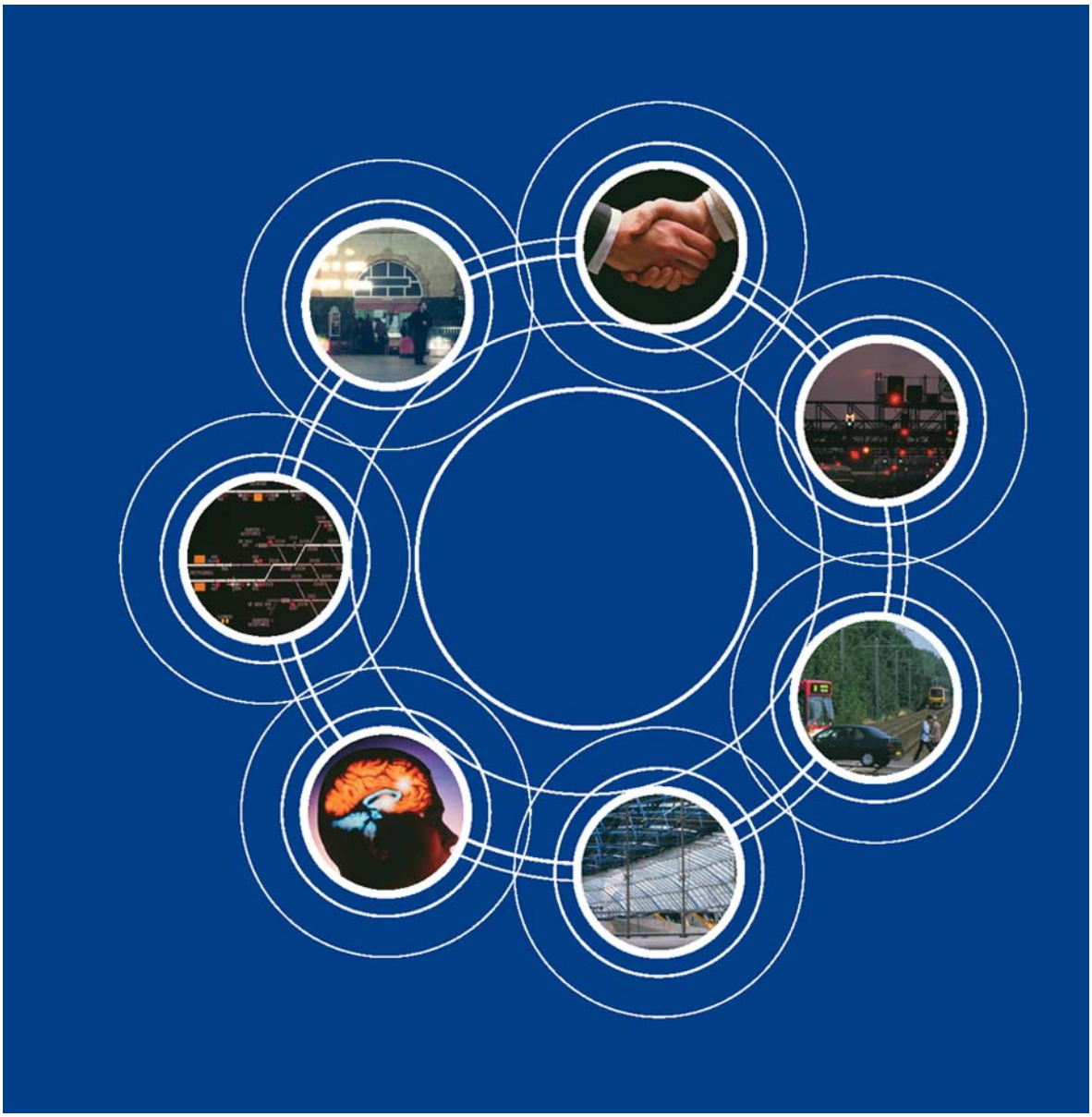
Research Programme

Engineering

Detailed overview of selected RCM areas - RCM Toolkit user guide



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Published August 2012

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Detailed overview of selected RCM areas

RCM Toolkit user guide

1 Introduction

1.1 Purpose

This document is a user guide for the Remote Condition Monitoring (RCM) Toolkit that was a deliverable for RSSB from the workstream T857-06 'Overview of the benefits and risks associated with condition monitoring'.

T857-06 Deliverables:

- T857-06 Overview of the benefits and risks associated with condition monitoring [report]
- T857-06 RCM Toolkit [Microsoft Excel tool]
- T857-06 RCM Toolkit User Guide [this document]

This document is a Toolkit User Guide only, the wider context of the T857-06 workstream and the associated Toolkit is clarified in the overall workstream report. The scope and budget for the associated toolkit were predefined by the RSSB.

1.2 Scope

The RCM toolkit is designed to be a high-level tool for evaluating industry business cases for adoption (or extending the use) of RCM technologies. The level of detail is therefore based on what is required for a 'first pass' business case to evaluate system-wide costs and benefits for the industry, with some indication of likely implementation periods for these. It is expected that any positive business cases would be further developed by the individual parties involved and this would require more rigorous evaluation through company-specific investment processes, at which point the toolkit's limits are reached (although inputs produced for the high-level toolkit may be of use in this follow-up phase).

1.3 Structure of document

The remainder of this document presents:

- A toolkit outline giving an overview of the toolkit and its structure (Section 2)
- A description of the main elements of the toolkit and how these should be populated and interpreted:
  - 'Input - General' sheets (Section 3)
  - 'Input - Assets' sheets (Section 4)
  - 'Input - RCM' sheets (Section 5)
  - 'Summary and Output' sheets (Section 6)

2 Toolkit outline

2.1 Overview

The RCM toolkit is a spreadsheet-based model that provides a means for capturing and evaluating the high-level costs and benefits associated with installing and integrating RCM technologies to address the risks associated with an asset or failure mode.

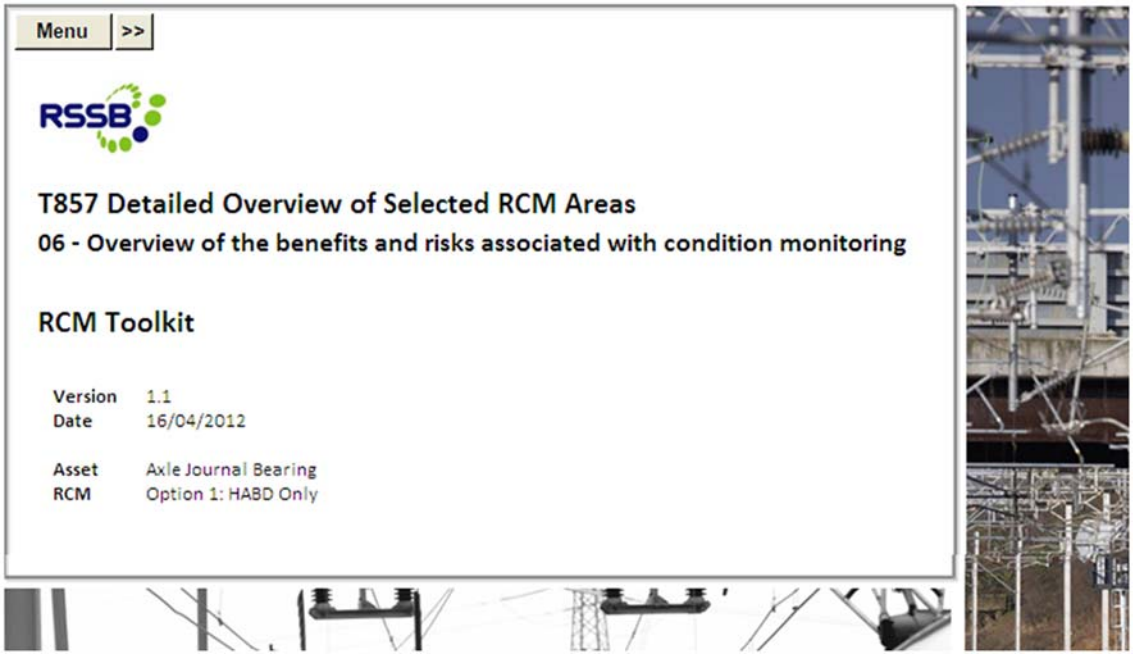

Figure 1 - RCM Toolkit

As a single workbook, the RCM toolkit can be used to capture the investment costs and system benefits (in terms of reduced system costs) of advancing a specified option through the RCM maturity levels framework, as defined in ISO13374 and summarised in Figure 2.

