], but this may simply be a result of the way the delay attribution codes are structured.

Taking each of the above three asset groups in turn:

4.1.1.1 Track Circuits

There are two quite different ways in which RCM can be applied to track circuits: (a) at the asset itself and (b) at the interlocking.

The first of these has the advantage that it monitors local parameters such as track voltage and hence gives an insight into local conditions, but it has the drawback of being costly as it has to be applied on a distributed basis (there are 65,000 track circuits on Network Rail infrastructure). The second method has the benefit of lower cost, as it is centralised and is generally part of a wider data logging system, but, whilst it monitors changes in the behaviour pattern of the track circuit, it does not give any information regarding the underlying causes of the observed behaviour.

Track circuits exhibit a complex set of failure modes. Some failures are preceded by a period of gradual degradation of a measurable parameter, such as falling ballast resistance; some by a definable precursor event, such as damage to a cable; whilst some failure causes are totally random, e.g. lightning strikes. But even where a failure is, in theory, predictable, it is necessary for the RCM system (a) to be monitoring the appropriate predictive parameter, and (b) to have a suitable predictive algorithm, in order to be able to foresee the actual failure.

[8] In the year ending at period 7 2008/9, Broken Rails/Track Faults (causation code 104B) constituted 4.8% of total delay minutes, and Point Failures (causation code 101) constituted 4.6%.

A breakdown of TI21 track circuit failure causes from FRAME, quoted in 'Developments in Track Circuit Condition Monitoring' (activity #53), gives the following:

TI21 equipment fault	Other equipment fault	Track fault	Unknown fault
14%	24%	16%	46%

The authors of the report associated with activity #53 acknowledge that the figures they quote in the first two boxes are probably too high, since many items of allegedly faulty equipment turn out to have nothing wrong with them; the actual fault cause probably being a loose connection elsewhere.

Taking these various factors together (i.e. distributed assets; complex fault modes; difficulty of producing algorithms; large proportion of unknown or incorrectly reported faults) no doubt explains why the extent of RCM applied to track circuits today is less than one might initially expect, given the extent of train delays attributable to track circuits. Indeed, apart from specific leaf-fall sites, there appear to be no installations of track circuit monitoring at the asset itself, and the Network Rail statistics (see Appendix B) do not have a separate category for recording such installations.

Currently, there is only one developed system for remotely monitoring the condition of the rail surface owing to leaf fall, i.e. ACIC leaf fall monitor (activity #154). The equipment used measures track circuit performance and changes thereon to predict when the leaf based film may affect both the ability of track circuits to detect trains and also report potentially poor adhesion. The system is deployed over Network Rail's Southern Territory and is used to direct the application of Sandite during the leaf fall season. In extremis the alarms generated are used to direct maintenance teams to clean rails. Both the issue and the solution appear peculiar to the area concerned as the system is well known about within Network Rail, but no other territories see a benefit in its use.

As far as train delay reduction is concerned, Network Rail's view is that the application of RCM to track circuits will give a 30% initial annual delay minute saving with a reducing subsequent benefits profile as worst performing assets will be dealt with first. There is no hard evidence from controlled experiments to support this figure, however engineering judgement and consideration of the failure modes suggests it is not unreasonable.

4.1.1.2 Points

A number of systems are deployed in the UK to improve the performance of points. Many of these are in a development stage with a number of trial sites set up by Network Rail around the country. Systems fall into two categories: those that improve the performance of points heating systems and those that monitor the motor. By being able to test heating systems and monitor performance remotely and in non-critical conditions, it has been proved that the likelihood of heater failure during a cold period when it is needed in anger is much reduced.

Several systems which monitor the performance of points machines are in use in the UK. These are highlighted in the activity list in Appendix C. They vary from simple data loggers which record events and mechanical and electrical parameters and pass these to a central data store, to sophisticated predictive trackside equipment which undertakes its analysis locally before raising any alarm. From the interviews it is apparent that there are advantages in both type of system. What is apparent is that all of the systems have not yet been developed to an extent where motor failure can be regularly accurately predicted. Other factors, many of them environmental, also affect motor performance and these have to be measured, analysed and considered before a true preventative maintenance regime can be developed.

As far as train delay reduction is concerned, Network Rail's view is that the application of RCM to points will give a 40% initial annual delay minute saving with a reducing subsequent benefits profile as worst performing assets will be dealt with first. In the light of experience in East Anglia these figures seem reasonable.

4.1.1.3 Signalling Power Supplies

The monitoring of signalling power supplies is generally carried out as part of a wider data logging system, and hence appears on the SRF as part of Infrastructure or Signalling RCM (e.g. activities #1, #10, #11) rather than on the box 'Power supplies'.

Some power supply failures are preceded by a period of detectable gradual degradation (e.g. earth leakage caused by cable fault), and hence are predictable; other failures happen suddenly without a definable precursor event (e.g. blown fuses), and hence are more difficult, if not impossible, to predict.

Network Rail's experience in areas where extensive power supply monitoring has been installed (e.g. Bender units on East Anglia Route) is favourable; and even when unpredicted failures occur, the existence of RCM can still save train delays by speeding up the process of fault rectification.

Network Rail's view is that the application of RCM to signalling power supplies will give a 75% initial annual delay minute saving with a reducing subsequent benefits profile as worst performing assets will be dealt with first. There is no hard evidence from controlled experiments to support this figure, however engineering judgement and consideration of the failure modes suggests it is not unreasonable.

4.1.1.4 Other Signalling categories

Other asset groups within Signalling, such as individual signals and cables, are in principle amenable to RCM, since they have relatively simple failure modes which are often preceded by a period of gradual degradation (e.g. reduced insulation resistance as a result of cable damage) or by a defined precursor event (e.g. failure of the first filament of a double-filament lamp). But these asset classes consist of large numbers of distributed assets, making the application of RCM expensive. Network Rail's policy of concentrating its RCM effort on the three key assets (section 4.1.1 above) is considered to be sensible.

In the case of level crossings, RCM is available as a spin-off from data-logging which is provided primarily for the purpose of post-incident investigation; but since the train delays caused by level crossing failures account for less than 1% of total delay, there is limited scope for savings.

4.1.2 Track

Track issues account for just over a quarter of all infrastructure-related train delays and the majority of these are caused by just two items: ‘Broken rails / track faults’ (4.8% of overall delay) and ‘TSRs’ (1.8% of overall delay).

The activities reviewed indicate a significant amount of RCM activity in both these areas, particularly rail temperature monitoring. The items in the RCM list have been developed primarily by locally driven initiatives on an as needed basis and very much dependent upon the importance given to them by the local Infrastructure Maintenance Manager (the title of the role relevant at the time). The items have, in some cases, been developed in conjunction with one supplier whilst elsewhere in the country a similar development may have taken place on another Territory with a different supplier depending upon local contacts. The activities are now being co-ordinated centrally within the maintenance organisation and this will hopefully lead to a better spread of knowledge and also reduce any duplication in effort expended on trial and error.

For many of the asset classes considered in this report, the application of RCM is intended to alert for a potential fault which can then be attended to before it develops into failure mode and will hopefully avert any delays to trains. For the majority, if not all of the Track items subject to RCM, the opposite is generally the case, in that the alert is given when a condition is reached where action is needed that actually causes delays in order to maintain safety. For example remote monitoring of rail temperature alerts the Infrastructure Teams when the temperature is about to exceed the Stress Free Temperature (SFT) at which point a precautionary TSR will be imposed to reduce risk in case of track buckles. Thus, the RCM device is giving added levels of safety but will inevitably lead to an increase in train delays rather than reduce them. Conversely, it could be argued that better knowledge of the asset condition and/or performance may allow the TSR to be imposed later than would have been the case without this level of monitoring and thus the delays may in some cases be reduced. Certainly in the case of SFT monitoring of the rail temperature, the increased number of locations should in general allow the TSR to be removed more quickly with an increased knowledge of the temperature as the rail cools down. However, because the rate at which TSRs are removed in hot weather is an inexact science it is impossible to quantify the level of benefit derived from having the rail temperature monitored.

