Chapter 6: Conclusion

The preceding four chapters were devoted to:

1. Defining the problems in the present definition and application of RCM.

2. Presenting a view of the current state of the methodology and related methodologies from present texts and papers.

3. Developing an improved version of the methodology, using a mixture of reported experience, whatever research exists on the subject, related techniques and own experience.

4. Testing the resultant methodology by application to a physical system and comparing the result with that of an existing RCM analysis for the system.

In conclusion, it now remains to compare the resultant methodology with 'classical' RCM and other methods, to assess whether a better result will be achieved. The comparison of the RCM analysis, performed using the proposed improved methodology, with that of a 'classical' RCM analysis in chapter 5 already indicated the superiority of the new methodology. However, that comparison was hampered by the fact that the 'classical' analysis was not very well executed, as well as that the 'classical' analysis was not done specifically for the GA-1402 system, but rather for a generic high risk pump with double mechanical seal.

In this chapter, the various methodologies are compared for functionality rather than for a specific analysis viewpoint.

6.1. Critical assessment of result

The main objective of any doctoral research is to contribute significantly to the knowledge base in the particular subject area. An assessment of the result of the present research and the resulting thesis will thus have to establish whether a meaningful contribution has in fact been made.

To try to establish the relative worth of the research and development presented in this thesis, it will be compared as a full product[1] to the various avail-

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[1] That is, including all the functionality present in present day versions of 'RCM', including that of Nowlan & Heap [1978], Moubray [1991], Smith [1993], MSG-3 [1993], Coetzee [1997/2] and the SAE Standard [1999].

able versions of RCM and related techniques. In summary, the comparison is done against the following five baseline references:

1. 'Classical' RCM as embodied in the SAE Standard JA1011 [1999]

2. 'Classical' RCM as embodied in the various RCM texts[2].

3. MSG-3 (1993), the latest version of the airlines' methodology.

4. The method of the Technical University of Eindhoven {Gits [1984, 1988 and 1992] and Le Clercq & Van den Broek [1999]}.

5. The method of Anthony Kelly {Kelly [1997]}.

A detailed comparison is given in table 6.1. Although it is clear from this table that the thesis makes contributions in many areas, some of them are very logical developments of the work contained in the various sources, as well as an integration of the various ideas. On the other hand, the thesis does make significant contributions in the following areas:

- The 'funnelling' approach - this is a major contribution of the present research to the knowledge base of the RCM methodology. It ensures that the RCM effort is concentrated on the most important failure modes of the organisation. It thus solves one of the major problem areas in the industrial application of RCM. Refer to the discussion in paragraphs 4.3.2.2, 4.3.2.3, 4.3.2.5 and 4.3.5 in this regard. This solves the problem identified in paragraph 4.1, factor c.

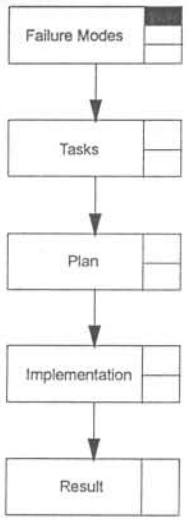
- The principle of progressive application (widening of the 'funnel'). This is a very logical progression from the 'funnelling' approach, as it makes sense to further improve on the initial benefit that is obtained from RCM analyses, following the application of the 'funnel'. Refer to paragraphs 4.3.2.3 and 4.4 in this regard.

- The second major contribution of this thesis lies in the inclusion of the Quality Improvement task in the task selection tree. In the application of the analysis technique in chapter 5, it identified no less than four opportunities for improving procedures of both operations and maintenance work to proactively prevent failure from occurring. This is not an original contribution of this thesis, as Harris (1985) identified the need, but it will certainly increase the effectiveness and relevance of RCM analyses greatly.

- Another contribution of significance is in the area of task packaging, which is an area totally neglected by all authors except Gits (1984). This area has never been properly addressed in any RCM text, and this chore is mostly left to the maintenance planner who has to

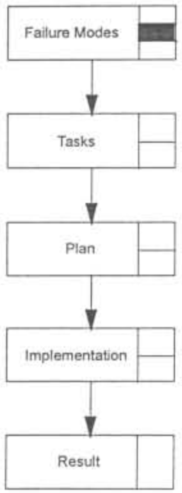
[2] Nowlan & Heap [1978], Moubray [1991], Smith [1993], Coetzee [1997/2].