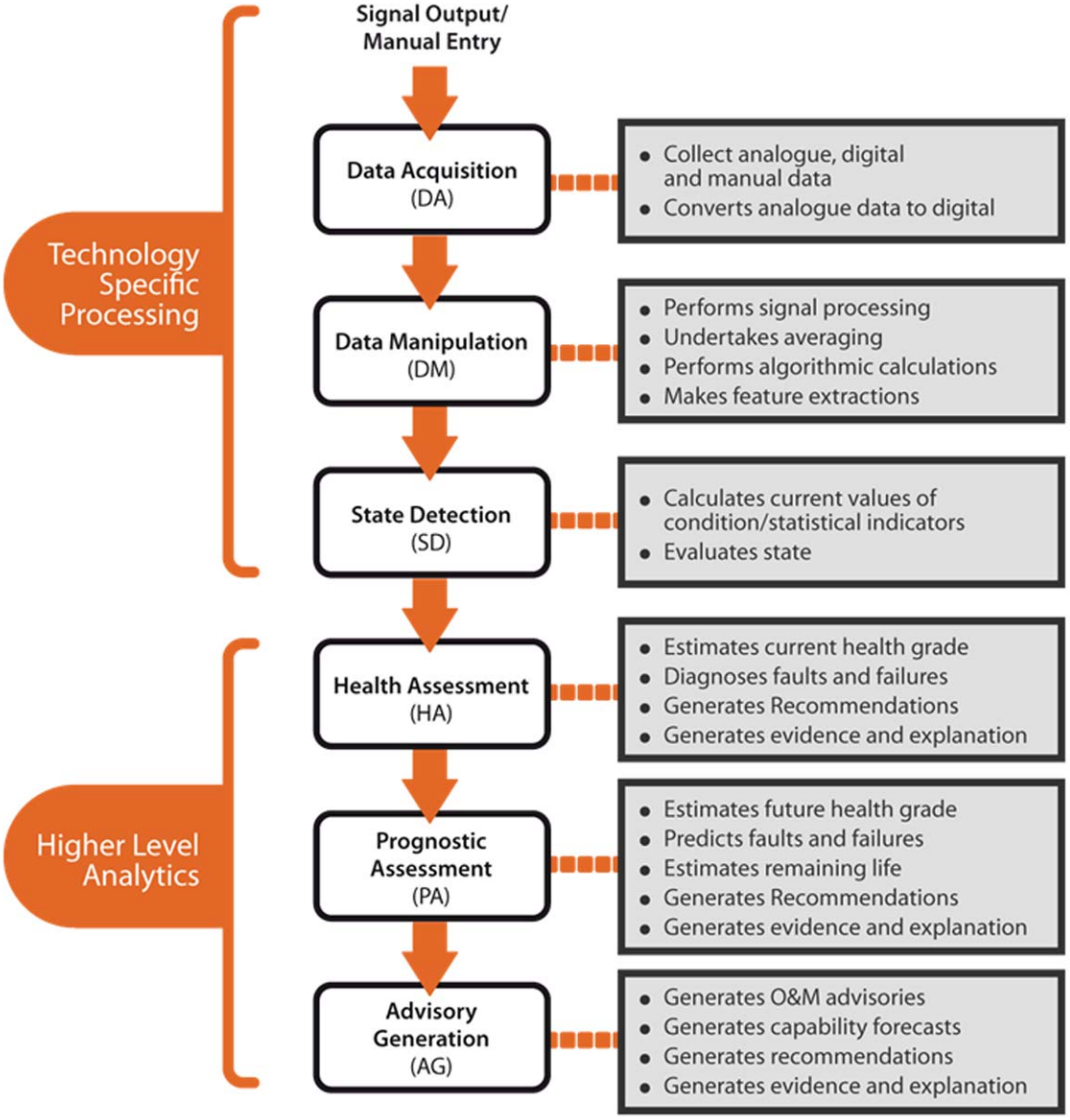

Figure 2 - ISO13374 Defined Levels of Maturity (DA to AG)

For example, the toolkit can be used to capture the additional benefits of installing further lineside equipment for monitoring parameters for axle bearings and then integrating data from the lineside equipment with other bogie health data to optimise bogie management regimes.

The outputs from multiple workbooks can be combined to compare the costs and benefits of different options. For example, this could be used for evaluating the costs and benefits of two types of technology looking at different parameters of axle bearing health that may address different risks, or for comparing two types of lineside equipment that monitor the same parameter but have different costs and reliability. Note the current toolkit does not perform these multiple workbook comparisons but the outputs for each option can easily be transferred to a separate spreadsheet or the company's own financial modelling software.

2.2 Concepts

The concepts and principles used by the toolkit are detailed in the companion document to this user guide, the report for the RSSB workstream T857-06.

2.3 Toolkit structure

The RCM toolkit contains a number of sheets, through which the user can navigate via the navigation menu shown in Figure 3. All sheets are listed in Table 1 with a brief description. These are presented in the table in the order in which they appear in the toolkit, but the detail is presented in a slightly different order within this document for clarity (see cross-references under 'Sheet Type').

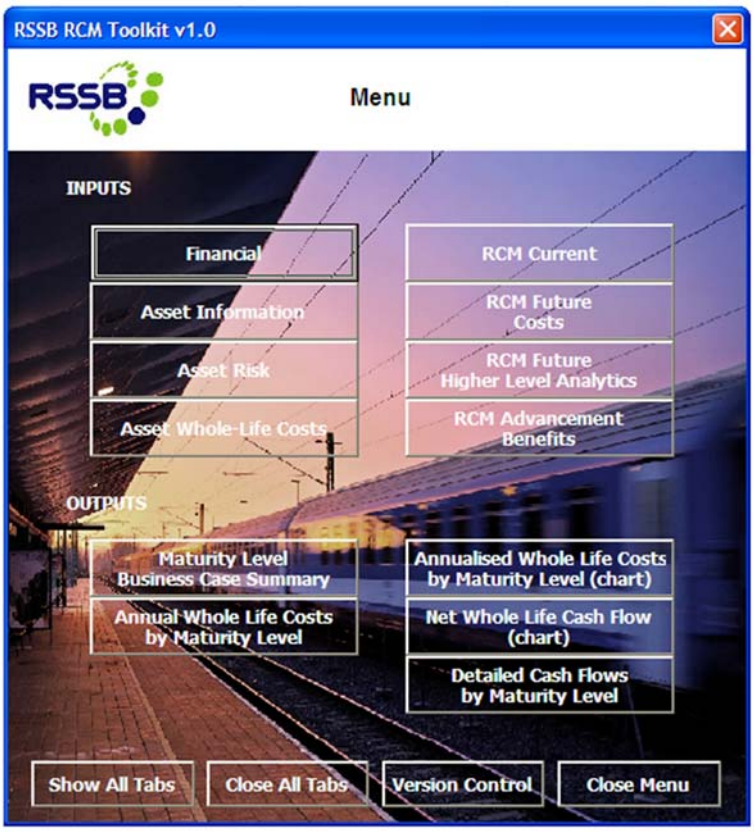

Figure 3 - Navigation menu

Note there are two main types of input sheets - those associated with the Asset that is to be (condition) monitored and those associated with the RCM technology that performs the monitoring and assessment. It is important that these are not confused when inputting data.

Table 1 - Sheets in RCM Toolkit

Sheet Type	Sheet Name	Brief Description
Summary Outputs (see Section 6)	Version Control	Front cover / admin sheet (version control, etc.).
	Maturity Level Summary	Illustrative summary of the steady state system costs associated with each level of option maturity and the investment costs required to advance to this level.
	Annual (Steady State) WLC by Maturity Level	A breakdown of the steady state costs at each maturity level including a graphical summary of these.
	Annual (chart)	Chart showing the annualised (steady state) whole life costs by Maturity Level.
	Net Cash Flow (chart)	Chart showing the contribution of each Maturity Level to the Net whole life Cash Flow.
Input - General (see Section 3)	Financial Data	An input sheet with the global financial parameters and the estimated time for implementing RCM system changes.
Input - Asset (see Section 4)	Asset Info	An input sheet for capturing the current values of key parameters used to estimate the number of assets present in the system and their utilisation (optional).
	Asset Risk	An input sheet for capturing the current values of key parameters used to estimate the Safety, Service (Performance) and Other Risk Impacts associated with the asset type.
	Asset WLC	An input sheet for capturing the current values of key parameters used to estimate the total costs of managing the asset over its life and converting this into an equivalent annual figure.