Several activities which are not in the RCM list from Network Rail were included in the review as it was felt they contribute to reducing delays while not generally regarded as RCM. For example track recording is generally thought of as being for track safety/quality and is regarded as an inspection. However, the NMT (activity #103) measures condition remotely and then the data provided is acted upon to plan maintenance work which in turn results in better track quality, reduced TSRs and faster train running. A similar argument could be put forward for Ultrasonic Test Trains (activity #21) which locate rail flaws and thus allow speedy removal which in turn reduces delays.

4.1.3 Civils, E&P, Telecoms

The biggest single delay causation within this category involves electrification systems ('OLE / 3rd Rail', 1.5% of overall delays).

4.1.3.1 OLE / 3rd Rail

There are a number of niche suppliers of 3rd rail RCM equipment. 3rd rail position measurement equipment is fitted to a small number of track geometry measurement vehicles used in the US, but to our knowledge not used in the UK or elsewhere in Europe. We have not progressed investigation into this equipment as there appears to be no business need for it in this country.

Both 3rd rail and OLE power supplies are remotely monitored. This tends to be undertaken at the feeder station using conventional data loggers and with alarm triggers to enable Electrical Control Rooms to monitor supplies and switch sections as appropriate. This monitoring is generally provided as an integral part of the traction power supply installation, and as such it is regarded as a legacy system for the purposes of this report.

A number of systems for monitoring the position and performance of both the catenary and the pantograph pick-up are in use in the UK and mainland Europe. Deployment and business use across Europe seems variable. A number of UK train operators indicated that they got benefit from the Panchex system (activity #7); NS in Holland undertake a significant amount of pantograph monitoring to improve performance in cold weather from which they gain benefit, whilst elsewhere some Panchex locations are not used at all and France does little OLE monitoring apart from position measurement.

4.1.3.2 Lineside Structures

In terms of lineside structures the main items subjected to RCM are Bridges (flooding and condition).

The extent to which lineside structures contribute to train delays is small (0.5% of overall delays); but, as with many of the RCM items relating to Track (see section 4.1.2 above), the alert is generally given when a condition is reached where action is needed that actually causes delays in order to maintain safety. For example in the case of bridge flood monitoring, the alert will be given when the water has reached a level at which a TSR or track closure must be imposed. Thus, the RCM device is giving added levels of safety but will inevitably lead to an increase in train delays rather than reduce them. Conversely, it could be argued that better knowledge of the asset condition and/or performance may allow the TSR to be imposed later than would have been the case without this level of monitoring and thus the delays may in some cases be reduced.

However, it can be further argued that better knowledge of the structure and flood conditions may allow the speed restriction and/or closure to be lifted earlier than would have been the case with conventional visual inspections.

Some embankments that are subject to instability are also being monitored such that alerts are given if any movement occurs. Previously the stability would have been monitored by means of visual inspections relying on the skill of local staff to notice any signs of movement at an early stage. The remote monitoring can thus allow for normal track inspection frequency to take place, safe in the knowledge that movement will be picked up immediately and alerted in order to impose precautionary corrective measures.

In a limited number of cases there are strain monitoring gauges on bridges that can warn of any potential overstress of the bridge after it has been subjected to load. This is currently in use on isolated and little used freight only branch lines where some older bridges need to be examined to allow passage of a limited number of trains. Prior to the bridges being instrumented in this way, a visual inspection would have been needed on each occasion.

4.2 Trains

Technical train faults are responsible for 15% of overall system delay, although this increases to 19% if uncoded faults and depot management and processes are included.

Noting the limitations of the analysis (Appendix D), the largest contributors to this delay are: battery/control systems (28%), doors (20%), air systems (10%) and signalling/warning systems (8%). The first of these contributes 4.1% of system delay, while the others between 1% and 3%.

Provided failure modes are gradual or preceded by a measurable event, the reliability of all train systems could benefit from RCM because it:

- Provides a precise record of what is happening so investigators have quality information on tap to advise the driver, assist recovery, facilitate post-mortem and help prevent recurrence. Investigators do not need to spend a lot of time gathering and sorting data as would have traditionally been the case.
- Facilitates reduction of repeat occurrences through provision of better information for fault diagnosis, in particular contextual information, i.e. what was happening operationally with the driver and the train at the time of failure.
- As reliability grows, RCM allows degraded modes to be addressed before they result in in-service failures; maintenance can become less reactive and more pro-active.
- Enables the planning of timely repairs whilst minimising resource utilisation, e.g. trains with an emerging fault can be directed to a depot that has the resources to carry out the repair and the depot can plan it into its workload.

Where fully integrated into business processes, RCM on trains has delivered some notable successes both for new build and retrospective application on existing trains. This explains the large number of blue markings at the top of the SRF in figure 13.

4.2.1 New Build

Trains built in the last decade all tend to have RCM functionality that utilises the Train Management System (TMS) which is fitted as standard and able to measure and record system and sub-system condition, although extent varies with build and supplier. As does the extent to which the train is able to communicate that information to the outside world, varying from on-demand interrogation or automatic alerts through to more passive local download when on depot.

Bombardier, Alstom and Siemens all have systems in operation[9] with some notable successes. For instance, Alstom's Fleet Console system (activity #52) used with data from Virgin's Cl390 Pendolinos has assisted in doubling train reliability during the 12 months following Fleet Console's introduction. Similarly, Bombardier's Orbita (activity #71) helped to contribute to a doubling of reliability on Scotrail Turbostars. It is difficult to quantify the exact benefit that such RCM processes have brought, but clearly RCM has played a significant role through the benefits outlined in section 4.2) above. This can be achieved relatively cheaply at build, particularly if the system integrator has already got a system that has been proven on other vehicles, and the communications can piggy-back onto a system that is already required for other functions such as provision of passenger and reservation information.

4.2.2 Existing Fleets

The challenge is to bring RCM to existing rolling stock where remaining life justifies it. DfT is seeking to use the franchise contract to encourage fitting RCM to rolling stock that has significant time left in service, through life extension or otherwise; a decision in which DfT is now playing a bigger role. However retrospective fitting of sensors and connecting them to data storage and communications is not necessarily cheap.

All three ROSCOs and a number of suppliers are actively engaged in retrospective fitting of RCM to existing fleets. The most advanced of these is TAPAS developed by HSBC Rail and Tesella (activity #50) where fitting to the Southern Cl455 fleet has helped reliability to triple from 7,000 miles per casualty to 19,000 over 18 months. Contributory to this, data availability has enabled a reduction from 30% no defects found, plus a significant quantity of misdiagnosis, to 2% no defects found.

Also of note regarding retrospective fitting, is a system fitted being fitted to loco hauled sets by National Express East Anglia (NXEA, activity #112) and a service that is being developed by Rail Door Solutions (RDS, activity #109):

- NXEA's strategy was not driven by a need to improve reliability as much as it was to minimise the consequences of failure by facilitating rescue. The system has been designed and integrated by NXEA from off the shelf equipment because nothing else was available commercially that met their needs; even the software is written to NXEA's specification. Raw data can be presented to ground based staff in real time, mimicking the cab condition

[9] Representatives from Hitachi have not been interviewed regarding the Cl395.

and also vehicle status on simplified schematics. It is effectively a health status monitoring system with remote visualisation.

- RDS is developing Rolling Stock System Management (RSSM) for monitoring the condition of doors initially, although the strategy could be applied to other systems. They have developed a box that can be quickly fitted to each door locally with minimal wiring that provides a simple visual indication of condition to maintainers with USB download providing raw data. This is being developed into a system that will allow a number of slave boxes to be fitted to doors which communicate wirelessly with a master box that will provide remote download capability. Although development is on-going and reliability would need proving, the strategy is significant because it could avoid the costs and downtime associated with extensive retrospective hardwiring.

4.2.3 Gaps in RCM use[10]

As of mid-2008 there was significant variety in the extent to which RCM was being used across TOCs. The National Task Force Fleet Challenge Steering Group and ATOC Engineering Council are seeking to remedy this and have all TOCs using RCM in the next 1-5 years. Noting that RCM on trains is facilitated by the presence of a TMS, there are a number of barriers to this:

- Most older vehicles are not fitted with monitoring systems and significant capital investment is required which may not be viable within the remaining vehicle life. TAPAS (activity #50) is a notable exception.
- Remote download is a feature on only the newest vehicles and manual download requires significant resources when it comes to collating fleet wide data.
- Even when available through remote download, large amounts of data do not necessarily mean useful information. At least one TOC is currently working on how to improve analysis of the many SMS messages it gets from TMS systems on one of its fleets.

