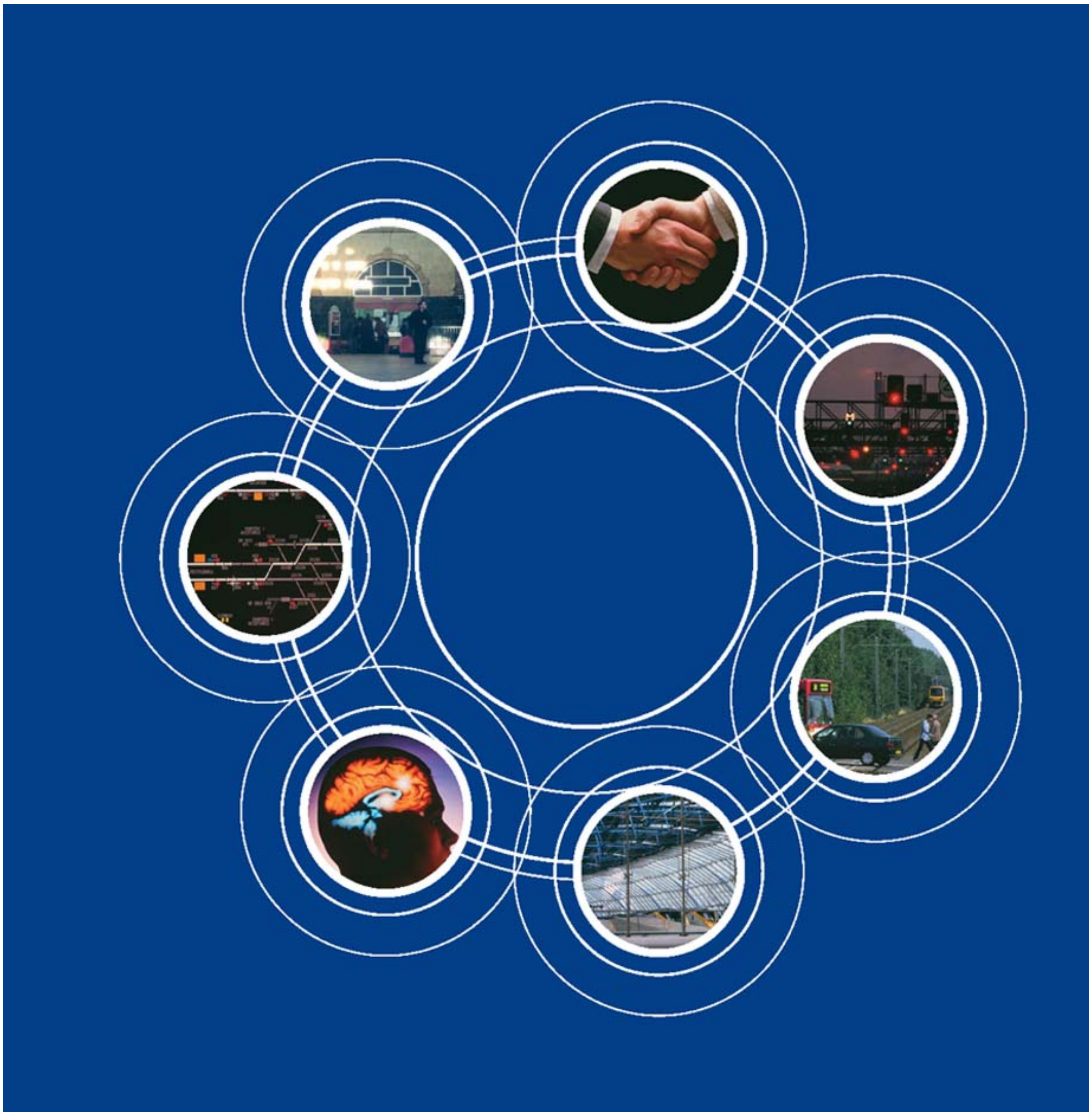
Research Programme

Engineering

Detailed overview of selected RCM areas - RCM Toolkit



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Detailed overview of selected RCM areas

RCM Toolkit

Executive summary

The rail industry faces a time of both challenge and opportunity following the publication of the study '*Realising the Potential of GB Rail*' in May 2011[1]. Following that study there is a renewed industry focus on delivering a more effective and efficient railway, with closer alignment of operations and infrastructure. The study identified the importance of improved asset condition information to make more informed asset management decisions and more efficiently deliver improved levels of service. The industry is already trying to move from an 'observe and react' approach to failures to a more pro-active 'predict and prevent' approach.

The advent of hardware and software systems that can capture and process asset condition data in real-time, generally termed *remote condition monitoring* (RCM), brings a real opportunity to achieve this. However, the success of these systems and the effective and efficient use of the associated data in the rail industry will be reliant on targeting those areas where substantial benefits can be achieved through cost-effective implementation.

To understand the above, RSSB commissioned Asset Management Consulting Limited (AMCL) on behalf of the Cross-industry Remote Condition Monitoring Strategy Group (XIRCMSG) to undertake a review of a number of RCM areas. This was to provide quantitative business case data that will assist the industry with making more informed operational and development decisions for current and future RCM systems. The full suite of individual work packages which make up the overall project (RSSB ref. T857) is shown below.

WP ID	Work Package Title
T857-01	Monitoring of Axle Journal Bearings using trackside systems
T857-02	Monitoring of Wheel Impact Loads
T857-03	Monitoring of Pantograph Integrity
T857-04	Monitoring of Overhead Line Integrity

1 McNulty, 2011. Realising the Potential of Rail - Final Independent Report of the Rail Value for Money Study. DfT/ORR.

T857-05	Ride monitoring
T857-06	Overview of the benefits and risks associated with condition monitoring
T857-07	Monitoring of the DC third rail interface - geometries and power supply

This report documents the output of work package T857-06, including AMCL's methodology and toolkit for evaluating the costs and benefits of RCM systems to inform these industry wide decisions. It provides a means to comprehensively assess the current industry approach and identify opportunities and justifications relating to the further implementation of current and future systems. Guidance is given for how to approach qualitative assessment of the relative strengths and weaknesses of these systems, and the opportunities and threats associated with their implementation. The report also outlines the stages required to further implement the relevant technologies in the future and the process for quantitatively assessing the costs and benefits associated with each stage.

This report is to be read in conjunction with the User Guide for the 'RCM assessment toolkit' also produced as part of this project (work package T857-06).

This report shows that there is a strong business case for exploiting RCM technology in all the areas specified by RSSB for review as part of this project. RCM can reduce service risks and realise benefits through the integration of data on asset condition and by facilitating changes to asset maintenance regimes to become more condition-led. The strongest business cases arise where existing RCM systems can be further exploited, or where sufficient information can be gained from a small number of RCM installations and the effort is put into developing tools for automating data processing and integrating condition information with asset maintenance planning tools.

There are currently barriers to progress in these areas that include the ability to share data between systems, and the current use of RCM systems as risk mitigation tools for the rail network or for dispute resolution. These barriers need to be overcome in order for RCM systems to become a proactive means of gaining knowledge that can then be used by the asset maintainer to drive down overall industry costs and improve asset performance.

AMCL considers that to maximise the potential benefits associated with RCM, cross-industry leadership will be required, otherwise the existing fragmented approach to the implementation and use of RCM systems is likely to continue.

The following recommendations are therefore made by this report:

1. XIRCMSG and the rail industry should review the outputs from this initial study to determine if the resulting business case is strong enough to proceed on an industry-wide basis with the preferred options identified.
2. If it is deemed that further analysis is required it should only be undertaken within the context of an overall optimisation approach for inspection and maintenance regimes of critical interface assets in order to secure industry-wide benefit.
3. The industry should apply failure modes, effects and criticality analyses (FMECA) to identify the key functional failures and consequences for critical interface assets in order to identify clear opportunities for RCM.
4. The business case for RCM should then be refined based on the root causes of failure and the routine Asset Management processes that could be rescheduled, reduced or eliminated if the identified condition data was available.
5. Condition data requirements should be utilised to drive the specifications for RCM system development. These systems specifications should be functional and not overly prescriptive.
6. RCM Suppliers should be engaged early in the specification and development process to encourage innovation.

In addition, in order to support the above XIRCMSG and the rail industry should also consider:

7. Provision of frameworks for capturing failure information against the identified failure modes to build industry-wide models of degradation.
8. Working with stakeholders (including Network Rail, RCM suppliers, the Association of Train Operating Companies (ATOC) and the Rail Freight Association) to review existing cost assumptions for key business case parameters and

draw on a sufficiently representative network sample to preserve confidentiality and improve robustness of the business cases.