Table 1 - Sheets in RCM Toolkit

Sheet Type	Sheet Name	Brief Description
Input - RCM (see Section 5)	RCM Current	An input sheet for capturing the current values of key parameters used to estimate WLC (whole-life costs) costs and RCM impacts.
	RCM Future - Costs	Two input sheets for capturing the required future changes to progress the option in terms of RCM equipment volumes and data integration costs, and hence estimating the total investment cost required to progress through the maturity levels.
	RCM Higher Level Analytics	
	RCM Advancement - Benefits	An input sheet for capturing the future benefits (or dis-benefits) of advancing RCM technologies to this maturity level. These are to be applied to the current costs as calculated above.
Detailed Outputs (see Section 6)	Detailed Cash Flows by Maturity Level: -DS-CF (Cash Flow) -HA1-CF -HA2-CF -PA-CF - AG-CF -Total-CF	These sheets carry out the Cost-Benefit Analysis by calculating the cashflows required to advance the RCM through the maturity levels given the assumptions in this option. The sheets then calculate the total RCM investment costs required for the RCM option and the total RCM benefits (in terms of the reduced steady state system costs over the evaluation period) for cost-benefit analysis

Note that some sheets have a mixture of input cells (shaded pale blue) and calculation cells (not shaded).

2.4 Password for un-protecting sheets and VBA code

To unprotect the sheets within the RCM toolkit and to view the VBA code behind the Excel model, the password is 'RSSB2011'.

3 'Input - General' Sheet Descriptions

3.1 Financial data

Global financial parameters can be added along with the estimated time for implementing system changes. These inputs are required by the Detailed Cash Flow modelling sheets, and include:

- Discount Rate: The agreed rate for discounting cash flows to provide Net Present Values at the 'Year 0' for the Cost-Benefit Analysis.

  Note: In this version of the RCM toolkit, the same discount rate applies to all costs and also to safety risk. This is an assumption made for this version of the toolkit, and because of the small value of the safety risk compared to the other business case drivers it does not have any significant impact on the comparison between options and Maturity levels.

- Year 0: The initial year for the analysis to make sure the output charts can be more easily aligned to control periods (note that the year needs to be a number so it can be more easily added - financial years should be input as 2010 to represent 2010/11 for example).
- Evaluation Period: the number of years to include in the Cost-Benefit Analysis.
- Value of Preventing a Fatality (VPF): this figure is annually calculated by RSSB. The VPF is used to convert the safety risk into an equivalent financial value for fair comparison with other costs, benefits and risks and for input into the cost benefit analysis.
- Implementation Timescales: The number of years taken to implement each RCM maturity level.

4 'Input - Asset' Sheet Descriptions

4.1 Introduction

This section presents brief guidance on populating the sheets of type 'Input - Asset' for the toolkit:

- Asset Info
- Asset Risks
- Asset WLC

These sheets are used to capture the current steady state industry position in terms of the costs and risks associated with the asset themselves.

Some general guidance is given for inputting data. The following information is then described for each of the sheets:

- The purpose of the sheet
- Any inputs required to complete the sheet
- Possible data sources for these inputs
- Examples of how different options can be modelled

4.2 General

Inputting data: User inputs on the current calculation sheets are highlighted in pale blue.

Not all cells need to be completed for the sheet to work. The populated data provided for the different topic areas of T857 demonstrates good practice for rolling stock, infrastructure and interface assets, showing which cells will be blank in each case.

Similarly, not all cost information is required to produce the business case, although the quality and completeness of the solution is dependent on the quality and completeness of the inputs.

Current 'steady state' data should be input for the parameters. If historic data is known to have atypical behaviour, this should be adjusted so that the input figures give data for a typical year.

Expected, Upper and Lower values: The toolkit calculates based on Expected (ie 'average') values, and also Upper and Lower values for the parameters which can be used for scenario modelling and sensitivity testing. Note that Upper values should be equal to or higher than Expected values and Lower values should be equal to or lower than Expected.

4.3 Asset Info

4.3.1 Purpose

An input sheet for capturing the current values of key parameters used to estimate the number of assets present in the system and their utilisation (optional).

4.3.2 Inputs required

Asset: The name of the asset, component or assembly that is monitored by the RCM technology. This can either be on rolling stock, on infrastructure or the interface between the two. This is used for labelling sheets.

Asset Count Calculation: This is where the number of the above assets is captured or calculated. For fleet assets (such as bogies, pantographs, bearings, etc.) this is broken down by the number of vehicles (cars, optionally split locos/motorised vs. wagon/trailer) and the number of assets per vehicle. For infrastructure assets this is input as a direct count (although in practice this may reflect a continuous asset, e.g. km of track or overhead line). There is an option to split between TOC, FOC, NR and 'Other' owned assets.

Asset Utilisation Calculation (Optional): This is optional additional data only required if asset lifecycle interventions are utilisation-based (eg, for mileage-based wheel maintenance or tonnage-based impacts on track). The average utilisation (or duty) for the asset needs to be captured. Once again this can be split to allow different utilisations for different asset owners.

4.3.3 Data Sources

These figures will need to be sourced from the appropriate asset owner or estimated based on industry data. The relevant subset should be used (eg, only units used in overhead line areas for testing pantograph integrity). The T857-06 workstream report captures some high level assumptions that can be used across different options and individual assumptions used in each topic area are captured in the individual T857 workstream reports.

4.3.4 Examples

For an example consider T857-01. The assets in scope are the axle journal bearings which are on the rolling stock and therefore managed by TOCs and FOCs. Information for the GB fleet (for mainline rail) would be input as shown in Diagram 4. Note while Network Rail (and others) has some rolling stock these have been omitted from the analysis due the relatively low proportion of assets. An average bearing will travel the distances shown in a year and therefore the total utilisation is calculated from this automatically.

Asset Information						
Asset	Axle Journal Bearing					
Information		EXPECTED				
		TOC	FOC	NR	Other	TOTAL
Asset Count Calculation						
Fleet	Locos/Motorised	6,200	1,500			7,700
	Wagon/Trailer	6,200	30,000			36,200
Config	Assets per L/M	8	6			
	Assets per W/T	8	4			
Subtotal		99,200	129,000	0	0	228,200
Infrastructure	Infrastructure Assets					0
Total Asset Count		99,200	129,000	0	0	228,200
Asset Utilisation Calculation (Optional)						
Average Vehicle Miles per year	Locos/Motorised	116,000	24,000			140,000
	Wagon/Trailer	116,000	20,000			136,000
Average Vehicle Impact per year	Infrastructure					0
Total Usage		11,507,200,000	2,616,000,000	0	0	14,123,200,000

Figure 4 - Asset information for axle journal bearings

4.4 Asset Risks

4.4.1 Purpose

An input sheet for capturing the current values of key parameters used to estimate the Safety, Service (Performance) and Other Risk Impacts associated with the asset type.

4.4.2 Inputs required

The following inputs need to be captured for a 'base year', i.e. an average year where the level of risk reflects the current industry position with the current population of assets and current approach to RCM.

Safety Risk: The equivalent Fatalities and Weighted Injuries (FWI) for the risks associated with the asset. Asset Specific risk should be that directly associated with the asset itself (eg, the risk directly associated with axle journal bearings). Asset Related risk is used to capture other relevant risks that would be mitigated by observing the asset but may not be directly caused by the asset itself (e.g. axle defects that can be spotted through monitoring the axle journal bearing). In practice, it does not matter exactly how the asset risks are captured here as long as the totals reflect the overall risk that can be mitigated through use of the RCM technology.

Service Risk: This needs to capture the service affecting incidents that are associated with the asset:

- Asset Specific: the number of service-affecting incidents where the asset is the root cause.
- Other Genuine: the number of service-affecting incidents where the asset is not the root cause but where the asset can provide an indication for the failure.

The Delay Minutes associated with an average incident also need to be captured, along with the Cancellation percentage (ie the percentage of incidents that are likely to incur a cancellation and significant lateness (CaSL) charge). The Delay Cost per Minute and Cancellation Charge are then used to convert the expected number of incidents into a financial impact for fair comparison with other costs, risks and benefits and for input into the cost-benefit analysis.