There is however at least one TOC where RCM is no longer an 'additional nice to have' and it is fully integrated into their management processes.

Aside from the more technologically advanced TMS, some TOCs are making significant use of OTMR data as a means of systematically analysing driving style, which could also be used to provide basic information on train condition. Such strategies are hampered by the wide number of OTMR systems in use (even within a TOC) and the differing abilities of the proprietary software to allow trend analysis and provide useful information across *a large number of vehicles and/or drivers.* At least one TOC has invested in data analysis software from Avenca (activity #110) which compares large amounts of OTMR records against a set of rules (describing an ideal run) to identify exceptions.

[10] This section is based on work done in a separate 2008 study by kind permission of ATOC.

4.2.4 Potential reliability improvement

It is estimated that roughly 40% of fleets in operation have some form of RCM capability (although not necessarily with remote download capability) and cover approximately 50% of fleet miles. Assuming:

- Successful implementation of RCM with remote downloading capability can facilitate doubling of reliability (although it is likely more can be achieved with time).
- Half of the fleets by mileage with RCM (i.e. a quarter by mileage overall) have already seen this improvement and this is reflected in the data used to produce the SRF. The remainder of the fleets with RCM, a quarter of fleets by mileage overall, have therefore still to see this improvement.
- Of the fleets not currently fitted with RCM (half by mileage):
  - RCM will not be justifiable for roughly a quarter of these fleets by mileage (1/8 by mileage overall), and will be eventually replaced with fleets that do have RCM.
  - The remainder will benefit fully from RCM (3/8 by mileage overall).

Then roughly a 30% fall in train delay minutes[11] can be expected when the benefits of RCM (doubling reliability) are seen on all fleets for which RCM is currently justifiable. When fleets where RCM cannot be justified are replaced, and the reliability of new fleets has matured, this is expected to increase to around 40%.

These figures are conservative and more is likely to be possible because:

- The estimation assumes that all trains contribute equally to existing delay minutes, when in fact more will be accumulated by those fleets which have yet to see benefits from RCM. Thus there will be a larger proportion of delay minutes that will be subject to reduction.
- RCM, in conjunction with other improvements, is likely to contribute to more than a doubling of reliability.

[11] Compared with the data used in the SRF.

4.2.5 Duplication of activities

At train system level there is considerable duplication of activities. Each train manufacturer has developed their own system and is using it to help manage fleets on which they are responsible for maintenance, or even providing it as a service to others who are responsible for maintenance on fleets that they have manufactured. However it is difficult to see how it could be any other way; putting aside the differences between vehicle management systems, would one manufacturer use another manufacturer's system? The realisable benefit here is to standardise the communications protocol between train and ground so that RCM which is fitted retrospectively can take advantage of proven analysis capabilities[12]. DfT would support this.

At sub-system level there is also duplication on door systems, driven no doubt by the fact that doors across many fleets remain a frequent cause of poor reliability. In addition to the train wide RCM systems (located against the 'Train' box on the SRF in figure 13), there are three other developments going on led by Angel Trains (activity #105), RDS (activity #109) and academic research by the University of Birmingham and Herriot-Watt University (activity #75). All are in the early stages of development.

There is also a number of systems capable of monitoring low adhesion: the Adhesion Management System (activity #41), TAPAS (activity #50), Cl390 Pendolino (activity #52), Orbita (activity #71) and Siemen's RCM (activity #106). However, rationalisation is unlikely here for the aforementioned reasons. Instead the latter four activities would be able to provide useful inputs to the first if it gets rolled out to lines on which the relevant vehicles operate.

4.2.6 Learning points and good practice

A number of learning points and suggestions for good practice are given in Appendix E.

4.2.7 Innovative approaches

- While as yet unproven, RDS (activity #109) plans to connect sensors wirelessly on the train to minimise long cable runs, although local ones will still be required for power.
- Vehicle engineers have traditionally been hesitant to fit equipment to vehicles without 'tractionisation' to prove reliability in the rail environment. However, a number of existing RCM systems have used Commercial Off The Shelf (COTS) equipment with success, bringing the advantages of lower costs, shorter lead times and less development risk.

[12] There is a number of data collection systems already in place for rolling stock and more are being developed. Each system typically has a dedicated ground based mechanism of analysis, so selection of the data collection system predicates the analysis system and vice versa. Standardising communication protocols between train and ground would mean independent selection of train equipment and analysis process, and enable anyone to develop a solution on one side of the interface which is automatically compatible with equipment available for the other side of the interface. National Task Force Fleet Challenge Steering Group and ATOC Engineering Council already recognise the value of such standardisation.

4.3 Rules & Processes

This category is relatively small in terms of overall train delay (3%), and contains only one significant individual causation, 'Possession over-run', which accounts for 1.4% of delays.

This category is not considered to be amenable to RCM, and there are no RCM activities currently associated with this category.

4.4 Operations

This category contains the biggest individual delay causation category, 'Traincrew', which accounts for 6.4% of delays. The majority of this delay (4.9%) is TOC self-inflicted (i.e. 'TOC on Self') and the remainder (1.5%) is 'TOC on TOC'.

This category also contains three other significant causations: 'Train operations' (4.4%), 'Station delays' (4%), and 'Signalling operations' (3%).

All these delay causations arise primarily as a result of human actions (or inactions), as opposed to equipment failure, and are not generally considered to be amenable to RCM. There are no RCM activities currently associated with this category, however recognising that drivers form only a part of the traincrew establishment, modern train TMS systems could provide value in monitoring events.

4.5 External

This category is second only to Infrastructure in terms of overall delays, with nearly a quarter of all train delays being caused by people or events which are outside the railway's direct control.

This makes prediction difficult, and the role of RCM is in many cases confined to reporting and recording events as they happen (e.g. CCTV on trains or at stations and level crossings).

But there are cases where RCM can be predictive, e.g. adverse weather can generally be forecast in time to enable precautionary measures to be put in place, such as speed restrictions to reduce the incidence of OLE damage during high winds, or TSRs where very high rail temperatures are expected, to reduce the impact of track buckles.

4.6 Other

This category comprises some 9% of total train delays which cannot, for various reasons, be sensibly allocated to a specific causation; it includes unexplained and uncoded faults, and non-technical delay attribution issues.

Since the causes are not known, this category is, almost by definition, not amenable to RCM, and there are no RCM activities currently associated with this category.

4.7 Opportunities for cross-interface activities

The monitoring classification analysis (section 3.2.2) shows that the majority of the RCM activities within our sample (80%) are self-contained within the asset type (i.e. trains monitoring trains or infrastructure monitoring infrastructure). But a surprisingly high proportion (60%) of RCM activities in the sample are 'cross-asset' (i.e. trains monitoring infrastructure, or infrastructure monitoring trains, or infrastructure monitoring the environment). Future opportunities to increase this still further are outlined in the following.

4.7.1 Trains monitoring infrastructure

From first principles, a train that has RCM fitted to all its main sub-systems should be able to monitor some aspects of its interfaces with the: track, train control system, communications system and traction supply.

Many of the RCM systems deployed on trains, particularly those based on TMS, are able to monitor some aspects of these interfaces from the train perspective. For instance, the Cl390 Pendolino (activity #52) has accelerometers fitted the bogies and can therefore provide an indication of track quality. It is also able to identify defective balises.

While there are a number of cases where this information is being communicated to Network Rail, many of those interviewed felt that a lot of data is being thrown away. The identification of data that could be better used is dependent on exactly what data is being captured by each system, and how useful that data would be to Network Rail in monitoring asset condition. Discussion on the detail is required between the affected parties.

4.7.2 Infrastructure monitoring Trains

The survey has identified a considerable number of different trackside train inspection and monitoring systems around the world.