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Ride monitoring

1 Introduction

1.1 Context

The rail industry faces a time of both challenge and opportunity following the publication of the study 'Realising the Potential of GB Rail' in May 2011[1]. Following that study there is a renewed industry focus on delivering a more effective and efficient railway, with closer alignment of operations and infrastructure. The study identified the importance of improved asset condition information to make more informed Asset Management decisions and more efficiently deliver improved levels of service. The industry is already trying to move from an 'observe and react' approach to failures to a more pro-active 'predict and prevent' approach.

The advent of hardware and software systems that can capture and process asset condition data in real-time, generally termed *remote condition monitoring* (RCM), brings a real opportunity to achieve this. However, the success of these systems and the effective and efficient use of the associated data in the rail industry will be reliant on targeting those areas where substantial benefits can be achieved through cost-effective implementation.

To understand the above, RSSB commissioned Asset Management Consulting Limited (AMCL) on behalf of the Cross-industry Remote Condition Monitoring Strategy Group (XIRCMSG) to undertake a review of a number of remote condition monitoring areas. This was to provide quantitative business case data that will assist the industry with making more informed operational and development decisions for current and future RCM systems.

This work aligns with the eight key principles for cross-industry RCM (see Appendix A.1). It is considered to support the vision of the Department for Transport (DfT) white paper to improve the industry knowledge of the state of its assets, to aid maintenance strategies that maximise component life and the objectives of the Uninterrupted Journey Group (UJG).

1 McNulty, 2011. Realising the Potential of Rail - Final Independent Report of the Rail Value for Money study, DfT/ORR.

1.2 Purpose of document

This report provides the high-level output of RSSB work package T857-06: 'Overview of the benefits and risks associated with condition monitoring'. It presents AMCL's methodology and a toolkit for evaluating the industry wide costs and benefits of RCM systems. It provides the means to comprehensively assess the current industry position and opportunities relating to the further implementation of current and future RCM systems. It offers guidance for qualitative assessment of the relative strengths and weaknesses of these systems, and the opportunities and threats associated with their implementation. It also outlines the stages required to implement these technologies and the process for quantitatively assessing the costs and benefits associated with each stage.

This report is to be read in conjunction with the User Guide for the 'RCM Assessment Toolkit' also produced as part of work package T857-06. Application of the methodology in this report, using the tool for each work package, is detailed in the work package reports for T857-01 to 05 and 07, with results summarised in this document.

1.3 Scope

The suite of work packages that make up the overall RCM research project (RSSB ref. T857) is shown in Table 1.

Table 1 - Research projects work packages

WP ID	Work Package Title
T857-01	Monitoring of axle journal bearings using trackside systems
T857-02	Monitoring of wheel impact loads
T857-03	Monitoring of pantograph integrity
T857-04	Monitoring of overhead line integrity
T857-05	Ride monitoring
T857-06	Overview of the benefits and risks associated with condition monitoring
T857-07	Monitoring of the DC 3rd rail interface - geometries and power supply

This work package, T857-06, provides an overall approach and toolkit for analysing the costs and risks associated with introducing RCM systems and summarises the results from the other work packages (T857-01 to T857-05 and T857-07).

1.4 Approach

1.4.1 Methodology

AMCL has carried out this package of work as part of the overall RSSB T857 project methodology presented in Figure 1. For each of the other work packages (T857-01 to T857-05 and T857-07), this consisted of a series of stakeholder interviews alongside desktop research to establish the current industry approach and potential future technologies, including the strengths, weaknesses, opportunities and threats. The stages required to further implement existing and future technologies were also identified. In parallel, data collection and analysis was undertaken to populate the decision support toolkit provided in this work package (T857-06). Initial analysis was carried out to identify the key parameters driving the business case for the implementation options, so that these could be reviewed and revised with stakeholders to improve the robustness of the business cases. Sensitivity analysis was also performed to test the impact of variations in these key parameters on the overall recommendations.

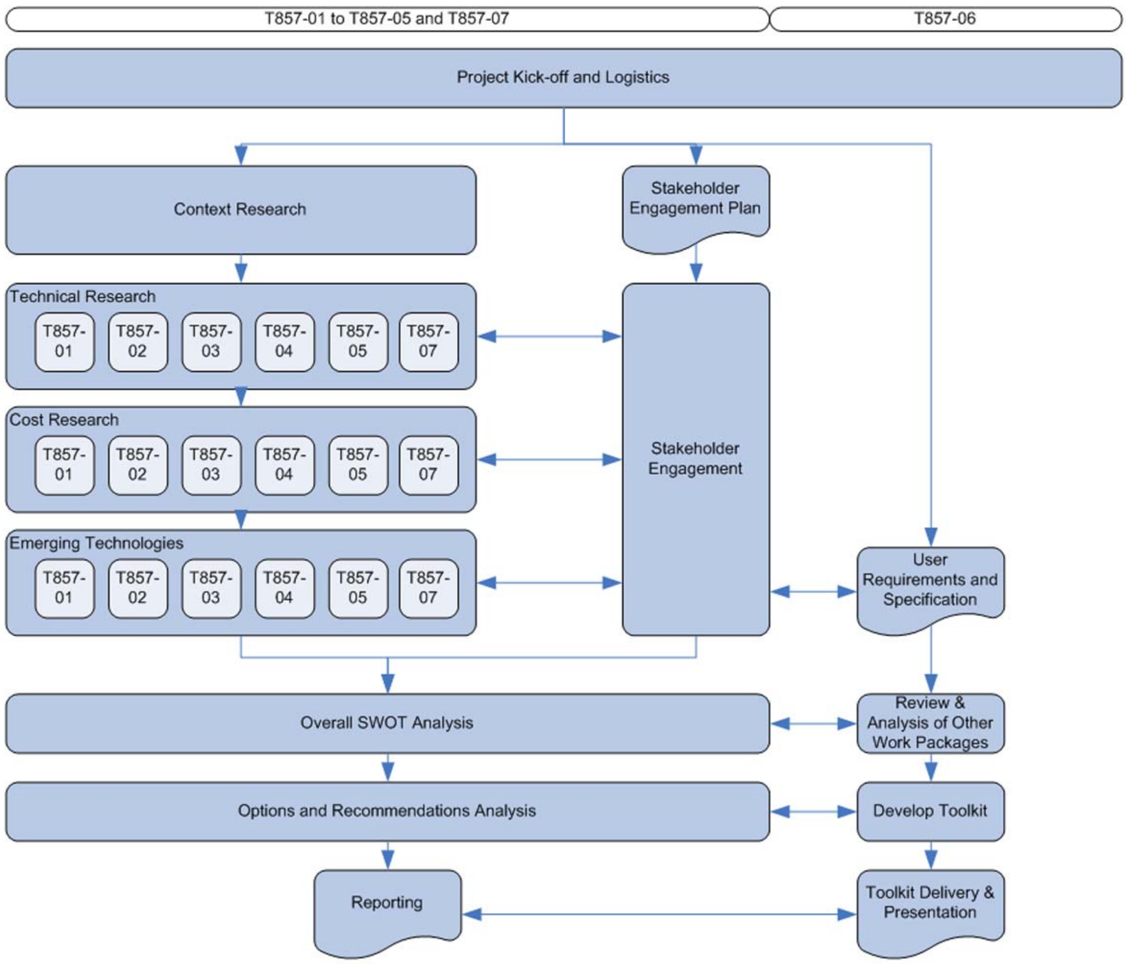

Figure 1 - Overall T857 methodology

1.4.2 Stakeholders and contacts

An industry review of condition monitoring needs input from stakeholders across the industry as the costs and benefits may be borne by different parties depending on the topic area. A summary of key stakeholders and their general roles is shown in Table 2.

Table 2 - Key stakeholders

Stakeholder	Role
Train operating companies (TOCs)	• Responsibility for failures relating to rolling stock and its maintenance and overhaul. • Required to implement train-borne RCM technologies.
Freight operating companies (FOCs)	
Network Rail	• Responsibility for failures relating to infrastructure and its maintenance and overhaul. • Required to implement infrastructure-borne RCM technologies.
Other infrastructure providers	• Information on application of RCM techniques on other networks
Rolling stock leasing companies	• Manage maintenance and overhaul services for (some) TOCs and FOCs
Manufacturers	• Provide maintenance and overhaul services for (some) TOCs and FOCs
RCM suppliers	• Produce RCM equipment and processing systems
Academia	• Future opportunities and developments in technologies and higher level analytics

The extent to which the key stakeholders own or are accountable for costs in each area depends on the position of the technology in terms of the four-quadrant RCM strategy, as illustrated in Figure 2. This also includes some of the wider questions to stakeholders for the areas outside of the core RSSB T857 project scope.