Other Impacts: Any other impacts can be modelled here, in terms of the more extreme incidents (such as a derailment caused by an axle bearing failure) or general wear and tear damage (on either infrastructure or rolling stock) that would be expected to improve with improved condition monitoring.

4.4.3 Data Sources

Safety Risk: This is taken from RSSB, with appropriate risk precursor codes used to generate a total figure for the asset.

Service Risk: Historic data is often available from TRUST, although due to the TRUST codes used some additional processing may be required to break down a high level incidents figure into an asset-specific figure. AMCL has used a variety of sources, such as Network Rail's HABD and WILD activations data (for T857-01 and T857-02), TOC/FOC data on rolling stock incidents, etc. The availability of this data will depend on who is carrying out the analysis and the level of cross-industry co-operation in sourcing the data. Note that some cost parameters are commercially sensitive (such as the cost per delay minute) and can vary by TOC/FOC so the general assumptions used in the network-wide cases may not be appropriate for individual TOC/FOC cases.

Other Risk: Where possible, historic data should be used, such as the RSSB incident data behind the precursor information used for the Safety Risks above. However, in some cases these amounts will have to be estimated. For example, it could be assumed that

poor pantograph integrity costs Network Rail an additional £xm in reactive maintenance on overhead line. This would be input into the 'General wear and tear' cells.

4.4.4 Examples

Diagram 5 shows sample asset risks for axle journal bearings.

Asset Risk

Asset	Axle Journal Bearing					
Risk		EXPECTED				
		TOC	FOC	NR	Other	TOTAL
Safety Risk						
FWI	Asset Specific	0.0303	0.0055			0.0358
	Asset Related	0.0143	0.0186			0.0329
	Total Safety Risk	0.0446	0.0241	0.0000	0.0000	0.0687
	Total Safety Cost	£75,820	£40,970	£0	£0	£116,790
Performance Risk						
Service affecting incidents	Asset Specific	13	7			20
	Other Genuine	45	25			70
	Total Incidents	58	32	0	0	90
	Delay Minutes per Incident	350	350			
	Total Delay Minutes	20,300	11,200	0	0	
	Cancellation %	100%	100%			
	Delay Cost per Minute	£33	£33			
	Cancellation Cost	£2,000	£2,000			
	Total Service Cost	£785,900	£433,600	£0	£0	£1,219,500
Other Impacts						
	Major incidents per year	0.1	0.1			0.2
	Cost per major incident	£5,000,000	£5,000,000			
	General wear and tear					£0
	Total Other Costs	£500,000	£500,000	£0	£0	£1,000,000
Total Asset Risk Cost		£1,361,720	£974,570	£0	£0	£2,336,290

Figure 5 - Asset risks for asset journal bearings

The safety risks are taken from RSSB data and show the totals for TOCs (passenger train risk) and FOCs (freight train risk) for axle-related causes, split between causes explicitly mentioning bearings and other axle-related causes. Service risk inputs are based on HABD activations data from Network Rail which was used to strip out genuine activations (that were caused by failed axle bearings or other root causes that impacted on the axle bearing) from those false alarms (eg reflected sunlight) that will need to be picked up in the RCM reliability figures (see Section 5.3).

Information provided by Network Rail on the HABD activations data also had information on the delay associated with these activations, which is used to calculate an average impact for a genuine activation. Cost data was estimated from network-wide evidence. Major incidents (derailments in this case) were taken

from the RSSB data in terms of frequency and the impact estimated at £5m due to the significant damage and line closure associated with such an incident having significant industry costs.

4.5 Asset WLC

4.5.1 Purpose

An input sheet for capturing the current values of key parameters used to estimate the total costs of managing the asset over its life and converting this into an equivalent annual figure.

4.5.2 Inputs required

The following inputs need to be captured for a 'base year', ie, an average year where the level of risk reflects the current industry position with the current population of assets and current approach to RCM.

Failures: The total number of (in-service) Asset Faults across all assets. Note that while this figure needs to be input as a total, the Number of failures per asset per year and Mean Time Between Failures (MTBF) are also calculated in this sheet to act as a sense-check on the implied asset reliability as a result of using this figure. The typical cost of fixing an average fault (Reactive Cost per Fault) also needs to be captured. Note that asset faults that are routinely picked up through out-of-service maintenance should be captured in the time-based and usage-based activities below.

There is an option to capture asset lifecycle management activities as either time-based activities or usage-based activities. Up to three activities of each type can be input separately, and any additional activities can be combined 'off-model' to be input as a yearly equivalent in the RCM toolkit. This allows a relatively flexible means for capturing asset lifecycle management costs for different types of assets.

Time-based Activities: For each activity the name (Service x), frequency (Interval x) and Cost (Cost x) needs to be input.

Usage-based Activities: For each activity the name (Service y), usage/utilisation threshold (Threshold y) and Cost (Cost y) needs to be input. The threshold is the point in the asset lifecycle (say after duty of 100,000 miles) that the intervention is required.

4.5.3 Data Sources

Data for all of the above are likely to come from the asset manager, e.g. TOC/FOC fleet managers, infrastructure asset managers, etc. The activities carried out by TOCs and FOCs vary depending on the asset ownership (for example with varying

lease arrangements with the ROSCOs). The access to such data is limited as it is commercially sensitive and managers are not always able (or willing) to break down higher level information into asset specific failure, cost and intervention interval data. Also, the management regime can vary widely between different companies and cost data is the most sensitive aspect of many commercial operations. Therefore any network-wide generalisations need to be carefully documented and reflected in the Upper and Lower ranges supplied alongside Expected values.

4.5.4 Examples

Information from trial runs of the toolkit for RSSB workstream T857-01 is shown in Diagram 6. This shows a combination of regular yearly bearing maintenance tasks (assumed to be carried out as part of routine maintenance) with longer-term overhaul and replacement activities.

A similar approach would apply for infrastructure WLC.

Asset Whole Life Cost

Asset	Axle Journal Bearing					
Whole Life Cost		**EXPECTED**				
		TOC	FOC	NR	Other	TOTAL
Failures	Asset Faults (in-service)	13	7			
	Reactive Cost per Fault	£2,000	£1,000			
	Fault Fixing Cost	**£26,000**	**£7,000**	**£0**	**£0**	**£33,000**
	In-service Failures per asset per year	*1.31E-04*	*5.43E-05*	-	-	
	In-service MTBF (years)	*7,631*	*18,429*	-	-	
Time-based Activities	Service 1	Maintenance	Maintenance			
	Service 2					
	Service 3					
	Interval (Years) 1	1	1			
	Interval (Years) 2					
	Interval (Years) 3					
	Cost per Service 1	£50	£50			
	Cost per Service 2					
	Cost per Service 3					
	Annualised Cost per Asset	£50	£50	£0	£0	
	Number of Assets	99,200	129,000	0	0	
	Total Time-based Cost	**£4,960,000**	**£6,450,000**	**£0**	**£0**	**£11,410,000**
Usage-based Activities	Service 1	Mid-life Overhaul	Mid-life Overhaul			
	Service 2	Full Overhaul	Full Overhaul			
	Service 3					
	Threshold 1	500,000	800,000			
	Threshold 2	1,000,000	1,200,000			
	Threshold 3					
	Cost per Service 1	£500	£375			
	Cost per Service 2	£2,000	£1,500			
	Cost per Service 3					
	Annualised Cost per Utilisation	£0	£0	£0	£0	
	Total Usage	11,507,200,000	2,616,000,000	0	0	
	Total Usage-based Cost	**£34,521,600**	**£4,496,250**	**£0**	**£0**	**£0**
Total Asset WLC Cost		**£39,507,600**	**£10,953,250**	**£0**	**£0**	**£50,460,850**

Figure 6 - Asset WLC for axle journal bearings

5 'Input - RCM' Sheet Descriptions

5.1 Introduction

This section presents brief guidance on populating the sheets of type 'Input - RCM' for the toolkit:

- RCM current
- RCM future - costs
- RCM higher level analytics
- RCM advancement - benefits

These sheets are used to capture the costs associated with the current 'steady state' industry implementation of existing RCM technologies and the additional costs and benefits associated with introducing new RCM technologies (or advancing existing technologies) and integrating the data from these to provide higher level analytics, ie increasing the maturity state defined in Section 2.1.