Nearly all of these systems use hot axle-box detection (HABD) equipment which is prevalent across most major networks and available from a number of international suppliers. It is used to protect passenger networks and also heavy haul freight. The experience of many users is that false alarms (resulting for instance from other heat sources on the train apart from failed axle bearings) are an order of magnitude higher than actual failed bearings. However, the disruption and damage effects of a failed bearing mean that rail networks accept the nuisance value of this poor detection rate. It is beyond the scope of this report to identify the advantages and disadvantages of each HADB system; suffice to report that many networks are into their second or third generation of equipment. Heavy haul lines with captive fleets network the HABDs and combine information with Automatic Vehicle Identification (AVI) systems, to monitor bearing and brake temperature along the route of a train in order to intelligently try and predict failures. Using this information many railways find they can more accurately predict early problem bearing units. In the future, it is Network Rail's intention to combine HABD measurements with AVI and use the information for condition monitoring.

In addition to HABDs many railways combine these inspection locations with other systems such as:

- Wheel Impact Detection
- Bearing Acoustics
- Dragging equipment
- Wheel profile measurement
- Bogie ride performance (hunting)
- Brake and wheel tread condition
- Vehicle gauge and envelope

There are a number of suppliers of these combined systems. Most supply to their local markets. The US has a significant demand for these systems owing to the need for remote inspection and the many miles a vehicle will travel before manual examination. However, DB (Germany) uses automatic inspection systems for its ICE trains and sophisticated systems are in use in South Africa, Australia, Japan and Hong Kong. Most of these railways use the information the systems provide as alarms protecting against significant incidents in remote locations; however wheel impact measurement and bearing acoustics especially are used to predict and programme maintenance of wheels and bogies. In many respects the UK rail industry does not deploy these RCM tools to the same extent nor use the information for predictive maintenance to the same level as many other rail networks. There has been considerable use of this equipment and much sophisticated research done by heavy haul railways across the world to use RCM information to reduce maintenance costs of both infrastructure and traction and rolling stock.

4.7.3 Automatic Vehicle Identification (AVI)

AVI is not as such remote condition monitoring. However, it became apparent from many of the interviews that without a standard, reliable and accurate method of identifying vehicles as they pass trackside remote monitoring sites much of the value of trackside RCM is being lost. If the RCM sites are only to be used as alarms for potential failure (as most of them are at present) then AVI is not required. However, many railway administrations are also using and enhancing these measurement sites as methods to record the normal performance of vehicles and track long term trends. They find that what may be an alarm for one vehicle type is not for another. Being able to differentiate this information is crucial to the performance of the monitoring systems. Currently in the UK it takes some time to combine HABD (activity #24) information with train ID, train consist and the vehicle number and it certainly cannot be done quickly and automatically. Panchex (activity #7) works successfully with AVI, but the extent of fitment is limited. Various vehicle fleets in the UK transmit GPS information or have different RFID tags which require different AVI readers. To be able to have a consistent and quick method to match vehicle information with recorded measurements and data will be of considerable advantage to future RCM developments in the UK.

5 Conclusions

Note 1: These conclusions are based on results from data supplied to generate the SRF (see section 3.1). Significant changes in system or sub-system reliability could therefore invalidate some of these conclusions.

Note 2: Some of the information used to formulate conclusions in this report was provided to ART in confidence and cannot therefore be documented.

- The principal causes of train delay can be considered as being of two broad types: 'Hardware' causes accounting for 47% of delay minutes (e.g. trains and infrastructure) and 'People' causes accounting for 53% of delay minutes (e.g. operations, processes, and external factors such as vandalism)[13].
- The 'Hardware' causes are generally amenable to the application of RCM, whereas the 'People' causes are not generally amenable to the application of RCM, although there is a grey area of around 10% where some benefit may be obtained from RCM, e.g. using trainborne TMS data to monitor driver behaviour, further CCTV to harden targets against vandalism and theft, etc[14]. Furthermore, while much of the 'People' causes may not be amenable to direct benefit from RCM, they may see some indirect benefit as improved asset reliability is likely to have knock-on benefits and reduce delays from such activities as possessions and track patrols.
- Within the 'Hardware' category, the extent of current application and maturity of RCM to Trains is much higher than for Infrastructure; and the extent to which RCM has already achieved reductions in train delays, whilst difficult to quantify, is considered to be correspondingly greater for Trains than for Infrastructure.
- The scope of current application of RCM to Trains covers all the main on-board systems and sub-systems; most new-build trains have comprehensive RCM capability when considered with ground based analysis systems. Few older fleets have been fitted retrospectively but, where fitted, significant reliability improvements have been seen and the RCM capability is thought to be at least contributory to this.
- The extent of existing application of RCM to Infrastructure is dominated by three asset classes: track, points, and electrification systems. These do not fully align with the major infrastructure causes of delay, which are track, points, track circuits, and signalling power supplies; but Network Rail's strategy for future RCM application will go a long way to ensuring that the most significant causes of delay are prioritised.

[13] 'Hardware' is made up of Infrastructure (28.8%), Trains (14.6%), and from External: Low Adhesion (2.2%) and Bridge Strikes (1.5%). 'People' is made up of Operations (20.7%), Rules & Processes (2.9%), External less Adhesion and Bridge Strikes (20%) and Other (9.2%). See SRF (section 3.1) for a detailed breakdown.

[14] It is estimated that 10% of this may realise some benefit to varying degrees from RCM related to: 'Passengers, Freight and (trainborne) Vandalism', Weather, (infrastructure) Vandalism/theft and Traincrew.

- The majority of the RCM activities within our sample (80%) are self-contained within the asset type (i.e. trains monitoring trains or infrastructure monitoring infrastructure). But a surprisingly high proportion (60%) of RCM activities in the sample are 'cross-asset' (i.e. trains monitoring infrastructure, or infrastructure monitoring trains, or infrastructure monitoring the environment).
- There is a reasonably even spread among activities across the first three monitoring levels (report, warn, warn with cause), but fewer activities are able to provide data to facilitate design improvements.
- As far as potential value to reliability is concerned, no activities appear in the green region[15], i.e. no activities had the highest possible score. It is also notable that all the activities in the blue region relate to trains, whereas the infrastructure activity with the most potential is in the yellow region. This reflects the greater maturity and success of train RCM solutions compared to infrastructure.
- On the basis of our sample, we have found a wide geographic spread of RCM activity. There is a significant concentration of activities in the UK reflecting the locus of the review and our knowledge, although it may also be due to the UK putting significant effort into RCM. Aside from the UK, no one country has an unusually high concentration of RCM activities. Within the UK it is noticeable that the highest concentration of infrastructure based RCM activity occurs in one specific area (East Anglia), but this is considered to be due to the fact that the installation of RCM on the infrastructure has historically been largely a matter for local managerial discretion, together with the fact that Anglia has recently been regarded as a pilot for RCM schemes.
- A significant proportion of RCM systems are intended primarily for purposes other than train delay reduction (e.g. as a form of hazard mitigation, or to facilitate post-incident investigation) but there is nevertheless some spin-off benefit either in terms of fault prediction or fault diagnosis and rectification.
- The benefits of RCM need to be seen not just in the context of reliability in the short term; RCM can also provide cost savings through optimised maintenance regimes, or by informing renewal and design activities, as follows:
    - Maintenance: The analysis of failure data obtained through RCM can be used in conjunction with reliability-centred maintenance techniques to optimise the asset inspection and maintenance regime (in terms of what is done and how often it is done) to suit predicted degradation, both for the assets which are monitored and generically for that asset class.
    - Renewal: The optimal timing of renewals (i.e. the determination of the point at which an asset has reached the end of its economic life, and it is better to renew it than to keep it in service) can be informed by RCM data regarding asset condition and predicted degradation.
    - Design: RCM can provide a better analysis of the root causes of asset failure than post-failure investigation can, hence giving a basis for improved design in the future.

[15] See section 3.3 for explanation of colour coding.