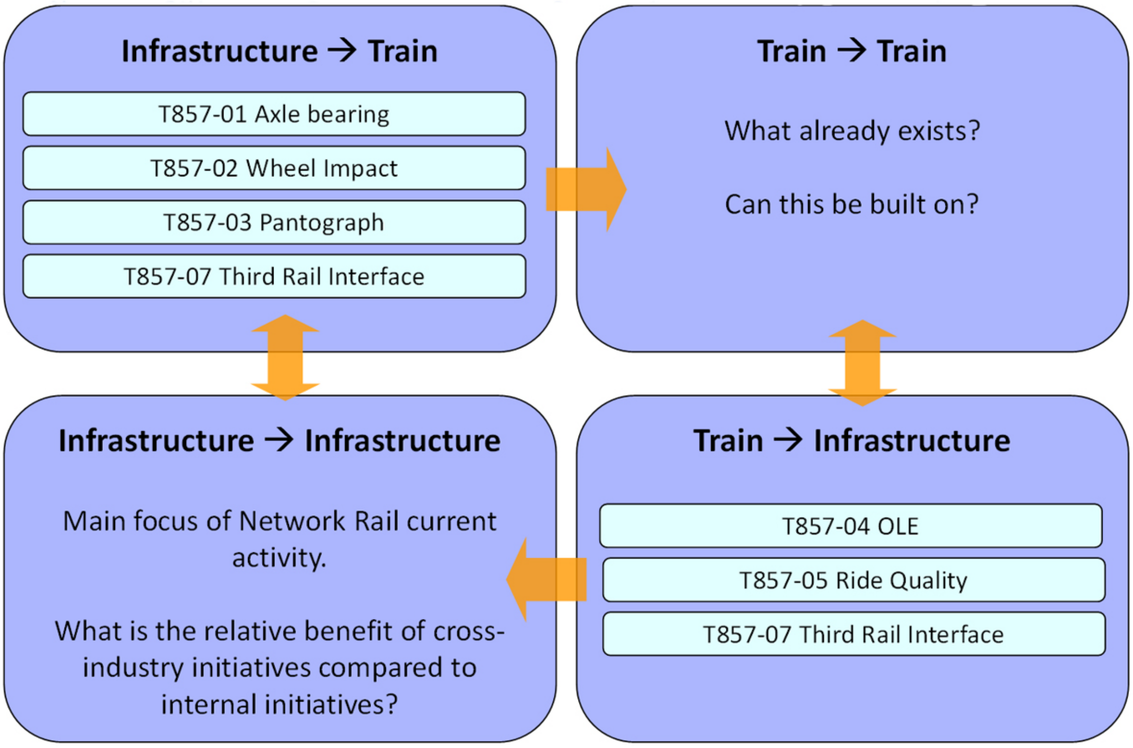

Figure 2 - Industry RCM strategy quadrant

1.5 Structure

The remainder of this document is structured as follows:

- Proposed methodology for reviewing the application of RCM: a 'good practice' guide for the research and analysis required to evaluate different options for RCM (Section 2).
- Overall themes from strength, weaknesses, opportunities and threats (SWOT) analysis: key results arising from applying the proposed SWOT analysis approach to the six topic areas, including industry-wide implications, other issues and observations (Section 3).
- Business case analysis results: key results from applying the proposed business case analysis approach to the six topic area work packages and an overall summary of industry-wide impacts (Section 4).
- Conclusions and recommendations: a summary of overall findings, identification of immediate and longer-term

opportunities and suggestions for embedding the approach in the industry (Section 5).

2 Industry overview

2.1 Introduction

This section sets out the proposed methodology for reviewing the application of RCM to address specific asset risks and wider industry opportunities. It provides a 'good practice' framework for the evaluation of different options for managing asset risk, including the extent of RCM involved and the level to which proposed systems are integrated with other RCM systems.

The general RSSB research project T857 approach outlined in section 1.4.1 is expanded further so that more detail is given on the stages required to be undertaken by industry stakeholders to populate the cost-benefit framework and establish the cost-benefit analysis.

The approach is supported by the RCM Analysis Toolkit which is another deliverable of this work package. Specific information on the toolkit itself is provided separately in the associated User Guide.

The methodology has been successfully applied to the six topic area work packages in RSSB research project T857 to produce an overview of costs and benefits in these areas. These results are summarised in Section 3 and 4.

2.2 Approach

There are two main phases involved in reviewing the application of RCM in the topic area. The research phase is used to understand the context and current industry position and to capture the information required to populate the analysis tools. The analysis phase is then used to take this information and use it to identify and evaluate suitable options for applying RCM.

Figure 3 illustrates this approach and shows the steps required in each phase. These are then explained in more detail.

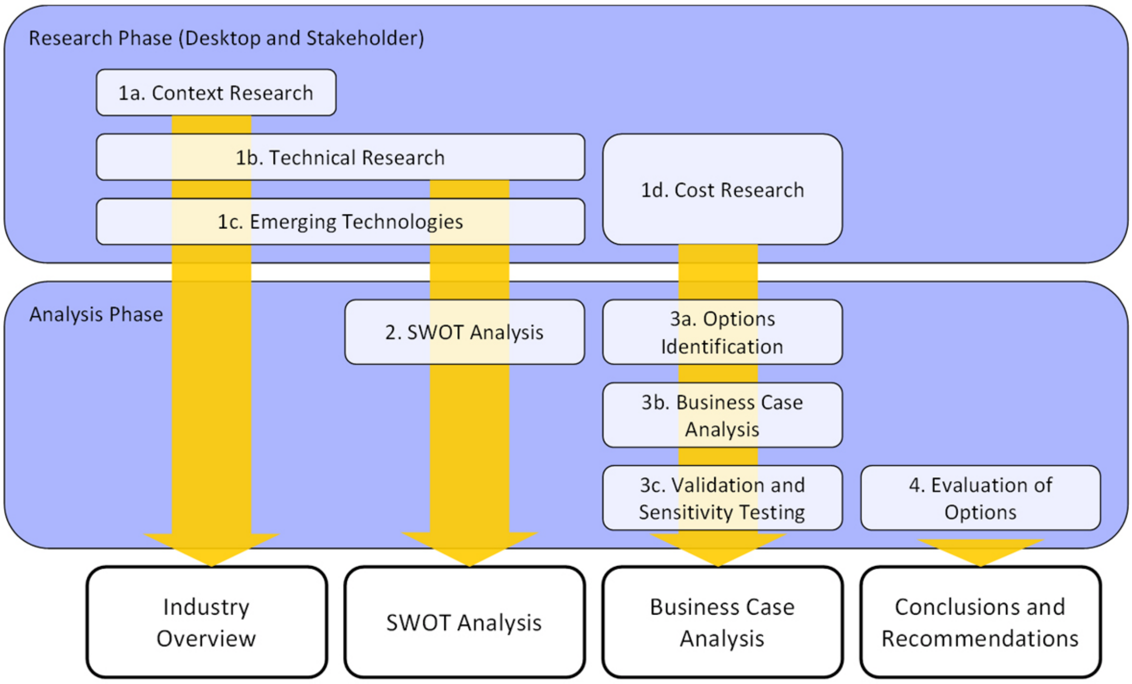

Figure 3 - RCM evaluation methodology

2.3 Research phase

2.3.1 General

The Research Phase covers both the desktop and stakeholder research carried out to gather the information required for the SWOT and Cost-Benefit analyses. While these are broken down into the types of research outlined in Section 1.4.1 the activities were carried out in parallel through desktop and stakeholder research. Table 3 shows how the areas of the scope are covered by the research areas and in which part of the topic area reports these findings are summarised.

Table 3 - Mapping of scope to research areas

Scope element	Description	Research area	Output
1	Identify, define and assess risk associated to failure.	Context Technical	Industry Overview
2	Costs associated with failure (dependent on topic area), stakeholder key performance indicators, industry penalty and compensation payments (schedule 4 and 8) etc.	Cost	Business Case Analysis
3	Costs associated with maintenance, limitations maintenance / overhaul periods, etc.		
4	What, where, why and when RCM systems are being used?	Context Technical	Industry Overview
5	Who uses it and how is it used?	Technical	
6	Current RCM asset value and expected life expiry.	Cost	Business Case Analysis
7	What data transfer and communications are required?	Technical	Industry Overview
8	Cost of installation, maintenance, repairs, operation.	Cost	Business Case Analysis
9	Identify emerging technology.	Emerging Technologies	Industry Overview
10	Assess strengths, weaknesses and opportunities.	All - assessed in SWOT	SWOT Analysis
11	Assess advantages and disadvantages.	All - assessed in SWOT	SWOT Analysis

2.3.2 Context research, technical research and emerging technologies

These elements of research are largely qualitative, in terms of understanding the potential asset risks and impacts, the indications for these potential risks and the technologies used to monitor these indications. This also provides relative strengths and weaknesses for the technologies under review. However, quantitative data can also be obtained during this stage, such as information on the scale and frequency of incidents, etc.

2.3.3 Cost research - current industry position

The first step is to identify the current industry position in terms of the costs associated with the current level of risk and existing RCM technologies. Note that the costs identified should be industry costs and not differentiate between the owner of the costs (eg FOC vs. Network Rail), however this is useful information to keep in support of the development of the business cases and potential barriers to implementation. The cost information required is summarised in Table 4.