Some general guidance is given for inputting data. The following information is then described for each of the sheets:

- The purpose of the sheet
- Any inputs required to complete the sheet
- Possible data sources for these inputs
- Examples of how different options can be modelled

5.2 General

Inputting data: As for the 'Input - Asset' sheets, user inputs on the current calculation sheets are highlighted in pale blue.

Not all cells need to be completed for the sheet to work. In most cases there will be some blanks as it is unlikely that four RCM technologies will be evaluated at the same time, or that both rolling stock and infrastructure assets will be monitored in the same option. However in cases where an interface is being monitored, there may be fewer gaps.

Similarly (as for the asset parameters), not all RCM cost information is required to produce the business case, although the quality and completeness of the solution is dependent on the quality and completeness of the inputs.

For the 'RCM Current' sheet, current 'steady state' data should be input for the parameters. If historic data is known to have atypical

behaviour, this should be adjusted so that the input figures give data for a typical year.

Expected, Upper and Lower values: The toolkit calculates based on Expected (ie 'average') values, and also for Upper and Lower values for the parameters which can be used for scenario modelling and sensitivity testing. Note that Upper values should be equal to or higher than Expected values and Lower values should be equal to or lower than Expected.

5.3 RCM current

5.3.1 Purpose

An input sheet for capturing the current values of key parameters used to estimate WLC costs and RCM impacts.

5.3.2 Inputs required

The inputs required are based upon the ISO Maturity Levels for Condition Monitoring (see Section 2.1). They are split into two groups, the RCM equipment providing activities and costs for the Data Acquisition, Data Processing and State Detection maturity levels and the Higher Level Analytics (through further hardware and software solutions) providing the activities and costs associated with the Health Assessment, Prognostic Assessment and Advisory Generation maturity levels.

Data Acquisition to State Detection

This picks up the costs associated with the lifecycle management of the RCM detection equipment, covering the activities associated with the Data Acquisition, Data Processing and State Detection maturity levels. This is generally the lineside or train-borne equipment (depending on whether the asset being monitored is infrastructure or train-based) and local processors that capture the data on the relevant parameters of an asset.

Space is provided to model a mix of up to four different RCM systems for Data Acquisition within an option. For each System the following data needs to be captured or estimated.

RCM Installations: The Name of the system and the number of Sites at which equipment is installed. Note that if a single location has several sites (eg multiple tracks) these should all be counted here. For equipment installed on a vehicle this should count the total of all of the on-board sites.

Failures: This is where to capture the number of failures for the RCM equipment, on a per asset basis. These are the failures of the system and also any false alarms that bring additional

disruption to the system through the presence of the RCM. Genuine activations are picked up in the 'Asset Risks' sheet (see Section 4.4). The reactive cost per fault (to the RCM equipment owner) should also be captured here. Note this is just the cost of fixing the physical fault. The additional costs in terms of Service Impact are calculated based on these overall faults by estimating a percentage of faults that have a service impact and the financial impact of the fault (via delay minutes and cancellation charges, as in Section 4.4).

Data Acquisition: This is where to capture the costs of the RCM equipment, such as installation costs (for steady state renewals calculations and estimating the cost of additional RCM sites to widen coverage of the monitored assets). This should include the cost of communications links at a site. The expected life of the equipment should also be estimated so this can be turned into an annualised cost. This is the full life of the asset, not the residual life. An annualised maintenance cost for each site should also be captured.

Data Manipulation and State Detection (DM/SD) operating costs: This is where the additional operating costs of running the central systems to further process and store the acquired RCM data should be captured. This is split into labour, systems, and support costs to cover various options for resourcing this.

Health Assessment to Advisory Generation

This area covers the higher level analytics which is more about bringing data sources and systems together than installing additional RCM equipment. The costs involved are therefore slightly different to those for the earlier maturity levels.

Data and systems costs: This is where the additional capex and opex costs of bringing together additional data sources for the higher level analytics are captured. Following consultation with relevant experts, AMCL considers it appropriate to have four different levels of complexity for this data linking in the toolkit. The costs of each of these types of links need to be captured here, along with any annual costs for storing and maintaining the additional data:

- Data link: simple link between within a software system (e.g. linking two Oracle databases or two Gotcha-compatible RCM equipment types)

- System link: link between two (relatively) compatible software systems within a company (eg, linking two Windows-based applications)
- Complex systems: link between obsolete / legacy system and more modern equivalents requiring custom linkages (eg, linking information from older equipment to an Oracle database)
- External link: link between two parties within the industry (eg, Network Rail system to TOC).

5.3.3 Data sources

These figures will need to be sourced from the appropriate RCM equipment owner or supplier, or estimated based on industry data. There is sufficient data on existing RCM systems to come up with realistic estimates of likely costs per site for generic RCM equipment. However, if there are options for different technologies with known differences between these technologies (e.g. cheaper installation costs but shorter lives, or higher failure rates) then these will need to be included.

Similarly, default costs of the different types of data links can be estimated based on orders of magnitude and have been provided by AMCL. In practice, the complexity of different system links may not be covered by the levels above, so these may need to be adjusted appropriately. It is unlikely that more than four different types of cost will be required, so as long as the rationale for the costs used is included this should not be a material issue.

5.3.4 Examples

For an example, consider RSSB workstream T857-01. HABD and acoustic are the two RCM systems for data acquisition as shown in Diagram 7.

RCM Current

Asset	Axle Journal Bearing					
Data for RCM Current Calcs		**EXPECTED**				
		System 1	**System 2**	**System 3**	**System 4**	**TOTAL**
Trackside Costs						
RCM Installations	Name	**HABD**	**Acoustic**			
	Number of Sites	227	2			
Failures	Faults per Site per Year	1.5	0.75			
	Reactive Cost per Fault	£100	£100			
	Fault Fixing Cost	**£33,500**	**£150**	**£0**	**£0**	**£33,650**
	Service Affecting Failures	100%	100%			2
	Service Affecting Incidents	335	2	0	0	
	Delay per Incident	50	50			
	Cancellation %	0%	0%			
	Delay Cost per Minute	£33	£33	£0	£0	
	Cancellation Cost	£2,000	£2,000	£2,000	£2,000	
	Service Impact	**£552,750**	**£2,475**	**£0**	**£0**	**£555,225**
	Service Impact per Site	*£2,435*	*£1,238*	*£0*	*£0*	
Data Acquisition (include comms costs)	Installation Cost per Site/Train	£200,000	£500,000			
	Expected Life	25	25			
	Annualised Capex Cost per Site/Train	£8,000	£20,000	£0	£0	
	DA Annualised Capex Cost	**£1,816,000**	**£40,000**	**£0**	**£0**	**£1,856,000**
	Annual Mtce per Site/Train	£100	£100			
	DA Annualised Maintenance Cost	**£22,700**	**£200**	**£0**	**£0**	**£22,900**
Central Costs						
DM/SD Operating Costs	Annualised Labour	£100,000	£0			£100,000
	Annualised Systems	£100,000	£0			£100,000
	Annualised Support Contracts	£0	£100,000			£100,000
	Total DM/SD Operating Cost	**£200,000**	**£100,000**	**£0**	**£0**	**£300,000**

Figure 7 - RCM current costs from T857-01

The number of current sites is known, and the faults per site for HABD was calculated based on false alarms from the HABD activations data provided by Network Rail. The reactive cost is an estimate based on an average fault fixing cost for similar types of equipment. All activations of the HABD system currently have a service impact (hence 100%) and from the data provided by Network Rail the average impact of the false alarms (in terms of delay minutes) was also calculated. The installation costs were based on the last large-scale renewal of HABDs and the expected life estimate based on standard design lives for this type of equipment. An average maintenance cost per year was estimated based on similar lineside equipment - this includes corrective maintenance arising from routine inspection (i.e. any out-of-service faults).

The annualised labour and systems costs for Data Manipulation and State Detection are estimates based on the size of the current central team providing the HABD data processing activities. The annualised support contracts for the Acoustic

systems are based on an estimated annual cost of support from a service provider that would capture and process the lineside data and provide user access to the processed data via a web interface, bypassing the need for an in-house central team.

Data and systems costs are estimates based on the relative levels of complexity and size of IT projects of a similar nature.

This sheet will need to include all systems that will be considered within the future options for RCM, for example when replacing with (or migrating to) a new system.

