CHAPTER 4

EXAMINATION OF THE OVERALL R&M ACTIVITY

CONTENTS

1 INTRODUCTION

1.1 Many engineers and managers know of R&M through a number of techniques which they have been contracted to apply or a limited set of R&M performance requirements. While such an appreciation is better than none, it is unlikely that it will enable the engineer or manager to properly integrate R&M with other elements of the system development process. Nor will the R&M activities undertaken be as effective and efficient as they might be. For optimum performance, engineers and managers need:

a) an appreciation of the scope of R&M;

b) a general understanding of R&M activities;

c) a general understanding of their intra-relationships; and

d) a general understanding of their relationships with non-R&M activities.

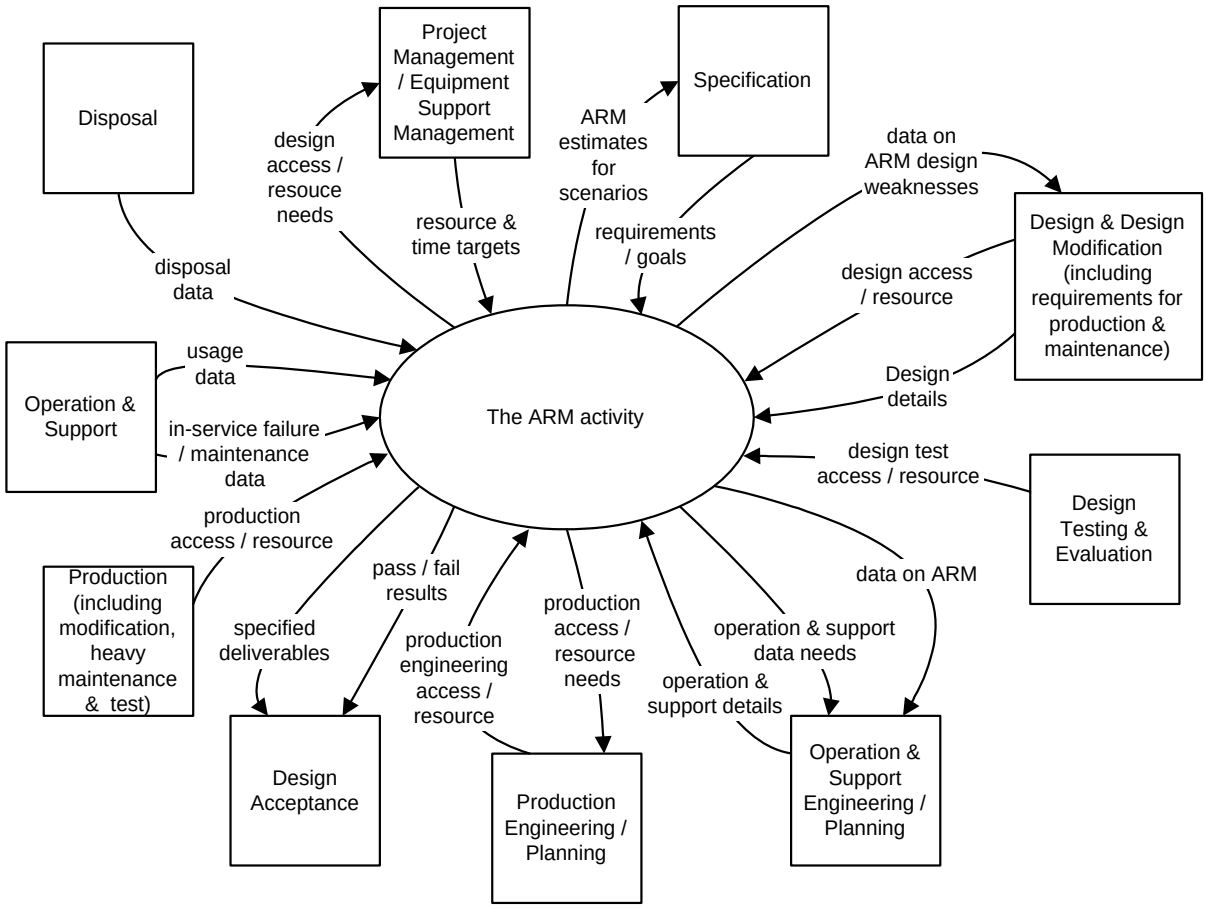


Figure 1: Data flow in and out of the generalised AR&M activity

1.2 This Chapter addresses these areas through a structured analysis of the generalised R&M activity. The existence of this generalised activity is assumed* as the starting point. Figure 1 illustrates its relationships with non-R&M specific activities through the data flowing in and out†. The generalised activity is then divided into activities associated with specific elements of a system lifecycle. It is interesting (see Figure 2) that the R&M activities do not interact directly but indirectly through data stores. This is necessary in order that they can be undertaken at different times. Finally these lifecycle related activities are further divided to produce a set of activities that are addressed by defined techniques (Figures 3 to 8). These activities are addressed individually by the Chapters of Part B to this Manual.

1.3 This Chapter also introduces the techniques that can be employed in order to carry out the derived activities and the theoretical basis of those techniques. Thus the reader can relate the activities being addressed to familiar techniques.

1.4 Figure 1 of PtACh1 summarises the results of this examination. It shows the activities, techniques and supporting theory identified in this Chapter and their inter-relationships. The two styles of diagram are complementary: Figure 1 in PtACh1 provides a contextual overview while those in this Chapter provide a more rigorous and detailed appreciation of the actual data needed and produced by each activity. Table 1 in this Chapter provides a similar summary of the inter-relationships but in tabular form.