This information is a key input into the RCM Analysis Toolkit and as well as the best estimate of the cost, any information on the likely range of values for each parameter should be captured as 'High' and 'Low' scenarios.

Table 4 - Current industry position cost data requirements

Cost Area	Type	Key information	Underlying drivers	Main Source
Asset Info (note - cost driver rather than actual cost)	Asset count	Total number of assets displaying risk	Asset configuration	Asset Owner information Industry information
	Asset utilisation	Note: Optional Total operating cycles of asset per year and/ or asset loading (eg EMGTPA)	Various depending on asset	Asset owner information Industry information

Table 4 - Current industry position cost data requirements

Cost Area	Type	Key information	Underlying drivers	Main Source
Asset Risk	Safety	Total monetary value of current industry risk relating to safety	Safety Risk FWI Number of safety-affecting incidents Value of Preventing a Fatality	RSSB Data
	Service	Total monetary value of current industry risk relating to service as measured by performance penalties (Schedule 8)	Service affecting incidents ('genuine' incidents) Delay minutes Schedule 8 cost per delay Cancellations and significant lateness (CaSL) penalty	TRUST Data (Network Rail) Bugle or equivalent (TOC/FOC)
	Other	Total monetary value of current industry risk relating to damage caused by the asset during incidents	Various - could include wear and tear impacts and significant incident impacts	Various
Asset Whole-Life Costs (WLC) by Asset Owner		Total cost of repairing asset failures	Underlying faults (genuine faults) Fault fixing cost	Asset Owner information
		Total cost of maintaining and renewing / overhauling assets	Maintenance / Renewal / Overhaul frequencies Unit cost of activity	

Table 4 - Current industry position cost data requirements

Cost Area	Type	Key information	Underlying drivers	Main Source
RCM Costs	RCM WLC	Total Annualised cost of operations, maintenance and renewal for RCM installations	Number of RCM installations Expected service life Installation cost Operating cost per asset (including support system costs / data processing contracts) Maintenance cost per asset	RCM Owner costs
	Service Impact	Total cost of failures of RCM equipment	Number of false alarms Performance impacts of false alarms	

From the cost data above the relative 'size of the prize' in terms of improvements in these areas can be better understood. By carrying out this current cost base analysis in the early phase of the analysis, the key parameters driving the costs and potential benefits can be identified and hence the option identification focused on the viable options likely to bring the biggest benefits.

2.3.4 Cost research - RCM technologies

The cost research phase also provides the opportunity to understand the costs associated with advancing the level of RCM processing technology associated with the proposed technologies. The level of RCM processing is based on the existing ISO 13374 *Condition monitoring and diagnostics of machines - Data processing, communication and presentation* framework used by RSSB and illustrated in Figure 4.

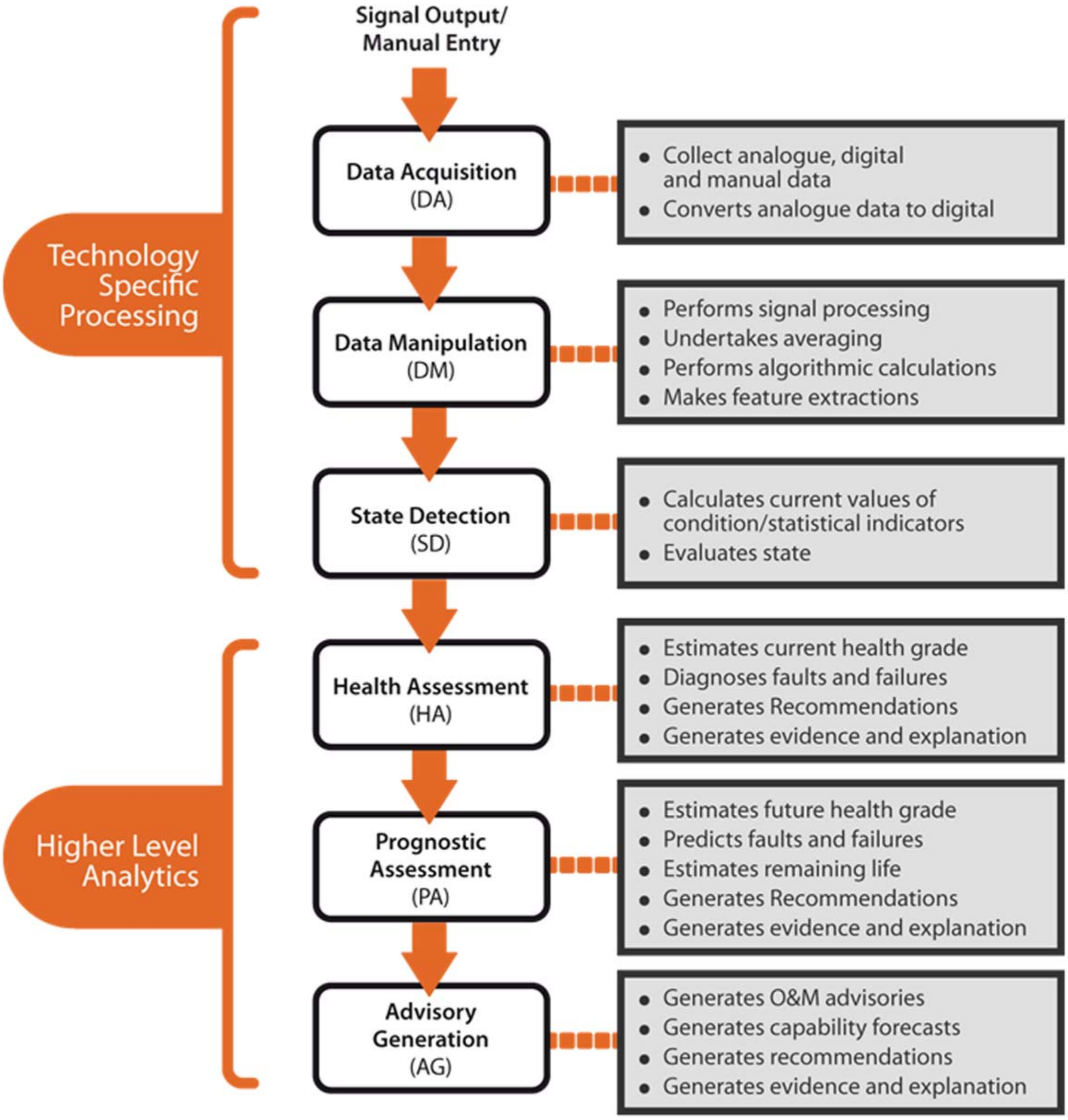

Figure 4 - ISO 13374 RCM Processing Level Framework

The cost information required for these steps is broadly the same as the assessment for existing RCM installations and therefore as summarised in Table 5.

Table 5 - RCM advancement costs

Cost Area	Type	Key information	Underlying drivers	Main Source
RCM Advancement	Additional planned RCM asset management costs	Total additional annualised cost of operations, maintenance and renewal for RCM installations	Number of additional RCM installations Expected service life Installation cost Maintenance cost per asset	Suppliers RCM Owner costs
	Additional planned RCM data costs	Total additional data costs	Operating cost per asset (including support system costs / data processing contracts)	
	RCM reliability costs	Total cost of failures of RCM equipment	Predicted MTBF or number of false alarms Performance impacts of false alarms	

2.4 Analysis phase

2.4.1 SWOT analysis

SWOT Analysis was carried out through discussions of the existing and proposed technologies with the stakeholders and contacts listed in section 1.4.2. The analysis should categorise the key findings in terms of the following definitions for SWOT:

- Strengths: characteristics of the technology that give it an advantage over others in the industry.
- Weaknesses: characteristics that place the technology at a disadvantage relative to others.
- Opportunities: external chances to improve the success of the technology (eg, reduction in industry risk) in the environment.
- Threats: external elements in the environment that could cause problems with implementation of the technology.

The findings should be linked as closely as possible to either quantifiable elements of cost or qualitative factors that could bring uncertainty to the quantification of costs in the business case and therefore need to be considered as sensitivities or scenarios for modelling purposes.

The SWOT template is given in Appendix C.1.

2.4.2 Options identification

The results of the research stage and SWOT analysis are used to determine a manageable number of options for business case modelling.

There will be several options for performing the 'technology-specific processing' of ISO 13374 to get to the 'state detection' level of maturity. For example, in *Monitoring Axle Journal Bearings* (T857-01) there is a choice between using hot axle bearing detectors (HABD) or acoustic monitoring technology, or both. There will be costs and benefits associated with this level of maturity that will vary by option. There will then be additional benefits and costs in advancing further up the maturity scale.