5.4 RCM future - costs, and RCM higher level analytics

5.4.1 Purpose

Two input sheets for capturing the required future changes to progress the option in terms of RCM equipment volumes and data integration costs, and hence estimating the total investment cost required to progress through the maturity levels.

This is where different options will start to diverge in terms of the proposed mix of technologies and level of integration required. This is the forward-looking investment requirement aspect of the RCM toolkit.

5.4.2 Inputs required

Option Title: As this is the sheet where options start to vary, this is where the option is currently named. This should consist of an option number and brief description. Note that a new workbook should be created for each Option as in the examples provided for each topic area.

RCM Future: The inputs to this sheet are to propose a future 'steady state' Site Mix in terms of the number of sites of each RCM technology type. The costs associated with installing additional sites to get to this 'steady state' are then automatically calculated based on the data in the 'RCM Current' sheet.

Note: It is assumed that any redundant RCM equipment can be removed for negligible cost, no asset rationalisation / disposal costs are included in the toolkit. This would need to form part of a detailed follow-up analysis once the high-level business case was accepted in principle.

The RCM higher level analytics information then consists of inputting the number of data links of each level of complexity required to move up the advanced maturity levels of Health Assessment (HA), Prognostic Assessment (PA) and Advisory

Generation (AG). These levels are described more fully in the methodology in the main T857-06 workstream report. The types of link are described in Section 5.3.

Health Assessment is split into two levels:

1. Basic Health Assessment (HA1): At this level the health of the specific asset is known (eg, by trending several readings on a bearing).
2. Full Health Assessment (HA2): At this level the health of the associated assembly is known (by bringing in data on other elements of the bogie so overall assembly health is understood).

For some assets only HA1 will be required (ie, zero cost for moving to HA2), for other assets the only way to realise the higher level benefits (eg, changes to bogie maintenance and overhaul regimes) is to fully understand all elements of the assembly, so the move from HA1 to HA2 will be complex and require several data links.

5.4.3 Data sources

These figures will be based on the user's perception of the future configuration requirements. Issues to be considered are coverage (how many sites are required?) and data links (what additional information is required to enable the higher level benefits?).

For the worked examples in the T857-01 to T857-05 and T857-07 reports, AMCL has based these figures on discussions with industry stakeholders. The links required have been based on the current systems in place and owners of these systems (i.e. Network Rail can trend HABD readings internally through linking its existing information, but passing this information on to those responsible for management of the bearings would require a link to TOCs/FOCs).

There may be no right or wrong answer for this so the additional information stored on Upper and Lower Estimates for these values will be important in modelling scenarios and sensitivities.

5.4.4 Examples

The example in Figure 8 and Figure 9 is taken from the analysis for T857-01 workstream and illustrates the change in site mix for Option 3: HABD + Acoustic.

RCM Future - Costs

Asset	Axle Journal Bearing					
Option Title	Option 3 : HABD and Acoustic					
RCM Future		**EXPECTED**				
		System 1	**System 2**	**System 3**	**System 4**	**TOTAL**
Trackside Costs						
RCM Installations	Name	**HABD**	**Acoustic**	**0**	**0**	
	Existing Sites	227	2	0	0	
Failures						
	Fault Fixing Cost					
Data Acquisition	Site Mix	227	10	0	0	
	Change in Site Mix	0	8	0	0	
Additional Capex	*Capex Cost per Installation*	*£200,000*	*£500,000*	*£0*	*£0*	
	Total Additional Capex	£0	£4,000,000	£0	£0	**£4,000,000**
Additional Maintenance	*Mtce Cost per Installation*	*£400*	*£400*	*£0*	*£0*	
	Total Additional Maintenance	£0	£3,200	£0	£0	**£3,200**
Central Costs						
Additional DM/SD Costs	*Annualised DM/SD Costs*	*£200,000*	*£100,000*	*£0*	*£0*	
	DM/SD Costs	£200,000	£100,000	£0	£0	**£300,000**
RCM WLC - New Configuration						**£2,410,800**

Figure 8 - RCM future - costs from T857-01

RCM Higher Level Analytics

Asset	Axle Journal Bearing						
Option Title	Option 3 : HABD and Acoustic						
RCM Higher Level Analytics		**EXPECTED**					
		Data Source / Systems Integration					
		Data Link	**System Link**	**Complex System**	**External Data**	**TOTAL Capex**	**TOTAL Opex**
Cost Unit Rates							
	Capex	£10,000	£50,000	£500,000	£100,000		
	Opex	£10,000	£10,000	£10,000	£10,000		
System Configuration							
	Basic Health Assessment (HA1)	0	1	0	0	**£50,000**	**£10,000**
	Full Health Assessment (HA2)	0	0	0	1	**£100,000**	**£10,000**
	Prognostic Assessment (PA)	0	1	0	0	**£50,000**	**£10,000**
	Advisory Generation (AG)	0	1	0	0	**£50,000**	**£10,000**

Figure 9 - RCM higher level analytics from T857-01

In this scenario, one acoustic system is introduced on each main operating route (10 sites) to achieve the benefits of the acoustic system for longer term assessment of bearing condition and prediction of failure, but a rationalised number of HABDs are kept to mitigate against the main failure mode and risk to the railway.

The system link required for HA1 is the link between the acoustic system and HABD information to get the full picture of bearing health (this assumes AVI or equivalent is in place). In HA2 this

information is 'given' to the fleet manager (or engineer) and integrated with their bogie management system. At HA2 all required data is now in the hands of the fleet manager. PA links this in to the fleet manager's maintenance planning system and then AG is to determine optimal scheduling of maintenance activities.

Other examples can be seen in the sample tools provided as part of the T857 outputs as follows:

- T857-01 - Axle Bearing: Three different options showing the move to different configurations with a different mix of each type of technology, with infrastructure monitoring vehicles.
- T857-02 - Wheel Impact: 'Option 1a' and 'Option 1b' are both variants of migrating to a new system (infrastructure monitoring vehicles). These assume that the migration is forced so the choice is between two systems, a modern equivalent of the existing system and an alternative. 'Option A1: Remove RCM' shows how to model removing RCM by setting all sites to zero (see also the need to model RCM Advancement - Benefits in Section 5.5.4).
- T857-03 - Pantograph: 'Option 1: Imaging' models the migration to a new system (Infrastructure monitoring Vehicles). 'Option A1: Remove RCM' shows how to model the effects of removing RCM by migrating to zero sites (see also Section 5.5.4).
- T857-04 - OLE: Two different options, this time with Vehicles monitoring Infrastructure.
- T857-07 - 3rd Rail Interface: Four different options showing the move to different configurations with a different mix of each type of technology. Note this includes both Infrastructure monitoring Vehicle options, Vehicle monitoring Infrastructure options and a combination of both.

5.5 RCM advancement - benefits

5.5.1 Purpose

An input sheet for capturing the future benefits (or dis-benefits) of advancing RCM technologies to this maturity level. These are to be applied to the current costs as calculated in the other sheets.

5.5.2 Inputs required

For each maturity level (DA/DM/SD, HA1, HA2, PA and AG) the expected benefits need to be input as a percentage improvement (ie, decrease in the case of costs, increase in the case of things like maintenance intervals) on the current position.

All benefits are optional, and negative figures can be input to show increased risk/cost through losing RCM capability (or switching to less reliable technology).

Reduced RCM impacts: This picks up the benefits in improving the reliability of the RCM technology itself through better use of technology and data (e.g. by trending HABDs so that false alarms through issues such as 'reflected sunlight' can be reduced). These benefits can be input as reductions in the number of failures, or as reductions in the number of failures that have a service affecting impact. Note the effects are cumulative, so reducing underlying failures AND the percentage of those which have service impact can be modelled as well as each individual case.

Asset Risk Benefits: This picks up the benefits in the RCM technology reducing the amount of risks associated with the assets being monitored. This can be input in terms of a reduction in the number of underlying failures, or as a reduction in the number of these failures which are allowed to progress until they have a service, safety or other impact. This can be negative to reflect an increased risk. As for RCM impacts, these are cumulative so scenarios can be modelled where there are less failures, but more of these have an impact, for example.

Asset WLC Benefits: This picks up the benefits in the RCM technology enabling improved asset management regimes that allow intervals between maintenance/overhaul to be extended due to better confidence in the condition of the assets. The option to differentiate between the asset owners (TOC/FOC/NR/Other) is allowed here to take into account that the scale of opportunities may differ depending on the owner.