Table 6.1: Functional comparison between various RCM techniques

Context[1]	Function	Sub-function in new proposed method	Nowlan & Heap (1978)	Moubray (1991)	Smith (1993)	MSG-3 (1993)	Coetzee (1997/2)	SAE JA1011 (1999)	Gits (1984)	Kelly (1997)	Comments
	Selection of application areas (§ 4.3.2)	Identification of major systems (§ 4.3.2.1)			X		X				Nowlan & Heap did not need this, as they did the analysis at the major systems level.
		Choice of units for analysis (§ 4.3.2.2)			X		X			X	
		Progressive application (§ 4.3.2.3)									None of the authors use this principle, primarily because they do not limit the choice of units for analysis (see previous line). Smith and Coetzee limit the number of units for analysis, but do not propose a widening of the choice process later on.
		Partitioning (§ 4.3.2.4)	X	X		X	X		X	X	Moubray uses plant register, Smith only works with functional decompositioning
		Prioritisation of MSI's (§ 4.3.2.5)					X				
	Information assembly (§ 4.3.3)				X	X				X	Most of the other authors most probably assume this step.

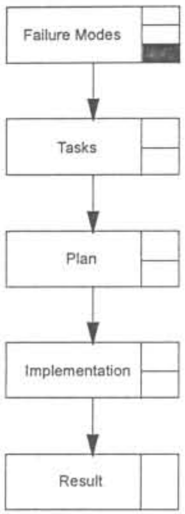
[1] Refers to context in terms of the model presented in figure 4-7

Table 6.1: Functional comparison between various RCM techniques (continued)

Context[1]	Function	Analysis columns	Nowlan & Heap (1978)[2]	Moubray (1991)	Smith (1993)	MSG-3 (1993)	Coetzee (1997/2)	SAE JA1011 (1999)	Gits (1984)	Kelly (1997)[4]	Comments
	Identification of failure modes (§ 4.3.4)	Item cross-reference		X	X				X		
		Item		X	X	X	X		X		
		Function		X	X	X	X				
		Functional Failure		X	X	X	X				
		Failure Mode		X	X	X	X		X		
		Functional Check									Smith does not have an actual functional check, but he implies one in his methodology.
		Failure Mode Cross Reference		X							
		Local Effects		X[3]	X						
		System Effects			X						
		Unit Effects			X						

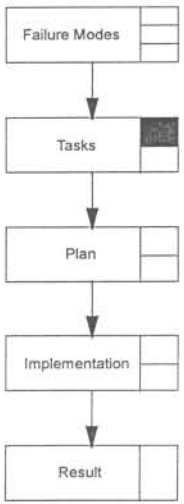
[1] Refers to context in terms of the model presented in figure 4-7
[2] Nowlan & Heap did not address the FMEA at all - refer to § 3.2.4
[3] Moubray combined the three effects levels in one column
[4] Kelly does not use an FMEA at all - he rather relies on the manufacturer's unit life plan or an engineering study of the item and its known failures.

Table 6.1: Functional comparison between various RCM techniques (continued)

Context[1]	Function	Sub-function in new proposed method	Nowlan & Heap (1978)	Moubray (1991)	Smith (1993)	MSG-3 (1993)	Coetzee (1997/2)	SAE JA1011 (1999)	Gits (1984)	Kelly (1997)[3]	Comments
	Relative criticality of failure modes	Prioritisation of failure modes (§ 4.3.5)							X		This is a facet of RCM which is not addressed by most authors. The only authors who prescribes the use of Criticality Analysis is Anderson and Neri (1990), based on the requirements of MIL-STD-1629A (1980). Jones (1995) proposes the use of quantitative risk techniques for this purpose.
		Classification of failure modes (§ 4.3.6)	X	X	X	X	X		X[2]		This is largely the original basis of RCM (the 'decision tree approach' that Matteson (1989) refers to).

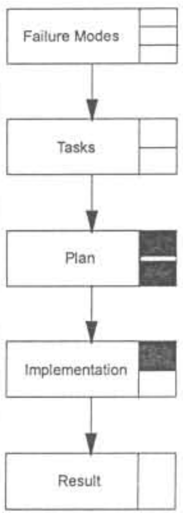
[1] Refers to context in terms of the model presented in figure 4-7
[2] Gits does not have a separate failure classification step, but it is inherent to his task selection process (see figure 3.26).
[3] Kelly does not use failure modes (see second page of table 6.1) or classification.