To reach 'Health Assessment' level will require linking and processing the 'State Detection' information with additional data captured elsewhere. The cost of these links and processing will depend on the compatibility of the additional data with the existing data under the 'State Detection' option. There will also be benefits from the additional data and processing. It is assumed that at this stage all data has been included to provide an adequate 'Health Assessment' for the asset, although the costs and benefits of doing so will depend on the option path taken.

The next stage brings in the cost of the additional software and processing to turn the 'Health Assessment' of the current condition into a plan for the asset, the 'Prognostic Assessment'. This is assumed to be the same for all assets, although the total costs and benefits to reach this point will vary by option.

The final stage brings in the cost of the additional software and processing to link the 'Prognostic Assessment' information to the asset owner's planning tools to deliver 'Advisory Generation'. Once again, this is assumed to be the same for all assets, although the total costs and benefits to reach this point will vary by option. This approach is illustrated in Figure 5 using HABD vs. acoustic monitoring as an example.

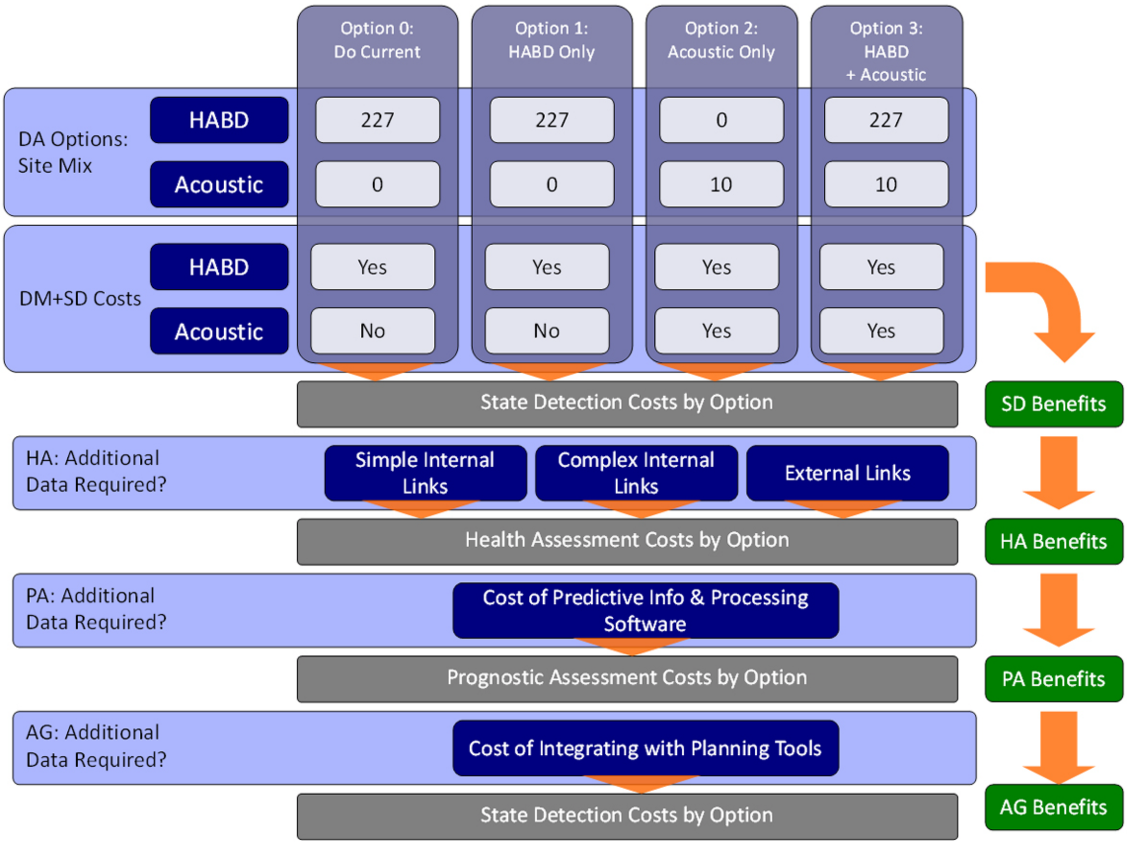

Figure 5 - Sample options evaluation

Throughout the analysis costs have been based largely on the technology required and have not considered in full the wider costs to the industry of adopting, developing and implementing these technologies. The T857 steering group has therefore suggested that the values used are at the low end of what would be expected in practice, due to the additional costs of development and implementation of the technologies, including the re-writing of standards and cost of business change. It is also likely that there would be 'bedding in' failures and false alarms as new technologies are implemented and better understood. This would need to be investigated further in developing the detailed business cases to evaluate their impacts on the overall conclusions.

2.4.3 Business case analysis

For each of the options above the 'Do Current' option is priced based on the existing industry position captured in Section 2.3.3. For each of the options to be analysed the steps from the existing to future state need to be valued in terms of costs and benefits.

The additional costs will generally be picked up in terms of the additional 'RCM Advancement' cost research in Section 2.3.4. Benefits are generated by assuming a percentage change in the underlying parameters driving the costs in the current position. This is illustrated in Figure 6 (refer to Figure 4 for abbreviations).

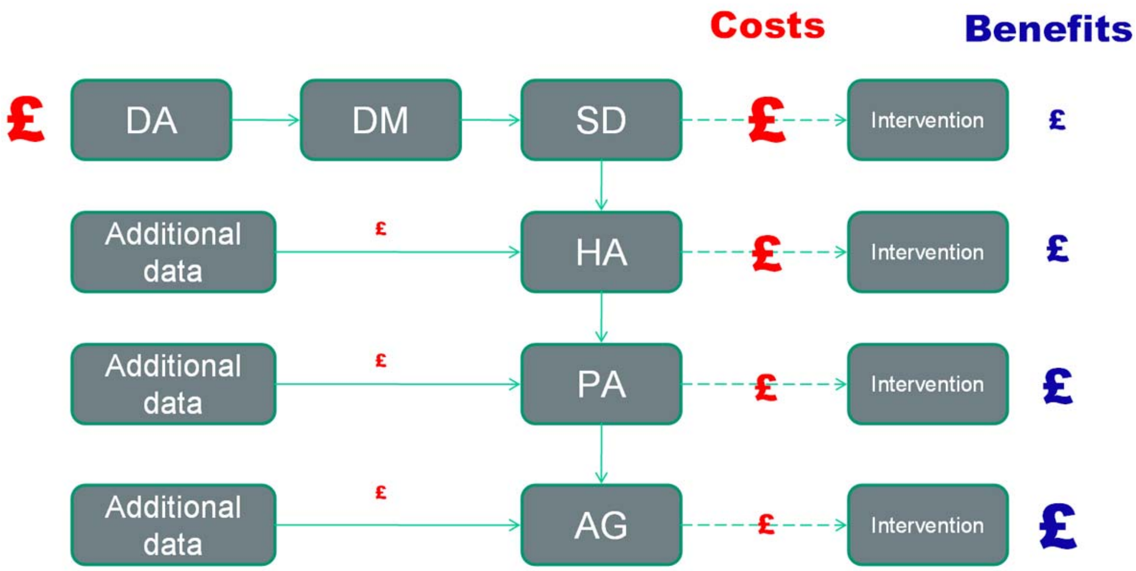

Figure 6 - Overall presentation of results for an option

For example, linking trackside RCM equipment in sequence to provide trending information may reduce the number of false alarms (as decisions are made on the basis of an increasing trend rather than spot value). This would be assigned as a % reduction in the number of false alarms.

The expected costs and benefits associated with each stage are a key input to the RCM Analysis Toolkit.

2.4.4 Validation and sensitivity testing

The 'high' and 'low' data captured in the cost research phase is then used to test the sensitivity of the outputs from section 2.4.3. The RCM Toolkit allows for a range of scenarios to be tested, from testing individual parameters to a combination of different scenarios for different parameters.

2.5 Evaluation of options

Once the key business case elements have been established through the analysis in Section 2.4.3, options can be evaluated against each other by comparing the relative costs and benefits. The RCM Analysis Toolkit allows the options to be compared to be selected and the analysis is carried out automatically. This enables the overall preferred option to be identified. Where the validation exercises and/or sensitivity testing have established areas of concern in the inputs and hence strength of the conclusions, these should be noted.

3 Overall themes from SWOT analysis

3.1 Introduction

This section picks up the key themes that have come out discussions in each of the individual topic areas work packages of the T857 research project. It also picks up general comments that were made by stakeholders during interviews relating to the overall industry strategy for RCM.

3.2 Overall RCM SWOT

The key themes have been summarised in an overall RCM SWOT in Figure 7.

Strengths

- Capturing information before it is damped by the secondary suspension.
- Capturing information in an area that is more directly affected by track condition.
- Can be trended to look at impacts of track on bogies and identify defects requiring urgent attention.
- High quality of resolution / accuracy (*Expensive systems on dedicated Engineering trains only*).
- High frequency of data capture if carried on normal freight / passenger trains (*Cheaper systems on In-Service trains*).