5.5.3 Data sources

These figures may be based on the user's perception of the future benefits of each configuration. The benefits need to be considered along with the costs in Section 5.4, such as increased / reduced coverage and the level of data linkages required to enable these benefits.

For the worked examples in the T857-01 to T857-05 and T857-07 workstream reports, AMCL has based these figures on discussions with industry stakeholders. The benefits are based on the strengths and weaknesses of the technologies, level of maturity of the current systems and size of the opportunities for each asset owner.

There may be no right or wrong answer for this so the additional information stored on Upper and Lower Estimates for these values will be important in modelling scenarios and sensitivities. The scale of the benefits can be based on trial data where available.

5.5.4 Examples

The example in Figure 10 is taken from the analysis for RSSB workstream T857-01 and illustrates the benefits associated with progressing through RCM maturity levels for Option 1: HABD Only.

RCM Advancement - Benefits

Asset	Axle Journal Bearing						
Option Title	Option 1: HABD Only						
RCM Advancement - Benefits			EXPECTED				
			DA/DM/SD	HA1	HA2	PA	AG
Reduced RCM Impacts							
RCM Equip Failure Reduction (as %)			0%	0%	0%	0%	0%
Additional Service Impact Reduction (as %)			0%	20%	20%	20%	20%
RCM Service Impact		£552,750	£552,750	£442,200	£442,200	£442,200	£442,200
Asset Risk Benefits							
Asset Failure Reduction (as %)			0%	0%	10%	10%	10%
Additional Impact Reduction (as %)	Safety		0%	0%	0%	0%	0%
	Service		0%	0%	0%	0%	0%
	Other		0%	0%	0%	0%	0%
	Safety		£116,790	£116,790	£105,111	£105,111	£105,111
	Service		£1,219,500	£1,219,500	£1,097,550	£1,097,550	£1,097,550
	Other		£1,000,000	£1,000,000	£900,000	£900,000	£900,000
Asset WLC Benefits							
Reduction in Time/Usage based Maintenance Activities (as %)	TOC		0%	0%	5%	10%	15%
	FOC		0%	0%	5%	5%	10%
	NR						
	Other						
	TOC		£39,507,600	£39,507,600	£37,532,220	£35,556,840	£33,581,460
	FOC		£10,953,250	£10,953,250	£10,405,588	£10,405,588	£9,857,925
	NR		£0	£0	£0	£0	£0
	Other		£0	£0	£0	£0	£0

Figure 10 - RCM advancement - benefits from T857-01

In this scenario, one acoustic system is introduced on each main operating route (10 sites) to achieve the benefits of the acoustic system for longer term assessment of bearing condition and prediction of failure, but a rationalised number of HABDs are kept to mitigate against the main failure mode and risk to the railway.

Therefore the migration to the future configuration for State Detection brings no material additional benefits. At HA1, information from both acoustic and HABD systems is used to

complement each other, which both reduces RCM impacts (as false alarms are reduced), Asset Risks and Asset WLC costs (as better condition information is available so less bearings are taken out of service early). At HA2 there are further improvements in Asset Risk and Asset WLC as this condition information is integrated with that for other elements of the bogie assembly to produce an understanding of the bearing condition relative to the whole of the assembly, which would help spot troublesome bearings and/or bogies. The higher levels (PA and AG) are focused more on the benefits of using this information to reduce Asset WLC costs as schedules and maintenance procedures are optimised around the new information.

Other examples provided through the case studies are:

- T857-01 - Axle Bearing: Three different options showing the move to different configurations with a different mix of each type of technology, with Infrastructure monitoring Vehicles and the benefits associated with each.
- T857-02 - Wheel Impact: 'Option 1a' and 'Option 1b' are both variants of migrating to a new system (Infrastructure monitoring Vehicles), assumed to have similar benefits. 'Option A1: Remove RCM' shows how to model removing RCM by adding the increased risk (through an increased number of underlying failures) as a negative benefit.
- T857-03 - Pantograph: 'Option 1: Imaging' models the migration to a new system (Infrastructure monitoring Vehicles) and estimated benefits associated with this. 'Option A1: Remove RCM' shows how to model the effects of removing RCM in a similar fashion to T857-02 Option A1.
- T857-04 - OLE: Two different options, this time with Vehicles monitoring Infrastructure.
- T857-07 - 3rd Rail Interface: Four different options showing the move to different configurations with a different mix of each type of technology. Note this includes both Infrastructure monitoring Vehicle options, Vehicle monitoring Infrastructure options and a combination of both. Note the combination of both gets both sets of benefits.

6 'Summary Outputs' sheet descriptions

6.1 Introduction

This section presents brief guidance on populating the sheets of type 'Summary and Output' for the toolkit:

- Version Control
- Maturity Level Summary
- Annual WLC by Maturity Level
- Annual (chart)
- Net Cash Flow (chart)

These sheets are used to summarise the costs associated with the current 'steady state' industry implementation of existing RCM technologies and the additional whole-life costs and benefits associated with introducing new RCM technologies (or advancing existing technologies) and integrating the data from these to provide higher level analytics.

The following information is described for each of the sheets:

- The purpose of the sheet
- What the sheet provides
- Any additional data required for the sheet
- How the results should be interpreted

6.2 Version Control

6.2.1 Purpose

Front cover / admin sheet (version control, etc.).

This sheet does not contain anything incorporated within the analysis and is provided as a front cover for information only.

6.3 Maturity Level Summary

6.3.1 Purpose

An illustrative summary of the steady state system costs associated with each level of option maturity and the investment costs required to advance to this level.

6.3.2 Sheet Contents

The sheet presents the outputs of the toolkit in a format consistent with the ISO RCM maturity levels as shown in Figure 2. This shows the following:

- The annual 'steady state' system costs at each level of maturity

- The change vs. the current industry position, and the preceding maturity level:
  - The Investment costs required to advance through the maturity levels, both un-discounted ('Investment', within the arrows), and discounted (ie, 'Total Investment', expressed in PV, or Present Value)
  - The net annual benefits (in terms of a reduction in annual 'steady state' costs)
  - The Net Present Value (NPV) of the Net Whole Life Cash Flow at each Maturity Level
  - The ratio of NPV divided by Investment (PV) for each Maturity Level

Figure 11 illustrates the outputs from the ' Maturity Level Summary' sheet.

Figure 11 - Maturity Level Illustration

6.3.3 Sensitivity Analysis

In addition, the Maturity Level Summary sheet contains user controls for undertaking sensitivity analysis. This is done via a set of slide bars, with which the user can develop a scenario by selecting a position within the Lower, Expected and Upper ranges by input group. All outputs on this sheet then automatically reflect this scenario, and allow the user to see the effect that the uncertainty in the inputs can have on the RCM toolkit outputs. This will help understand the range of potential outcomes for each business case scenario modelled with the RCM toolkit.

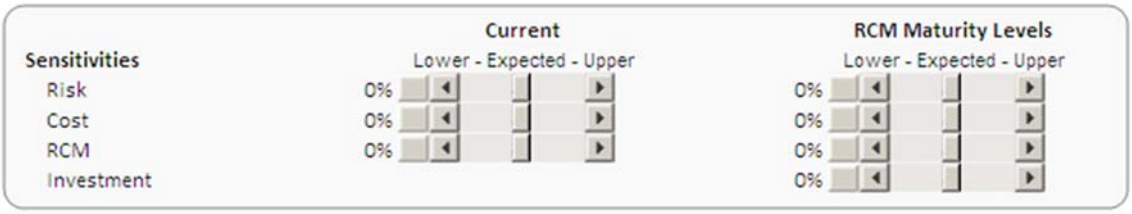

Figure 12 - Sensitivity Analysis Settings for Expected Values of Toolkit Inputs

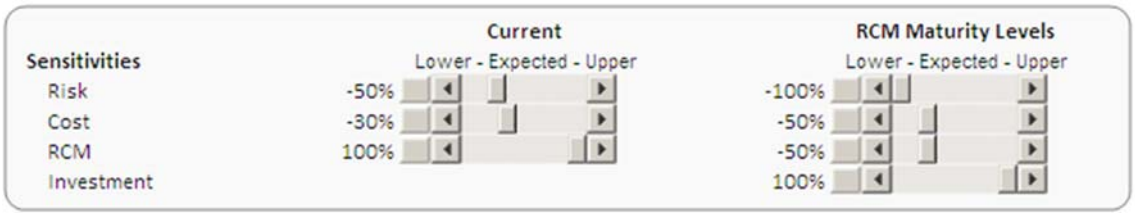

Figure 13 - Example of Sensitivity Analysis Settings

By pressing any of the square buttons between the percentage values and the scroll bars, the selection goes back to Expected. The percentage value shows the selected position within the overall range, either within the Lower to Expected inputs range, or the Expected to Upper inputs range. This percentage value is controlled automatically by the scroll bar. This percentage value is not a direct percentage adjustment on the input values, but a convenient way to move within the range of input values that have already been entered within the input sheets.