- For infrastructure, there is little in the way of objective evidence of the benefits already being accrued from RCM. We did not discover any cases of control experiments being carried out to compare the failure rates of RCM-fitted hardware with similar non-fitted hardware (although Network Rail's proposed pilot scheme in Scotland may rectify this situation). For trains there are some cases where RCM fitted trains can be compared against similar fleets without RCM, e.g. Scotrail Turbostars.
- The greatest potential for reduction in train delays is likely to come from a relatively small number of asset classes, as follows:

Asset class	% of overall train delay now	Potential for reduction by RCM	Reduction in % of overall train delay after RCM reduction
Track Circuits	5.1	30%	1.5
Points	4.6	40%	1.8
Signalling power supplies	2.5	75%	1.9
Rails	4.8	30%	1.4
Electrification systems	1.5	30%	0.5
Trains	15	30%	4.5
Total:			**11.6**

The 'Potential for reduction' figures in the table above are derived as follows:

- o Track circuits, Points, Signalling power supplies: These are based on Network Rail's figures, as discussed in sections 4.1.1.1, 4.1.1.2 and 4.1.1.3 respectively.
- o Rails, Electrification systems: The available data does not provide any equivalent quantification, and the figure of 30% in each case is our judgement based on the information provided by interviews.
- o Trains: The derivation of this figure is explained in section 4.2.4.

These potential reductions are central estimates and are subject to a tolerance of around +/- 30%.

- The total potential reduction in train delay minutes from the application of RCM (roundly 12% from the above table, perhaps 15% if the smaller contributions from other asset classes are included) is lower than current expectations within the industry. Given the importance attributed to RCM, these numbers should be tested through discussion with key industry stakeholders, taking account of the results of controlled experiments.
- To achieve these reductions, a number of actions need to be taken, over and above the straightforward fitment of more RCM systems; in particular, there needs to be an industry-wide strategy for RCM covering key issues such as data protocols, communication networks, ontology, and AVI. See suggestions for further work in section 6.

- To achieve better reductions than those quoted above, there would need to be considerable improvement in the effectiveness of the predictive algorithms currently used in RCM systems, to better link condition to incidence of failure (e.g. points and track circuits). Quite a lot of work has been done in this area but more is justified to enable better rates of fault prediction/prevention to be achieved, given their prominence in the SRF.
- There is a considerable amount of data available from train RCM systems that can provide information on infrastructure condition such as adhesion and signalling system condition. This is made all the more valuable when seen in the context of what other trains are seeing provided real-time data downloading is available. Some of this information is being used to assist Network Rail in responding to in-service problems however more is likely to be possible through a coordinated industry response.
- Real time downloads from the train are a necessity for the reasons outlined in Appendix E. Recent work by Interfleet on behalf of ATOC seeks to define a minimum specification for data downloading, which amongst other things includes ways in which train data can be used to monitor the condition of the infrastructure.
- Return on investment in RCM will only be maximised when monitoring is integrated in to business processes and sufficient resources are in place to manage and respond to monitored events. Even with processes in place, a change of culture may be challenging, i.e. convincing people who've spent their careers changing failed parts to believe the system when it is telling them to change a part that has not yet failed.
- A few RCM activities have not been included in this review because they have already solved the problem and are considered to be standard practice. They include:
  - Signal lamps (first filament failure).
  - Traction power supplies.
  - On Train Monitoring Recorders (OTMRs) although these are fitted primarily for safety reasons rather than reliability.

  While considered standard practice, hot axlebox detectors (HABDs) are included in the review because of alternative technologies which present opportunities.

  Appendix A give more information on some of these legacy activities.

6 Suggestions for further work

6.1 Cross-functional

- The predicted reliability improvements from RCM should be tested through discussion with key industry stakeholders, taking account of the results of controlled experiments.
- AVI is not as such remote condition monitoring but it is an essential enabling facility and a common system is needed throughout the GB rail network to enable efficient RCM. Several possible technologies are already available, e.g. RFID tags and GPS location information.
- Noting the considerable activity already taking place to reduce system delay, the industry needs to recognise that around 40% of delay is not amenable to reduction through RCM and act accordingly. The 'events' responsible for this delay are the bulk of those shown on the right hand side of the SRF (see section 5).
- The industry needs to consider standardising the communications protocol between train and ground.
- Many of those interviewed stated that a lot of data from trains is being thrown away; data which could be useful to Network Rail in monitoring asset condition. While some data is already being provided to them, more value is likely to be obtained by the affected parties identifying what specific data is available, what would be valuable and the mechanism required to provide it (e.g. development of a model contract). Measurements that can be shared across the interface include:
    - Track quality
    - Defective balises
    - Defective AWS magnets
    - Wheel Impact Detection
    - Bearing Acoustics
    - Dragging equipment
    - Wheel profile measurement
    - Bogie ride performance (hunting)
    - Brake and wheel tread condition
    - Vehicle gauge and envelope

  Activities reviewed which can provide useful measurements across the interface and which may not already be being used to full advantage are:
    - Cl390 Pendolino (activity #52)
    - Orbita (activity #71)
    - Siemen's RCM (activity #106)
    - TAPAS (activity #50)

- Consideration should be given to developing a '20 point plan' for RCM along the lines of that developed by NFRIP for reliability and by ATOC for energy management. This could incorporate best practice and could utilise many of the points raised in this report (see Appendix E).
- Many rail administrations around the world use information from combined RCM systems to provide alarms to protect against significant incidents in remote locations and to predict maintenance requirements, reducing cost. Notwithstanding the considerable learning and activity already present in the UK, there may still be scope to learn from this.
- Work is required to develop better algorithms that link condition to incidence of failure in the following areas:
  - Track circuits
  - Points monitoring
  - Video inspection and image recognition[16]
- A couple of the activities take advantage of 'stress wave analysis' to identify deteriorating condition (activities #69 and #107). Further investigation into this technique may be worthwhile.

6.2 Infrastructure

- Controlled experiments should be undertaken to enable the benefits of RCM fitment to be quantified to inform business cases.
- An industry wide ontology is required as a basis for integrated communications and data analysis. The Integrail work could provide a foundation for this.

6.3 Trains

- Fleets that do not currently have RCM need systematic consideration to see if RCM is justifiable, taking into account the train systems that will benefit most and the value that will bring over the remaining vehicle life. The National Task Force Fleet Challenge Steering Group and ATOC Engineering Council are already progressing this.
- Such RCM systems should be accompanied by real-time data downloading.
- There may be benefits in standardising some RCM components, yielding better utilisation of resources during development, greater reliability and reduced problems with obsolescence. However such standardisation might be at the expense of innovation.
- With similar fleets now being operated by more than one TOC, casualty coding systems should be transparent to facilitate early identification of failure trends in what can then be a larger sample of vehicles.

[16] Currently this is at an early stage and is proving difficult because of certain problems with image recognition but this should be developed for future use. There is potential for this to measure clearances, vegetation control etc. It may be possible to use this for certain inspections but the very varied installation of components such as numerous different types of rail fastenings makes recognition even more complicated.

- The results of this work need to be considered in the context of other recent work by National Task Force Fleet Challenge Steering Group and ATOC Engineering Council, including work done by Interfleet to establish a minimum specification for data downloading.

6.4 Activities providing similar function

There is a number of RCM activities with similar functionality. The industry may wish to consider standardisation to promote efficiency and compatibility, although this could be at the expense of innovation:

- Stress Free Temperature monitoring: SFT Pro (activity #5), MAPS (activity #83).
- Track geometry measurement: UGMS (activities #13, #61, #62), NMT (activity #103), IRIS 320 (activity #93).
- Points condition monitoring: ACIC (activity #68), Balfour Beatty (activity #12), PMMS (activity #3) and Strukton Rail ('POSS'), as well as legacy Network Rail installations (activity #25). INRETS (activity #76) and the University of Birmingham (activity #77) are also working on improving failure prediction.
- Vehicle Monitoring Systems: Cl390 Pendolino (activity #52), Orbita (activity #71) and Siemen's RCM (activity #106). These are all fitted at build; where as TAPAS (activity #50) provides similar capability as a retrofitment.
- Door failure prediction: In addition to the above vehicle monitoring systems, there are three other developments going on led by Angel Trains (activity #105), RDS (activity #109) and academic research by the University of Birmingham and Herriot-Watt University (activity #75). For retrofitment there is strong synergy between activity #105 which seek an effective means of transmitting data, and activity #109 which has a means of measuring door performance.
- Low adhesion detection: ACIC leaf fall monitor (activity #154), Adhesion Management System (activity #41) in addition to the above vehicle monitoring systems although it is likely that the latter would provide inputs to the adhesion management system if it gets rolled out the lines on which the relevant vehicles operate.
- Bearing failure prediction: HABDs (activity #24) and RAILBAM (activity #29).
- Wheel flat detection: Gotcha (activity #23), VIEW (activity #104) as well as legacy systems (Appendix A).