Table 6.1: Functional comparison between various RCM techniques (continued)

Context[1]	Function	Sub-function in new proposed method	Nowlan & Heap (1978)	Moubray (1991)	Smith (1993)	MSG-3 (1993)	Coetzee (1997/2)	SAE JA1011 (1999)	Gits (1984)	Kelly (1997)	Comments
	Task Selection (§ 4.3.7)	Lubrication/Servicing Task included in tree				X					
		No truncation for failure modes with safety consequences			X	X					
		Inclusion of Quality Improvement task									This task type, after Harris (1985), is a completely new addition to the present RCM task selection structure.
		Failure Finding task at top of tree in hidden consequences case				X					
		Choice of best combination of tasks for failure modes with safety consequences			X	X			X		
		Improvements to technical/economical feasibility measures (§ 4.3.7.2)									These are all changes which includes ideas from previous authors, but are changed/improved to such an extent that no one of the other authors' work conform to this standard
		Improvements to technical selection criteria (§ 4.3.7.3)									
		Improvements to default tasks (§ 4.3.7.4)									
		Improvements to documentation standards (§ 4.3.7.5)									

[1] Refers to context in terms of the model presented in figure 4-7

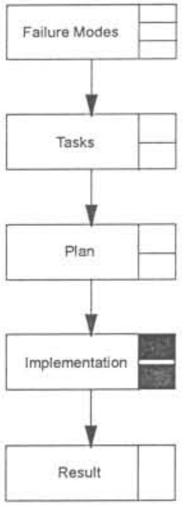
Table 6.1: Functional comparison between various RCM techniques (continued)



Context[1]	Function	Sub-function in new proposed method	Nowlan & Heap (1978)	Moubray (1991)	Smith (1993)	MSG-3 (1993)	Coetzee (1997/2)	SAE JA1011 (1999)	Gits (1984)	Kelly (1997)	Comments
	Task Frequencies (§ 4.3.8)	Variety of techniques applied in a scientific way	X	X	X		X				Some authors, such as Moubray and Smith are somewhat simplistic in their approach to task frequencies. One gets the impression that they shy away from the analysis involved. Moubray is the only author with a good approach to the calculation of Failure Finding Task frequencies.
	Task Packaging (§ 4.3.9)	Grouped per plant / system / machine		X[2]					X[3]		
		Grouped per set-up type							X[3]		
		Grouped per task frequency class	X	X[2]					X[3]		
		Grouped per trade		X[2]					X[3]		
		Grouped according to production requirements		X[2]					X[3]	X	
	Critical Assessment of resulting program (§ 4.3.10)	Good audit approach based on the work of Nowlan & Heap (1978) - see § 3.2.10	X								Coetzee and Moubray identifies the need for auditing of the resultant program, but does not handle it in any proper depth.

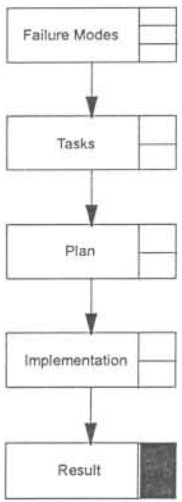
[1] Refers to context in terms of the model presented in figure 4-7
[2] Moubray's handling of task packaging shows that he understands the process, but he does not provide the user with a methodology.
[3] Gits' scheme is quite elaborate, but difficult to understand.

Table 6.1: Functional comparison between various RCM techniques (continued)

Context[1]	Function	Sub-function in new proposed method	Nowlan & Heap (1978)	Moubray (1991)	Smith (1993)	MSG-3 (1993)	Coetzee (1997/2)	SAE JA1011 (1999)	Gits (1984)	Kelly (1997)	Comments
	Application Structure and Methods (§ 4.4)	Using more 'intuitive' traditional ways of establishing a maintenance plan for the '99' % of equipment for which RCM is not applied (fig 4-24)								X	Kelly is the only author that addresses this way of setting up a maintenance plan, but then for 100% of the equipment, thus excluding the optimisation afforded by RCM application.
		Progressive application (progressive increase of the 'funnel' opening)									None of the authors uses this principle, primarily because they do not limit the choice of units for analysis. Smith and Coetzee limit the number of units for analysis, but then do not propose a later widening of the choice process. Also refer to the first page of table 6.1 above.
		Continuous Improvement through closed loop application of RCM based on best experience (RCM living programme)			X						Smith is the only author stressing the importance of continuous improvement of the maintenance plan.

[1] Refers to context in terms of the model presented in figure 4-7

Table 6.1: Functional comparison between various RCM techniques (continued)

Context[1]	Function	Sub-function in new proposed method	Nowlan & Heap (1978)	Moubray (1991)	Smith (1993)	MSG-3 (1993)	Coetzee (1997/2)	SAE JA1011 (1999)	Gits (1984)	Kelly (1997)	Comments
	Organisational issues (§ 4.5)	Application of RCM in the full context of maintenance organisation realities.									There is very much a dearth of understanding of the full complexity of applying RCM in full maintenance organisational context.
		RCM training requirements planning guidelines.									The focus is much more on application than on the training required, although the various texts certainly support and are used in the training effort (but with a very simplistic approach to training).
		Use of a steering committee to steer the RCM effort.	X			X					
		The use of a Management Champion to provide and conserve energy for the process.									
		Use of a well trained RCM facilitator.		X			X				
		Use of an independent reviewer as auditor	X	X							
		Use of failure data as important source of information.	X				X				
		Support of the RCM process through inclusion of RCM related requirements into CMMS databases.									