Weaknesses

- Need robust accelerometers to withstand bogie impacts.
- Some systems are not easily portable.
- Doesn't reflect passenger/freight experience.
- Intensive maintenance of equipment required because of its vulnerable position, subject to high accelerations.
- Present UGMS systems require lengthy data processing to extract useful information.

Opportunities

- Can be applied to either engineering trains or in-service passenger/freight trains.
- Incorporate into new rolling stock designs as standard given relative costs of system.
- Cheaper to design into system than fit retrospectively.
- Test vehicles could be instrumented to help rolling stock acceptance process.

Threats

- Not considered high priority.
- Progress in accelerometers may mean short life prior to obsolescence.
- Barriers between infrastructure maintainer, operator, and rolling stock manufacturer to resolving ride quality issues due to different operational and commercial priorities.

Figure 7 - Overall industry RCM SWOT

3.3 Other observations

Other observations that will have an impact on the successful industry implementation of RCM and realisation of the identified benefits are summarised in Table 6. In addition, it should be noted that for the T857 research project RSSB stated that it should be assumed that automatic vehicle identification (AVI) was available for all RCM options, as this is a key enabler of many RCM technologies. The case for AVI is being considered separately.

Table 6 - Observations

Theme	Observations
Asset interfaces	The temptation is to be technology-led rather than risk-led so the technologies are purchased, installed and then applied to asset risks in the hope of bringing benefits, rather than specifying the risks and specifying functionality of RCM equipment to address these. Very few examples of a whole-asset risk approach to RCM - instead it is normally focused on a particular failure mode or observable parameter.
Decision makers	The 'right' decision maker needs to be identified for the RCM technology, in terms of the person accountable for making a stop/go decision based on RCM outputs. For example, drivers and signallers may be overly conservative in responding to potential warnings from an on-board system. Alert thresholds need to be carefully defined so that only alerts requiring urgent action are sent directly to decision makers.
System interfaces	Using open source languages will enable a wider pool of academics and suppliers to produce data-processing tools and front ends. Incentivise the market to develop RCM processing applications. The data interfaces need to be specified in a way that means key data is easily exchanged but the information requirements don't produce a barrier to data usage (over-specified).
Data usage	The importance of the timing of the decision is critical in how the data is stored and shared. Asset health checks should be undertaken as/before trains enter service. Data can be live or recorded, depending on whether it is required for planning or alerting purposes.

Table 6 - Observations

Theme	Observations
Combining metrics	Overall health measures are more useful for planning mid/long-term interventions than short-term alerts that don't. A dashboard-type front end for a competent engineer (fleet engineer, route asset engineer) will provide sufficient information for many short-term purposes.

4 Business case analysis results

4.1 Introduction

This summarises the overall results from the individual topic areas and the implications for the overall industry RCM strategy. It consists of an assessment of the overall industry position, comparing the costs and risks across the topic areas and the overall business case.

4.2 Key assumptions

Several key assumptions were advised by RSSB to make discrete analysis of the business cases easier. They should still be considered as potential issues and/or barriers to successful implementation of RCM should they not materialise. These are summarised in Table 7.

Table 7 - Key assumptions

Theme	Assumption	Notes
AVI	Assume in place for all topic areas.	This is an area in which many previous business cases have fallen down as they would be expected to fund AVI as well as the direct RCM technology and processing.
Data availability	Assume additional data can be 'bought' for 'Higher Level Analytics	'In practice, there may not be a business case for monitoring the other parameters required to complete the 'Health Assessment' phase.
Discount rates	5% cost of capital	Latest advice suggests safety benefits should be discounted at 3% so this could be refined in future models. Cost of capital (and hence discount rate) may vary between stakeholders.

4.3 Current industry position

The current industry costs were calculated for each area based on the current levels of RCM. The figures for each area are summarised in Table 4. Note that these figures suggest the biggest opportunities lie in improving management of assets (through condition-led maintenance and renewals regimes) rather than targeting asset risk.

Table 8 - Current annualised industry costs (all topic areas)

Annualised Costs (£m)		T857-01 Axle Journal Bearings	T857-02 Wheel Impact Loads	T857-03 Pantographs	T857-04 OLE	T857-05 Ride Monitoring	T857-07 3rd Rail Interface
Asset Risk	Safety	0.1	0.1	Neg.	Neg.	5.3	Neg.
	Service	1.2	0.7	1.1	13.5	29.1	3.0
	Other	1.0	10.0	5.0	1.6	9.2	Neg.
Asset WLC	TOC	48.5	179.6	7.6	-	30	5.7
	FOC	7.7	28.3	0.5	-		
	Network Rail	-	-	-	57.6	90	13.2
RCM Costs	Service Impact	0.6	0	0.7	0	Neg.	0
	WLC	2.2	1.4	0.7	0.7	N/A	0
TOTAL		**61.3**	**220.2**	**15.6**	**73.4**	**154.4**	**21.9**

4.4 Analysis results by topic area

Detailed information on each topic area is provided in the individual work package reports T857-01 to T857-05 and T857-07. The results for each work package are summarised in the following sections.

4.4.1 T857-01 Axle journal bearings

Three options were tested fully in the RCM Toolkit:

- Option 1: Exploit existing HABD systems
- Option 2: Migrate to acoustic monitoring systems
- Option 3: Keep HABD systems and introduce acoustic monitoring systems in parallel

The phased business case results are shown in Table 9, Table 10, and Table 11. These suggest that exploiting the data from the existing HABD systems and integrating it with other bogie health measures to influence TOC/FOC wheelset maintenance has the best business case for the smallest investment. Note that the benefits of HABD and acoustic together are actually lower than those for the individual systems as the whole life cost of maintaining both sets of systems offsets the benefits. In practice there may be an optimal balance of HABD and acoustic monitoring systems.

Table 9 - Option 1: Phased Business Case Results

Option 1: HABD Only	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(0.00)	(0.01)	(0.10)	(0.14)	(0.19)
Total PV (£ million including benefits)	1.2	2.0	22.5	36.5	50.5

Table 10 - Option 2: Phased business case results

Option 2: Acoustic Only	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(3.6)	(3.6)	(3.7)	(3.7)	(3.8)
Total PV (£ million including benefits)	13.4	21.0	30.9	38.2	42.8

Table 11 - Option 3: Phased business case results

Option 3: HABD + Acoustic	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(3.6)	(3.7)	(3.8)	(3.8)	(3.8)
Total PV (£ million including benefits)	(4.8)	7.8	17.3	24.6	29.3

4.4.2 T857-02 Wheel impact loads

Two options were tested fully in the RCM Toolkit:

- Option 1a: Replacement of existing wheel impact load detection systems with similar, intrusive systems.
- Option 1b: Replacement of existing wheel impact load detection systems with fibre optic systems.

The phased business case results are shown in Table 12 and Table 13. These suggest that there is potential value in replacing the systems providing the data from the systems can be exploited to improve overall health assessment of wheelsets to influence TOC/FOC wheelset maintenance.

Table 12 - Option 1a: Phased business case results

Option 1a: Intrusive	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(8.18)	(8.19)	(8.27)	(8.30)	(8.33)
Total PV (£ million including benefits)	(7.2)	(3.0)	36.4	65.1	83.9

Table 13 - Option 1b: Phased business case results

Option 1b: Fibre Optic	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(5.91)	(5.92)	(5.99)	(6.03)	(6.06)
Total PV (£ million including benefits)	(0.6)	3.5	42.9	71.6	90.4

4.4.3 T857-03 Pantographs

Only one option was tested fully in this area:

- Option 1: Migrate existing PanChex™ systems to imaging systems.

The phased business case results are shown in Table 14. This suggests that there is potential value in replacing the systems with the modern imaging systems to address existing service risks. There are additional asset whole life cost benefits, providing the data from the systems can be exploited to improve overall health assessment of pantographs and influence TOC/FOC maintenance regimes.

Table 14 - Option 1: Phased business case results

Option 1: Imaging	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(5.09)	(5.10)	(5.17)	(5.21)	(5.24)
Total PV (£ million including benefits)	9.84	13.76	17.36	17.73	18.45

4.4.4 T857-04 OLE integrity

Two options were tested fully in the RCM Toolkit:

- Option 1: Increase use of instrumented in-service vehicles
- Option 2: Increase use of optical systems on in-service vehicles

The phased business case results as shown in Table 15 and Table 16. These suggest that a small number of instrumented in-service vehicles could provide enough information for Network Rail to realise significant benefits from both reducing service risks and improving its OLE maintenance regime.