6.5 Activities to be considered for deployment

The following activities used elsewhere in the world should be considered for application in the UK:

- Railsense (activity #57) is being employed in an operational setting in the Netherlands. It aims to search for the real cause of hitherto unexplained fault behaviour, and to build empirical models as a basis for a dynamic maintenance management system to improve reliability.

- RAILBAM (activity #29) in use in Australia, US, Canada and Brazil. It acoustically measures bearing condition.
- IRIS 320 (activity #93) in use in France. It measures several parameters beyond those measured by traditional track measurements trains i.e. catenary, signals and telecoms.
- SFT Pro (activity #5) in use in Canada mainly. It measures rail stress free temperature.

The following activities are in limited used in the UK and should be considered for further deployment, noting that other products may already be performing a similar function:

- Automatic Vehicle Identification.
- ACIC leaf fall monitor (activity #154), currently used on Southern.
- ACIC points condition monitor (activity #68), currently used on Southern.
- UGMS (activity #13), currently used on Chiltern, WCML and ECML.
- Strainstall bridge monitoring (activity #94), currently used in Wales.
- Findley Irvine weather station (activity #4), currently used in Banbury and Paisley.
- ACIC weather station (activity #102), currently used on Southern.
- As far as trains are concerned, manufacturers should continue to implement RCM at build (activities #52, #71, #106)[17], and existing vehicles should be considered for retrofitment. Good examples are:
    - TAPAS (activity #50) currently used on Southern and to a lesser extent Scotrail.
    - The RCM being fitted by NXEA to their loco-hauled sets (activity #112).

Note: From the list of installed items it was obvious that local initiatives had taken place at varying rates throughout the UK leading to a concentration of some activities in East Anglia for example. The newly formed central team in Network Rail will hopefully be drawing upon the benefits derived from each of the systems so far installed and will roll out the ones deemed to give the best contributions to improving performance/reliability and hence reducing delays.

[17] This is consistent with DfT policy which seeks to ensure all new trains have RCM with real-time download capability, thus enabling problem diagnosis off the train (not just by the driver).

6.6 Activities needing further investigation

The following activities could not be investigated in detail due to insufficient information being available in time. Further investigation is suggested:

- 'New Condition Monitoring Techniques for Vehicle Suspensions', University of Leeds, UK
- 'Condition Monitoring from Theory to Practice', Alstom Transport Ltd, UK
- 'E-master', DeltaRail
- 'Argus (Wheel Profile Module)', Hegenscheidt MFD
- 'Wheelscan', KLD Labs
- 'Argus (Roundness / Flat Module)', Hegenscheidt MFD
- 'WCM', Tecknis
- 'HTD', Salient
- 'Argus (Crack Detection Module)', Hegenscheidt MFD
- 'Pegasus', ITSS
- 'HTK 499', Harbin VEIC
- 'Snooper', Docklands Light Railway
- 'POSS Points Condition Monitoring', Strukton Rail

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Appendix A Legacy RCM Equipment

The use of remote condition monitoring equipment for both traction and rolling stock and also infrastructure is not new to the UK rail network. There was a significant amount of research into practical applications by British Rail Research during the 1980's, which led to the development of a number of systems, including:

- Wheelchex (an infrastructure-based Wheel Impact Load Detector).
- Panchex (an infrastructure-based device which measures interaction between pantographs and OLE).
- OLIVE (a train-based device which measures interaction between pantographs and OLE).
- PADVIEW (a brake pad inspection system at Bletchley depot which proved effective at not only monitoring brake pad thickness, but also brake actuator performance indirectly).
- A train-based passenger counting system.
- A train-based track monitoring system.

Research was also carried out in a number of related areas, including optical recognition of vehicle numbers, and advanced analysis techniques for data recognition, movement of earthworks and tunnels, wireless networks within trains, and points monitoring.

Some of these systems were rolled out into service application, and their level of success depended as much on the business process in place at the time as on the intrinsic engineering effectiveness of the systems. Other equipment remained at the prototype stage, often because of cost, and reducing equipment costs have significantly increased the affordability of RCM systems since then.

Private companies were also undertaking RCM development at this time, e.g. Salient Systems in the US, and a Danish company called Caltronic A/S developed wheel flat detection equipment, and several companies developed hot axle box detection equipment. A number of these systems were deployed throughout mainland Europe and North America.

At this time modem transmission of data was very rudimentary and the bandwidth using dial-up technology limited. Nevertheless, a number of vehicles, notably Class 87 locos, an HST, EMUs, and also Class 37 locomotives were fitted between 1987 and 1990 with sensors, data capture equipment and modem transmission capability over the embryonic mobile telephone networks. The systems were used by Intercity, NSE, Regional Railways and the Freight businesses then in existence. They were developed to determine the business case for wider deployment of condition based maintenance techniques and to provide on-vehicle alarms for high coolant temperature, low fuel level and other parameters which at the time affected the operational reliability of rolling stock. However, in addition to immediate alarms transmitted to a local base, other condition based measurements were taken and held in a data logger for remote download, such as:

- Track quality.
- Passenger numbers.
- Power equipment duty cycles.
- Voith gearbox input and output bearing acoustics.
- Engine and gearbox oil temperature cycles.
- Operation, use and effectiveness of train Webasto heating systems.

From an infrastructure perspective:

- For many years it has been common practice to remotely detect the failure of the first filament of a double filament signal lamp as a means of predicting and avoiding complete signal failure.
- The remote monitoring of traction power supplies by electrical control operators by means of Supervisory Control and Data Acquisition (SCADA) systems has long been an intrinsic feature of electrification schemes.

Appendix B Existing Network Rail RCM Installations

B.1 Summary of existing installations

The current extent of Network Rail RCM activity is summarised in the following table[18]:

RCM type	RCM Population (period 9 2008/9)
Air condition monitor/HVAC	46
Axle counter monitoring	8
Bridge bash monitoring	0
Cable insulation monitoring - (Signalling)	132
Cable Theft logger	1
Data Logger - Interlocking Data Logger - TC (RCM)	563
Data Logger - Level Crossing	794
Flood Monitoring	46
Hot axle box detector	150
Pantograph uplift monitoring	30
Point condition monitoring (PCM)	247
Point heater monitoring	560
Power supply monitoring	146
Pumping	9
Rail temperature monitoring	161
Railhead condition monitoring (Leaf Fall)	72
Railhead condition monitoring (Salt)	0
Signalling power monitoring (Bender)	98
SSI logger	203
Standby generator management	30
Telecoms monitoring	29
Time-Division Multiplexer	45
UPS Management	63
Weather Station/Anemometer	9
Wheel impact monitoring	30
Total	**3472**

Some of these figures refer to the number of assets being monitored (e.g. point ends) and others refer to the number of monitoring sites (e.g. hot axle box detectors), so a straight arithmetic addition of the figures may not accurately represent the extent of assets being monitored.

However, the numbers do give a good appreciation of the extent of infrastructure-based RCM activity across the network (corresponding to categories 'I monitoring I', 'I monitoring T' and 'I monitoring E' as described in section 3.5), by asset type.