6.3.4 Additional Data Required

There are no additional data requirements for this sheet.

6.3.5 Interpreting Results

This sheet can be used to see the 'size of the prize' in terms of a reduction in annual system costs (once in 'steady state') and the costs required to get to this point. This sheet is broadly an illustrative output with many costs 'bundled' together. Detail on what the various figures mean is best described in the 'System Costs by Maturity Level' sheet (see Section 6.4).

6.4 Annual (Steady State) WLC by Maturity Level

6.4.1 Purpose

A breakdown of the net steady state system costs at each maturity level including a graphical summary of these.

Note: this net value includes the system costs and the cost savings (i.e. benefits) associated with that cost, for example, the benefits of improving RCM equipment reliability will be seen as a reduction in RCM service impact costs.

6.4.2 Sheet Contents

The chart provides the breakdown of the net steady state system costs at each maturity level as both numbers and a graphical representation. The following costs are summarised:

- Risk: The annualised total risk associated with the asset expressed as a £ equivalent for fair comparison (broken down by Safety, Service (Performance) and Other, see Section 4.4);
- WLC: The annualised total costs associated with managing the asset (broken down by asset owner, TOC/FOC/NR/ Other, see Section 4.5); and
- RCM: The annualised total costs associated with the RCM technologies in place at this maturity level (split by WLC and Service Impact, see Section 5).

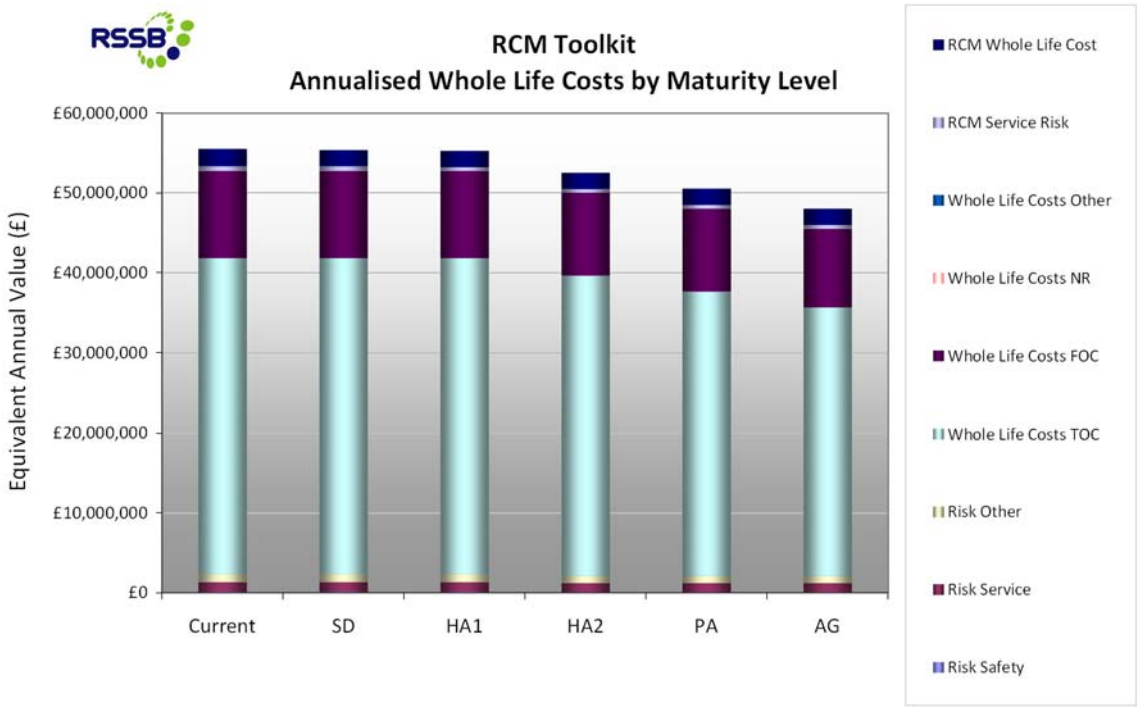

Figure 14 - Graph of Net System Costs

The sheet also contains a summary of the Capex requirements (in terms of equipment and data links) to advance the RCM technology through the maturity levels.

6.4.3 Additional Data Required

There are no additional data requirements for this sheet.

6.4.4 Interpreting Results

This sheet can be used to see the 'size of the prize' in terms of a reduction in annual system costs (once in 'steady state') and the costs required to get to this point. The sheet also shows which of the cost areas are impacted on by each step in maturity, and how the different cost areas compare in terms of relative weightings. For example, Risk costs may be negligible compared to Asset WLC costs, showing that reductions in failures of the asset is of less benefit than using RCM data to better manage overall asset maintenance.

7 'Detailed Outputs' Sheet Descriptions

7.1 Cashflow sheets

7.1.1 Purpose

These sheets carry out the Cost-Benefit Analysis by calculating the cashflows required to advance the RCM through the maturity levels given the assumptions in this option.

These sheets then calculate for each Maturity Level the total RCM investment costs required for each RCM option and the total RCM benefits (in terms of the reduced steady state system costs over the evaluation period) for the cost-benefit analysis.

7.1.2 Sheet Contents

The main output of this sheet is the cashflow analysis of the investment costs required and the level of benefits to be realised (as a reduction in 'steady state' system costs). This is provided both in terms of numbers and a graphical illustration (as shown in Figure 15).

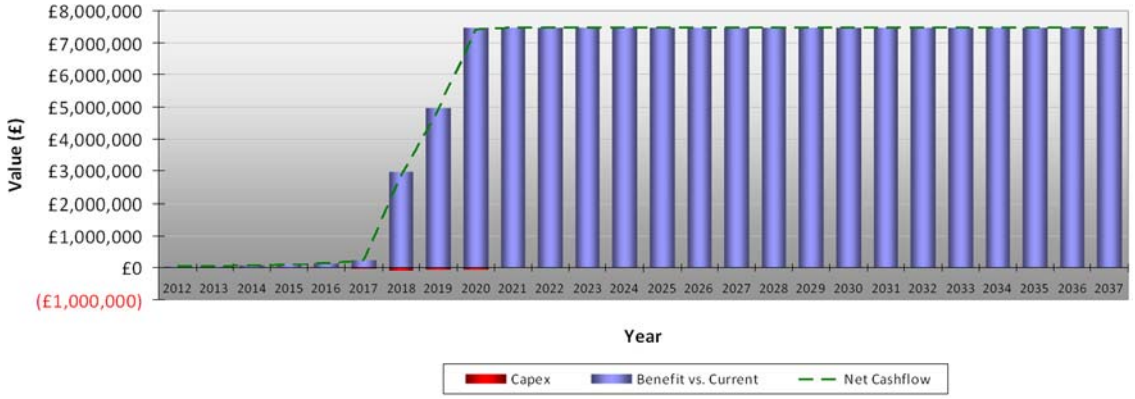

Figure 15 - Cashflow Analysis Chart

7.1.3 Interpreting Results

The results in this sheet are typical of a cost benefit analysis and can be interpreted as such. The Investment Capex is the investment capital expenditure required to implement the option. The 'benefits' are the reduction in the 'steady state' costs associated with reaching the maturity level. This sheet can be used for evaluating the relative attractiveness of each option in terms of affordability (how large are the investment costs and over what period?), speed of implementation and size of benefits.

Note that due to the need to provide 'Steady State' estimates and PV-based investment evaluation, the model can currently 'double-count' the capital costs of investing in a new technology (where new installations are required). This is not a problem when comparing options that have been set up in a similar way, but care should be taken in interpreting the absolute PVs generated by the case. Be aware of what assumptions are in your 'Do Current' option.

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