Table 15 - Option 1: Phased business case results

Option 1: Instrumented In-Service	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(0.02)	(0.03)	(0.11)	(0.16)	(0.20)
Total PV (£ million including benefits)	13.5	19.0	33.7	39.4	51.3

Table 16 - Option 2: Phased business case results

Option 2: Optical In-Service	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(0.36)	(0.37)	(0.45)	(0.48)	(0.52)
Total PV (£ million including benefits)	5.0	8.4	16.9	19.9	25.4

4.4.5 T857-05 Ride monitoring

No options were tested fully in the RCM Toolkit in this option. Instead the use of ride monitoring to improve rail attractiveness to freight users and passengers and increase market share was explored. The role of in-service vehicles in track quality recording was also investigated. The analysis suggested that there was potentially significant benefit to using ride monitoring on a subset of freight wagons targeting higher value goods. The benefits for passenger ride were less clear. The analysis also suggested that having more frequent observations of track quality through the use of monitoring via in-service vehicles would be of substantial benefit.

4.4.6 T857-07 DC 3rd rail iterface

Four options were tested in this area as it covered both sides of the interface:

- Option 1: Introduce trackside equipment to monitor shoegear condition
- Option 2: Introduce instrumented shoegear on in-service trains to improve management of conductor rail
- Option 3: Monitor current collection on in-service trains to understand areas of poor condition and improve management of conductor rail
- Option 4: A combination of the above technologies looking at the interface as a whole

The phased business case results as shown in Table 17, Table 18, Table 19 and Table 20. These suggest that a small number of instrumented in-service vehicles could provide enough information for Network Rail to realise significant benefits from both reducing service risks and improving its conductor rail maintenance regime.

Table 17 - Option 1: Phased business case results

Option 1: Trackside Only	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(2.7)	(2.8)	(2.8)	(2.8)	(2.8)
Total PV (£ million including benefits)	(1.7)	(1.5)	(1.1)	(0.6)	(0.4)

Table 18 - Option 2: Phased business case results

Option 2: TB Instrumented Only	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(0.08)	(0.12)	(0.20)	(0.20)	(0.21)
Total PV (£ million including benefits)	1.8	2.7	3.9	5.6	5.6

Table 19 - Option 3: Phased business case results

Option 3: TB Current Only	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(0.00)	(0.04)	(0.12)	(0.13)	(0.13)
Total PV (£ million including benefits)	1.2	1.5	2.3	2.9	3.4

Table 20 - Option 4: Phased business case results

Option 4: Combined Interface	DA/DM/SD	HA1	HA2	PA	AG
Investment PV (£ million)	(2.8)	(2.9)	(2.9)	(2.9)	(2.9)
Total PV (£ million including benefits)	(0.1)	1.3	3.1	4.6	5.2

4.5 Sensitivities

The RCM Toolkit allows ranges to be put on all parameters for sensitivity testing. This was carried out for each of the individual topic areas to identify the key parameters.

As most of the cost (and hence opportunity) lies in the cost of maintaining the assets, these parameters were generally the main drivers of the business cases. Therefore the assumptions around these parameters are important in determining the feasibility of these options.

The key parameters for each topic area are listed in the topic area work package reports.

5 Summary of findings, and recommendations

5.1 Introduction

This report has presented AMCL's review and analysis of the use of RCM across the six topic areas in RSSB research project T857, namely work packages T857-01 to T857-05 and T857-07. Section 1 provided an outline of the context of the research and the topic areas under consideration. In Section 2 the methodology for reviewing the use of RCM in an area was proposed. Section 3 summarised the key themes from the SWOT Analysis carried out in each topic area and general considerations on the use of RCM. Section 4 then presented the results of applying the RCM Toolkit to each of the topic areas in terms of the business case outputs.

This section summarises the findings of the review and analysis and presents recommendations for RSSB and the industry to develop the opportunities for the use of RCM to minimise the risks associated with relevant assets or interfaces for the lowest whole-life cost.

5.2 Findings

The application of the T857-06 methodology has suggested that there appears to be a strong business case for exploiting RCM technology in all the areas specified by the RSSB for review as part of this project. RCM can reduce service risks and realise benefits through integrating data on asset condition and by facilitating changes to asset maintenance regimes to become more condition-led. The strongest business cases arise where existing RCM systems can be further exploited, or where sufficient information can be gained from a small number of RCM system installations and the effort is put into developing the systems and tools for automating data processing and integrating condition information with asset maintenance planning tools.

There are currently barriers to progress in these areas that include the ability to share data between systems, and the current role of RCM systems as risk mitigation tools for the rail network or for dispute resolution. These barriers need to be overcome in order for RCM systems to become a proactive means of gaining knowledge that can be used by the asset maintainer to drive down industry costs and improve asset performance.

AMCL considers that to maximise the potential benefits associated with RCM will require cross-industry leadership, otherwise the existing fragmented approach to the implementation and use of RCM systems is likely to continue.

5.3 Recommendations

The following recommendations are made as a result of the analysis carried out across all topic areas:

1. XIRCMSG and the rail industry should review the outputs from this initial study to determine if the resulting business case is strong enough to proceed on an industry-wide basis with the preferred options identified.
2. If it is deemed that further analysis is required it should only be undertaken within the context of an overall optimisation approach for inspection and maintenance regimes of critical interface assets in order to secure industry-wide benefit.
3. The industry should apply FMECA to identify the key functional failures and consequences for critical interface assets in order to identify clear opportunities for RCM.
4. The business case for RCM should then be refined based on the root causes of failure and the routine Asset Management processes that could be rescheduled, reduced or eliminated if the identified condition data was available.
5. Condition data requirements should be utilised to drive the specifications for RCM system development. These systems specifications should be functional and not overly prescriptive.
6. RCM Suppliers should be engaged early in the specification and development process to encourage innovation.

In addition, in order to support the above XIRCMSG and the rail industry should also consider:

7. Provision of frameworks for capturing failure information against the identified failure modes to build industry-wide models of degradation.
8. Working with stakeholders (including Network Rail, RCM Suppliers, ATOC and the Rail Freight Association) to review existing cost assumptions for key business case parameters and draw on a sufficiently representative network sample to preserve confidentiality and improve robustness of the business cases.

6 RCM Toolkit

6.1 Introduction

This section provides a brief outline of key characteristics of the RCM Toolkit as per the scope defined by RSSB, namely:

- Format
- Functionality
- Possible future support/maintenance
- Proposed use
- Platform for implementation
- Verification and acceptance
- Training and knowledge transfer
- Model ownership following completion of research
- Access

It also provides suggestions on possible future improvements to the model.

6.2 Format

The RCM Toolkit is an Excel-based application that has Visual Basic for Application (VBA) code embedded to allow user navigation and presentation of key outputs.

6.3 Functionality

The RCM Toolkit is designed to support the methodology outlined in Section 2. For details of the full functionality see the associated RCM Toolkit User Guide.

6.4 Possible future support and maintenance

Discussions on future support and maintenance will be managed separately by RSSB and are not included here.

6.5 Proposed use

The RCM Tookit is designed to be used by an informed user who understands the topic area under consideration for RCM and the proposed RCM systems to be implemented. It also assumes the user understands basic cost-benefit analysis and asset management concepts.

6.6 Platform for implementation

See Section 6.2

6.7 Verification and acceptance

The prototype RCM Toolkit was issued to the RSSB research project T857 Steering Group who subsequently also circulated it to a wider industry steering group for testing. Feedback from this review was fed into the final stages of the RCM Toolkit development. The RCM Toolkit has subsequently been issued to the RSSB steering group alongside the topic area work package reports.

6.8 Training and knowledge transfer

It is proposed that AMCL will present the RCM Toolkit and a brief user session in early 2012 following completion of the project.

6.9 Model ownership following completion of research

The RCM Toolkit is provided to RSSB who will be the owners on behalf of the industry.

6.10 Access

The RCM Toolkit is provided as a self-contained spreadsheet. Formulae are locked in the spreadsheet to disallow accidental user error, but passwords are provided in the User Guide to allow RSSB to access the underlying cells and code.

6.11 Model improvements

6.11.1 Non-RCM-driven improvements to costs and risks

Currently, in this version of the RCM Toolkit, maintenance costs are assumed to be constant. In practice these may improve due to continuous improvements made by the maintaining organisation.

Similarly, there may be potential initiatives that will take place that may reduce the opportunities for future application of RCM in these areas (such as a move from third rail electrification to overhead electrification). Introducing a more flexible definition of future scenarios should be considered (although this would require additional data to populate).

6.11.2 Discount rates

In addition, the same discount rate applies to all costs and also to safety risk. This is an assumption made for this version of the RCM Toolkit, and because of the small value of the safety risk compared to the other business case drivers, in the topic areas reviewed for this project, it does not have any significant impact on the comparison between options and maturity levels. However, future developments of the RCM Toolkit may want to consider implementing this.