18 Data Source: Network Rail, 22/12/2008

B.2 Key features

A number of features stand out from the above:

- The extent of application of RCM varies considerately across asset classes; some assets (e.g. interlockings and level crossings) have a large proportion of the asset population fitted, and others (e.g. points) have a small proportion of the asset population fitted
- In some cases it is possible to form a view as to the completeness of coverage of RCM by considering the total asset population; e.g. there are roundly 20,000 worked point ends on Network Rail infrastructure, so the 247 instances of point condition monitoring represent about 1.2% of the assets
- In some cases it is possible to form a view as to the completeness of coverage of RCM by considering the distribution of monitoring sites (e.g. there are 150 hot axle box detectors (HABD), which means the average distance between installations is 65 miles. It is likely that a large proportion, if not all, the UK vehicle fleet will encounter a HABD on a regular basis, but the proportion of hot axleboxes detected will depend on the distance a vehicle can run whilst a developing a hot axlebox (which could be a lot less than 65 miles).
- There is no separate category for track circuit monitoring, apart from where this is done at the interlocking as opposed to at the asset itself.

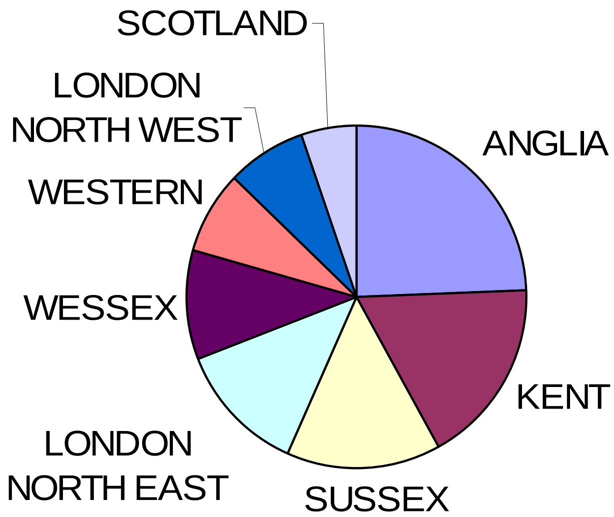
B.3 Geographical Spread

The geographical spread of activity is as follows:

Route	Total RCM population	Route miles	RCM population per route mile
ANGLIA	613	744	0.82
KENT	300	508	0.59
SUSSEX	160	319	0.50
LONDON NORTH EAST incl MIDLANDS & CONTINENTAL	891	2120	0.42
WESSEX	222	648	0.34
WESTERN	473	1769	0.27
LONDON NORTH WEST	516	2061	0.25
SCOTLAND	297	1640	0.18
Total	**3472**	**9809**	**0.35**

The concentration of RCM activity (normalised by route miles) is shown below:

Figure B1: Concentration of infrastructure based RCM activity



It is seen that the greatest concentration of infrastructure-based RCM activity is in Anglia, and the lowest is in Scotland. The variance is due to the fact that the installation of RCM has historically been largely a matter for local managerial discretion, together with the fact that Anglia has recently been regarded as a pilot for RCM schemes.

Appendix C Activity List

The 52 activities that passed through to stage 3, and are shown in the maps, are listed below in the order in which they appear on the SRF (figures 8 to 13):

Location on SRF	Activity ID	Product/ activity
0. Uninterrupted Journey		
	35	Integrail
1. Infrastructure		
	1	AssetWatch
	22	Intelligent Infrastructure
	59	Infrastructure monitoring
	93	IRIS 320 Train
	103	NMT
1.1 Signalling		
	10	SSI data recorder
	11	Asset View
1.1.1 Track Circuit		
	53	Track Circuit Monitoring
	154	ACIC leaf fall monitor
1.1.2 Points		
	2	ICEALERT (Points heating monitoring)
	3	PMMS (Points machine monitoring system)
	12	Points condition monitoring (BB)
	25	Points condition monitoring (NR)
	66	Data analysis for PCM et al
	68	Points condition monitoring (ACIC)
	76	Predicting points failures (INRETS)
	77	Predicting points failures (UOB)
	99	ICEALERT (Points heating control)
1.2 Track		
1.2.1 Broken rails/faults		
	21	Ultrasonic Test Trains
	23	Gotcha
	84	Novel rail flaw detection (Japanese)
1.2.2 TSRs due to track		
	5	SFTPro
	13	UGMS
	21	Ultrasonic Test Trains
	61	UGMS (Japanese 1)
	62	UGMS (Japanese 2)
	83	MAPS
	84	Novel rail flaw detection (Japanese)
	96	Radio rail temperature monitoring
	101	T2IMS
1.2.3 Reaction to P-coded TSRs		
	5	SFTPro
	13	UGMS
	21	Ultrasonic Test Trains
	61	UGMS (Japanese 1)
	62	UGMS (Japanese 2)
	83	MAPS
	84	Novel rail flaw detection (Japanese)
	94	Strainstall bridge monitoring
	96	Radio rail temperature monitoring
	101	T2IMS
1.2.7 Gauge Corner Cracking		
	21	Ultrasonic Test Trains

Location on SRF	Activity ID	Product/ activity
1.3 Civils, E&P, Telecoms		
1.3.1 OLE/3rd rail		
	7	Panchex
	18	High Speed Pantograph Measurement
1.3.5 Telecoms		
	20	Radio Signal Strength
2. Train		
	50	TAPAS
	52	Cl390 RCM
	57	RailSense
	71	ORBITA
	106	Trainborne RCM (Siemens)
	110	Trainborne RCM (Avenca)
	111	Trainborne RCM (Porterbrook)
	112	Cl90 RCM
2.2 Doors		
	75	Door Monitoring (paper)
	105	Benefits driven RCM
	109	Door Monitoring (RDS)
2.4 Other systems - Pantograph		
	7	Panchex
	18	High Speed Pantograph Measurement
	85	Condition Monitoring of Pan/OLE interaction
	86	NMT instrumented pantograph
	101	T2IMS
2.7 Underframe & bogies		
	23	Gotcha
	24	HABDs
	29	RAILBAM
	104	VIEW
2.8 Engine		
	105	Benefits driven RCM
2.10 Brakes		
	104	VIEW
3. Rules/Processes		
4. Operations		
5. External		
5.3 Weather		
	4	Findley Irvine Weather Station
	41	Adhesion Management System
	102	ACIC Weather Station
5.4 Low adhesion		
	41	Adhesion Management System
	50	TAPAS
	52	Cl390 RCM
	71	ORBITA
	106	Trainborne RCM (Siemens)
	154	ACIC leaf fall monitor
6. Other		
	Nil	

Appendix D Derivation of SRF figures

D.1 Infrastructure data:

The ‘Industry Performance Period Report Supplement dataset’ split delays down into three main areas by allocation: ‘Network Rail on TOC’, ‘TOC on TOC (as victim)’ and ‘TOC on self’.

The data from the first area ‘Network Rail on TOC’ was provided in 43 separate causation codes and used to identify:

- Categories in the SRF and their relative contribution to system delay.
- The asset/event groups within all except the train category and their relative contribution to category delay.

The asset/event group ‘Power Supply’ under Signalling relates only to signalling power supplies; delays due to traction power supply failures are included in the asset/event group ‘OLE/3rd rail’.

D.2 Rolling stock data:

The asset/events groups within the train category were established using the rolling stock data. Although there is a good balance between new and old rolling stock and the results compare well with popular wisdom, there are several concerns about how representative the data is:

- The data covers only 20% of GB fleets and these fleets cover only 14% of overall fleet mileage.
- There is a small sample of intercity operations, none of which is diesel hauled.
- No DC traction is in the sample.
- Whilst valuable for this work, building a picture of the most unreliable systems on an average train is of limited value given that these systems will vary with types of track and operation. For instance the most unreliable system on a DMU might be engines, whereas on a mid-life EMU it might be doors.
- The analysis was based on technical casualties as it was the only common metric across the datasets provided, while the project is focusing on minutes delay. However, splitting minutes delay in proportion to technical casualties may not be a bad approximation as it takes out the serendipity associated with location and time.

Notwithstanding these concerns, as it was the best information available, the data was used to populate the SRF as follows:

- Average number of technical casualties across all fleets in the sample was established for each train system code normalising by fleet size and the number of periods over which each fleet’s data was available.
- The contribution of each system to trains category was then apportioned according to the average number of technical casualties.