[1] Refers to context in terms of the model presented in figure 4-7

try to do the task structuring as well as possible without any particular knowledge regarding task packaging. Gits (1984) has developed an elaborate, but virtually unintelligible, scheme for task packaging. Nevertheless, his thoughts were used very profitably in the development of the task packaging procedure proposed by this thesis. Refer to paragraphs 3.2.9 and 4.3.9 in this regard.

- The combination of the RCM maintenance plan (for '1%' of the failure modes) with the more intuitive conventional plan for the remaining 99% of failure modes to achieve a best maintenance plan for the organisation. This, combined with the progressive application principle depicted above, leads to a maintenance plan that is subject to continuous improvement and will produce an increasing contribution to the profit of the organisation.

- A very important contribution follows from the application of sound management principles in the implementation of RCM. These include understanding the position of RCM in the organisational context (§ 4.2 and 4.5.1), proper structuring of RCM training (§ 4.5.2), use of mechanisms such as a Steering Committee (§ 4.5.3), a management champion (§ 4.5.4), a well trained facilitator (§ 4.5.5) and proper reviewing of the resultant plan (§ 4.5.6). Good failure information support will also be ensured if the requirements of RCM regarding failure data are incorporated into the company's CMMS database (§ 4.5.7 & 4.5.8).

- The most important contribution of the present thesis to the RCM methodology most probably lies in blending concepts from different RCM authors and those of related techniques, together with the innovations listed above into one logical whole. It will certainly assist users in applying the methodology more effectively and obtaining better results for the organisation. This includes the various new diagrams that assist the user in understanding the full scope and use of the methodology. These include:
  - Figure 4-9: Outline of RCM methodology
  - Figure 4-12: Item breakdown decision diagram
  - Figure 4-13: RCM prioritisation processes
  - Figure 4-14: Summarised RCM prioritisation processes
  - Figures 4-19 to 4-22: RCM Task Decision Trees
  - Figure 4-23: RCM Decision Tree
  - Table 4.3: Technical Feasibility characteristics
  - Table 4.4: Economical Feasibility characteristics
  - Figure 4-27: RCM in context
  - Figure 4-28: RCM task selection process summary
  - Figure 4-29: RCM progressive application
  - Table 4.6: Suggested RCM training requirements

RCM is a core methodology in ensuring that the organisation can achieve World Class results from its production equipment. The proposed new RCM approach (methodology), can play a very important part to achieve this goal. It will specifically make a major contribution in ensuring that the organisation's maintenance effort is as proactive as possible.

6.2. Recommendations

In the approach and research of this thesis, the premise was to do a total study of the RCM methodology and, as far as is possible, propose a methodology without any inadequacies. This was largely achieved.

In § 3.2.7.3, it was envisaged to develop a task selection 'decision diagram for dummies'. This goal was not achieved. It is extremely difficult to achieve this, while remaining within the constraints imposed by proper reliability practice. It is nevertheless important to reach this goal, to make RCM more accessible to the average maintenance practitioner.

As was stated in § 4.3.8, it is not within the scope of this thesis to investigate and research better methods for the choice of task frequencies. This is the field of Operations Researchers. Although much work is done in this area, it is often done from a theoretical angle, without any consideration for the maintenance practicalities. One of the greatest concerns is that the maintenance function often has to work with a scarcity of data, while operations researchers tend to assume that there are ample data available for the application of their models. Operations Researchers also tend to think simplistically or try to make as many as possible simplifying assumptions, which does not serve the practical maintenance's purpose. A wide range of decision-making models is needed to ensure optimal RCM task and frequency decisions. Refer to table 4.5 for a listing of the required models.

As was identified in paragraph 4.5.8, it is necessary that Computerised Maintenance Management Systems start adding RCM facilities to their functionality and especially to their databases. There are a number of RCM computer packages, but they are all standalone systems with little or no interfacing facilities with CMMS's. These systems also do not address the full complexity of the RCM process as set forth in this thesis.

The changes proposed and set forth here should be incorporated into the SAE standard [SAE J1011 (1999)]. Furthermore, an ISO standard should be produced as part of an international strategy for proper maintenance standards. The RCM leaders should take the leadership in this action. This will entail burying their differences and developing a single standard for the maintenance community.