6.11.3 User interface

It is likely that as the RCM Toolkit is used by RSSB there will be improvements identified for the user interface, such as ways to define scenarios and more flexible means for inputting data. This would also allow charts and results to be presented in more user-friendly style. The tool is currently based on the original spreadsheet analyses carried out and there is an opportunity to simplify the user experience so the model can be more widely used.

The labelling of the rows and columns could also be made more user-friendly with the inclusion of brief descriptions and/or guidance on how to populate the tool (reducing the need to rely on the user guide).

6.11.4 RCM development and implementation costs

Current cost estimates are based on technology solutions and support. Future versions of the model should consider incorporating development, implementation and business change costs to realise each level of RCM maturity.

6.11.5 Bedding in failures

Linked to the above implementation costs, the model should allow 'bathtub' curves for failure rates to show the possible additional risks involved in the early years when adopting new technologies.

6.11.6 'Remove RCM' and 'Do Nothing' add-ons

While the model can simulate simple 'Remove RCM' and 'Do nothing' options, this produces outputs that are not particularly meaningful given the focus of the model. The user interface for these types of models could be improved.

6.11.7 Sensitivity analysis

The existing 'Upper' and 'Lower' estimate approach is fine for high-level estimation, but for proper sensitivity and uncertainty analysis a Monte Carlo simulation would be required. This could be built on to the model if required.

A: Stakeholders and contacts

A.1 T857 Steering Group

Name	Organisation
Paul Antcliff	DB Schenker
Andrew Burchell	Eversholt Rail
David Edwards	Virgin Trains
Amanda Hall	Network Rail
Gareth Tucker (initially Neil Halliday)	RSSB
Gladys Udeh	RSSB

A.2 T857-03 Key stakeholders

Table 1 - Key stakeholders

Name	Organisation	Role	Description
Derek Jackson	ATOC	Performance Development Engineer	Supplied information on fleet sizes and utilisation.
Barry Winchurch	MRX Technologies	General Manager	Supplied information on MRX activities and products in this topic area.
Nick Pinder	Network Rail	Integrated	Providing data on Wheelchex and HABD strategy and performance.
Steve Mitchell	National Express East Anglia	Fleet Technical Engineer	Provided TOC view on asset costs and benefits associated with RCM for various topic areas.
Edward Blacoe	Eversholt Rail Group	Head of Engineering	Operational methodology of RCM systems across UK rail network.
David Edwards	Virgin Trains	Fleet Systems Engineer	Provided TOC view on asset costs and benefits associated with RCM for various topic areas.

Table 1 - Key stakeholders

Name	Organisation	Role	Description
Matthew Elmes	Vertex System Engineering	Managing Director	As a HABDs expert, supporting AMCL on assumptions made on topic areas and sections relating to HABDs.
Helen Coxon	Network Rail	Senior Development Manager	Data validation and verification, including assumptions on proposed WID systems.
Phil Downes	Vertex System Engineering	Operations Director	General information on RCM activities in rail and other industries.
Paul Antcliff	DB Schenker Rail	Engineering Standard Manager	Information and data on freight activities.
Nicholas Kay	Siemens	Manager Innovative Technologies	Technical information on Acoustic.systems
Clive Roberts	Birmingham University	Professor, School of Electronic, Electrical and Computer Engineering	Overview of existing and future developments in various topic areas
Eric Holmes	Bombardier	Business Development Manager	Outline of Bombardier's approach to on-board RCM and integration with other data.
Simon Jarrett	Chiltern Railways	Engineering Manager	Technical information on use of GOTCHA
David Hickson	Southern Railway	Fleet Engineer	Asset Information from Sussex Route.
Chris Welford	London Underground	Condition Monitoring Manager	LUL approach on RCM technologies.
Ilse Vermeij	Lloyd Register	Consultant	Representative of Gotcha. Providing information on benefits of GOTCHA.
John Andrews	Nottingham University	Lecturer	Information on algorithms being used to develop higher level analytics.

Table 1 - Key stakeholders

Name	Organisation	Role	Description
Andy Bell	National Express East Anglia	Fleet Engineer	Provided TOC view on asset costs and benefits associated with RCM for various topic areas.
Rob Harrison	University of Sheffield	Lecturer	Information on algorithms being used to develop higher level analytics.
Phillip Hinde	Crossrail	Rolling Stock and Depots Manager	Information on RCM approaches being considered for Crossrail
Roger Goodall	Loughborough University	Lecturer	Information on algorithms being used to develop higher level analytics.
Roger Dixon	Loughborough University	Lecturer	Information on algorithms being used to develop higher level analytics.
Tez McCall	Network Rail	Engineering Development Manager	Technical information on pantograph monitoring and engineering trains systems.
John Reddyhoff	Eversholt Rail Group	Head of Engineering	Technical information on RCM systems.
Michael Jacks	Virgin Trains	Fleet Reliability Manager	Technical information on OLE.
Michael Dobbs	Network Rail	Senior Asset Engineer	Technical information on Pantograph monitoring.

B: RCM background and theory

B.1 Eight key principles of cross-industry RCM

The following is taken from the remit of the V/VSIC sub-group XIRCMSG.

The sub group was given a remit from SIC Chairs to *'Develop the principles of what the industry wants to achieve (information requirements etc.) in each of the 4 quadrants of the Intelligent Infrastructure Strategy where there is a cross industry aspect'*. This has culminated in the development of eight key principles and an associated activity list for cross-industry remote condition monitoring

1. Principles are applied to RCM activities in any of the four quadrants where there is cross-industry impact.
2. Business cases shall include all cross-industry elements including evaluation of benefits and costs.
3. An end-to-end cross-industry RCM operating model (including processes and contracts) is clearly described and agreed (defined shape).
4. Solutions shall conform to cross-industry RCM Reference Architecture.
5. Network wide enablers (eg processes, technology, standards) are justified separately from solution projects but aligned with their plans (funding/delivery).
6. Cross-industry RCM standards shall be applied to technical solutions and business processes.
7. Application of these cross-industry RCM principles has governance that is industry recognised.
8. Business as usual (BAU) procurement activities should consider application of cross-industry RCM principles.

C: SWOT analysis template and questions

The template below has been used for the SWOT Analysis, along with sample questions used to elicit the strengths, weaknesses, opportunities and threats. Note that questions on strengths and weaknesses are interchangeable and give the relative strength / weakness of one technology vs. another.

Strengths

- Most areas have some degree of further benefits that can be realised through RCM.
- Several systems are already in place with proven success in reducing risk.
- There is a move towards 'predict and prevent' approaches rather than 'observe and react'.
- RCM is safer than sending maintenance staff to work trackside.
- Many data communication systems are already in place due to existing installations and other trackside technology.

Weaknesses

- To date there has been a piecemeal approach to implementation meaning individual business cases are rarely justifiable.
- Even within a topic area the benefits of integrating information from several installations is rarely maximised.
- There is fragmentation due to different systems and ownership issues.
- There are reliability and competence issues with existing / proposed systems that mean current benefits are not fully realised and future benefits may not be either.

Opportunities

- Closer alignment of TOC/FOC/Network Rail interests at local level provides opportunity to look at system benefits.
- Main opportunity is exploiting data from existing systems through 'Higher Level Analytics' tools to provide better overall system diagnostics to increase maintenance / overhaul intervals.
- Remote operation can reduce the amount of maintenance staff in the trackside environment.

Threats

- Too much focus on the performance of the technology solution rather than maximising the benefits from data analysis.
- Funding and affordability - who pays and when?
- Cultural barriers to ownership and change.
- Over-specification of technology (i.e. too prescriptive) rather than focusing on the functional requirements.

D: List of abbreviations

Abbreviation	Description
AG	Advisory generation
AMCL	Asset Management Consulting Limited
ATOC	Association of Train Operating Companies
AVI	Automatic vehicle identification
BAU	Business as usual
Capex	Capital expenditure
CaSL	Cancellations and significant lateness
DA	Data acquisition
DfT	Department for Transport
DM	Data manipulation
EMGTPA	Equivalent Million Gross Tonnes Per Annum
FOC	Freight operating company
FMECA	Failure modes, effects and criticality analysis
GB	Great Britain
HA	Health Assessment (HA1 is used to refer to 'Basic' HA and HA2 'Full' HA)
ISO	International Standards Organisation
MTBF	Mean Time Between Failures
OLE	Overhead Line Equipment
Opex	Operating expenditure
PA	Prognostic assessment
PV	Present Value
RCM	Remote condition monitoring
ROSCO	Rolling stock leasing company
RSSB	Rail Safety and Standards Board
RUS	Route Utilisation Strategy
SD	State Detection

SWOT	Strengths, weaknesses, opportunities and threats
TOC	Train operating company
TOPS	Total Operations System
TRUST	Train Running System TOPS
UGMS	Unattended Geometry Measurement System
UJG	Uninterrupted Journey Group
WLC	Whole-life cost
XIRCMSG	Cross-industry Remote Condition Monitoring Strategy Group

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