- Delay minutes for each system code were calculated from the 'Technical fleet delays' attributed to 'TOC on TOC (as victim)' and 'TOC on self' in the infrastructure data.
- Delays attributed to three system codes were deemed non-technical and allocated to other categories in the SRF:
    - o System code X 'Scheduled work system' responsible for 5% of technical casualties, was allocated to the SRF category 'Rules/Processes' as 'Depot processes'. It includes such issues as: faults found by the driver on preparation, late delivery for exam, over running scheduled exam, scheduled work system, unscheduled work and winterisation procedures.
    - o System code Y 'Depot activities' responsible for 1% of technical casualties, was also allocated to the SRF category 'Rules/Processes' but as 'Depot Management'. It includes such issues as: depot mismanagement, availability issues, depot diagramming error, depot emergency incident, depot infrastructure defect on depot and late release by the depot.
    - o Uncoded data responsible for 15% of technical casualties was allocated to SRF category 'Other' as 'Fleet uncoded'.
- Other delays attributed to the 'TOC on TOC (as victim)' and 'TOC on self' infrastructure data were assigned as follows:

Delay type	**SRF category**	**SRF asset/event group**
Non-technical Fleet delays	Other	Non-technical fleet
Train operations	Operations	Train operations
Traincrew causes	Operations	Traincrew
Station delays	Operations	Station delays
External Causes (Train Operator)	External	Passengers, freight and vandals
Freight Terminal/Yard delays	External	Passengers, freight and vandals
Low Adhesion inc. Autumn (Train Operator)	External	Low adhesion

It is important to note that:

- Some of the delays listed in the 'Network Rail on TOC' are also attributed to some of the above asset/event groups, e.g. 'wheel slip due to leaf fall' is also assigned to 'low adhesion'.
- In the context of this work, delays attributed to freight operation as seen as external because they are external to the passenger railway.

Appendix E Learning points and good practice

The following identifies learning points and suggests good practice to get the most from RCM on trains. Its focus is on retrospective fitment as that is where the challenge is, although some of the points apply equally to new build:

- To maximise reliability improvement, maintenance and development needs to be data driven rather than event driven, enabling failures to be pre-empted. RCM can provide such data and thus insure against the unexpected as long as failure is gradual or preceded by a measurable event.
- Implementation of RCM must be driven by business goals; everything can be measured and communicated but not everything will be valuable. A generic solution for all fleets is unlikely to deliver value as the systems causing delay vary with vehicle type; RCM on a DMU might need to focus on engines, whereas on a mid-life EMU it might be doors. The reliability of individual train systems will identify the system(s) giving greatest return on investment.
- Once the systems to be measured have been identified, the nature of the measurements needs to be considered: frequency or event driven, Boolean (yes/no) or analogue. Boolean data requires little data capacity, communications and analysis but is limited when it comes to establishing the condition of components and when they are likely to fail.
- Data is useless unless it is turned into useful information in a resource efficient manner. The computational power available today makes this possible using such strategies as: artificial intelligence and seeking deviations from rules prescribed by the user or even automatically by the system using statistical process control.
- Once analysed the information needs to be presented in a way that can easily be understood by users, c.f. NXEA's remote mimicking of the cab condition to visualise what the driver is seeing, as well as depicting vehicle status on simplified schematics to facilitate real-time fault finding (activity #112). Likewise both Orbita (activity #71) and Alstom's Fleet Console system (activity #52) put much effort into this.
- The information obtained from data analysis is useless unless something is done with it, i.e. business processes are in place to take timely action. Even with processes in place, a change of culture may be challenging, i.e. convincing people who've spent their careers changing failed parts to believe the system when it is telling them to change a part that has not yet failed.
- A clear strategy is required for how much analysis is to be done on the train and how much on the ground where software deployment costs are less and computational power and storage relatively unlimited. Train-borne analysis could be limited to only that which is needed to identify functional failures to prompt the driver, whereas ground-borne analysis needs sufficient raw data to allow it to identify and predict all technical failures whether or not they directly impact on train function.
- RCM equipment and particularly its sensors need to be at least an order of magnitude more reliable than the equipment being monitored; otherwise time will be wasted investigating spurious indications.

- Sensors need to be connected in way that won't compromise the train if they fail, and analysis software needs algorithms to enable detection of sensor failure.
- Direct connection to the OTMR comes with the complexity associated with modifying safety critical equipment, so is best avoided, but this does not preclude keeping a copy of OTMR data in the RCM storage facility to provide contextual information to assist with fault finding.
- Real time downloads from the train are a necessity because:
  - They can help to reduce delay minutes by providing information that can help failure investigators establish the problem when it happens, advise the driver and facilitate recovery.
  - Where failures are imminent or the train is operating in degraded mode, it can help planners route the train to an appropriate maintenance facility which has appropriate materials and resources to effect a repair.
  - More fundamentally manually downloading data from trains is labour intensive and, unless downloaded to assist with a specific fault, it is a job that is likely to be deferred in favour of more immediate priorities thus preventing access to a valuable data history.
- The train/ground communications mechanism needs consideration: GSM is unlikely to have sufficient capacity for all but relatively small data packets, GPRS can be expensive when it is needed on every train, Wi-Fi is the cheapest but needs trains to pass Wi-Fi hotspots with sufficient frequency. Wi-Fi to provide regular download with the backup of GPRS to allow interrogation on demand could be the way forward.

Appendix F UJG's Remit

Note: References to appendices have been removed to avoid confusion with other appendices in this report.

F.1 Background

Technical Strategy Advisory Group has identified as a key strategic objective the idea of an uninterrupted journey, i.e. a railway system where journeys are routinely completed punctually, and has also identified that Condition Monitoring is likely to play a significant part in delivering this.

It is clear that significant activity is already taking place, within the domains of both trains and infrastructure, but no overall picture exists, making it difficult to identify gaps, or potential benefits of cross-industry activity.

A high level allocation of unreliability has been established, and with input from systems engineering and reliability experts an initial and indicative draft of a high level 'system reliability framework' of the railway has been produced. This framework will be used as the basis for two further pieces of work, one of which is specified here (the other involves what has been called the 'IT architecture' needed to support condition monitoring systems).

F.2 Task: mapping existing activities onto system reliability framework

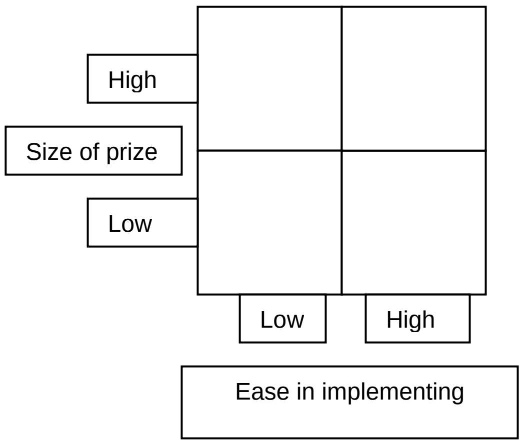
The starting points will be the list of current activities and the system reliability framework, and the objective is to provide an insight into

- how far existing capability and planned development within the scope of remote condition monitoring are improving or are expected to improve reliability in the most significant areas
- what scope exists for development and application of new and innovative approaches?

The task is likely to include, but not necessarily be limited to:

- augmenting the breadth of coverage of the draft high level system framework as appropriate, and confirming the metrics to identify areas where attention is most needed
- understanding the broad status of current activity. The accompanying list provides an indication of current activity. It may need to be augmented where additional key activity is identified, or treated selectively to cover only key areas i.e. a comprehensive analysis is not required.
- mapping current activities against the four monitoring classifications (trains and infrastructure monitoring themselves and each other), providing visibility of the opportunities for delivering benefit by improved cross/interface activities. This task would identify gaps and overlaps in current and planned activity.

- identifying the broad geographic spread of RCM activity.
- assessing activity against the four monitoring levels (report of failure, warning of future failure, warning with cause identified, data to facilitate designing out future failure). This task would provide visibility of where there is most scope for:
  - dissemination of existing good practice
  - harnessing data that is collected but not used effectively
  - application of new and innovative approaches
- Making prioritised recommendations for further work/ implementation
- Providing visibility of the size of the prize versus the ease of achieving it, for the possibilities identified, plotting results on a matrix shown below, or otherwise.



The output is to be in a form which reveals conclusions implicitly.

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