2 THE GENERALISED R&M ACTIVITY

2.1 The generalised R&M activity has a number of inputs from and outputs to many other activities as shown in Figure 1. These other activities are drawn as squares, rather than further ellipses like the R&M activity, to emphasise that their function is outside the scope of the discussion. They are addressed only where they provide data to or take data from the R&M activity. The data flowing between the activities is also shown, as directed lines. Note that data flowing between activities outside the scope of the discussion are not shown.

* Several types of R&M activity are undertaken, it is possible to group these activities, regarded as R&M activities, into one generalised activity.

† A number of data flows in Figure 1 need explaining. R&M activities take place in the real world. They compete with other activities for access to equipment when required and need to inform other activities of their need for data. Hence several data flows are labelled “access / resource” where the R&M activity needs access to equipment and the provision of resources from another (non-R&M specific) activity (in general the activity goes to the equipment and not vice-versa). Other data flows are labelled “data needs”. These generally go to planning activities such that the provision of appropriate data can be written into the procedures.

Activities															Techniques	Supporting theory											
1 Potential Sceario Modelling	2 ARM Performance Specification	3 Design for ARM Performance	4 Practical Review of Design for ARM	5 Theoretical Review of Design for ARM	6 Theoretical Estimation Of ARM	7 Failure Consequence Analysis	8 Practical Demonstration of ARM	9 Production Engineering for ARM	10 ARM Evidence Collation	11 ARM in Production and Maintenance	12 In-Service ARM Data Gathering	13 Project Management and ARM	14 ARM Data Management		1 Boolean Algebra	2 Baysian Statistics	3 Statistical Distributions	4 Monte-Carlo Simulation	5 Pareto Analysis	6 ARM Parameters & Redundancy	7 Analysis of Practical Data	8 Reliability Growth Models	9 Availability Demonstration Plans	10 Reliability Demonstration Plans	11 Maintainability Demonstration Plans
●														1 Operational Needs Analysis			●			●						
●														2 Environmental Conditions Analysis												
●														3 Modification Impact Analysis						●						
	●													4 Trade-Off Studies					●	●						
	●	●												5 Allocation / Apportionment			●			●						
	●	●												6 High Integrity Specification												
		●												7 Part Derating												
		●												8 Lifed Item List												
		●												9 Critical Item List												
		●												10 High Integrity Design												
		●												11 Redundancy Optimisation						●						
		●												12 ARM Design Criteria						●						
			●											13 Test, Analyse and Fix												
			●											14 Step Stress Testing			●			●						
			●											15 Reliability Grow th Testing								●				
			●											16 Highly Accelerated Stress Testing			●			●						
			●											17 Dynamic Testing of Softw are												
			●									●		18 DRACAS	●	●	●			●	●					
				●										19 Sneak Circuit Analysis												
				●										20 Tolerance Analysis			●									
				●										21 Built-In-Test Effectiveness Analysis			●			●						
				●										22 Testability Analysis			●			●						
				●										23 Arm Checklists												
				●										24 Physics of Failure												
				●										25 Worst Case Stress Analysis												
				●										26 Static Analysis of Softw are												
				●		●								27 Fault Tolerance Analysis												
						●								28 Dependent Failure Analysis						●						
						●								29 Fault /Success Tree Analysis	●					●						
						●								30 Reliability Block Diagrams	●					●						
						●								31 Task Analysis (Human Factors)												
						●								32 Human Reliability Assessment												
						●		●						33 FMECA						●						
						●								34 Event Tree Analysis						●						
					●									35 Availability Prediction						●						
					●									36 Reliability Prediction						●						
					●									37 Maintainabilty Prediction						●						
					●									38 Markov Modelling						●						
							●							39 Availability Demonstration		●	●			●	●		●			
							●							40 Reliability Demonstration		●	●			●	●			●		
							●							41 Maintainability Demonstration		●	●			●	●				●	
							●							42 Testability Demonstration		●	●			●	●				●	
									●					43 Assurance through the R&M Case						●						
										●				44 Production Reliability Acceptance Testing			●			●	●					
										●				45 Environmental Stress Screening			●				●					
											●			46 Data Classification												
											●			47 In-Service Data Collection							●					
												●		48 ARM Aspects of Sub-Contracts												
												●		49 ARM Plans & Programmes												
●	●	●	●	●	●	●	●	●	●	●	●		●	50 ARM Data Storage												

Table 1: Relationships between activities, techniques & supporting theory

2.2 For any activity to be worthwhile there must be a real or perceived benefit to be gained. The reasons why we undertake any R&M activity can be listed as:

a) Sustained achievement of equipment performance in service[‡];

b) Improved knowledge of the real R&M performance in service in support of other activities;

c) Provision of realistic and achievable R&M specifications;

d) Demonstrating that one or more systems meets its R&M specification and is fit for service (from an R&M point of view); and

e) Satisfying the contract where the R&M activity is required by the contract.

The first three items listed are the really useful outputs of the R&M activity. The fourth is necessary in checking that a system being delivered is as good as the supplier states. The last item is, unfortunately, all too often encountered. It is quite possible to conduct activities under the heading of R&M but fail to secure useful results or to act upon them. Where an activity is required by the specification, the benefit to be achieved must be understood both by the person managing the activity and the person, or people, carrying it out. This Manual addresses the potential purposes of each activity and the links between activities in order to facilitate the optimisation of the benefits to be gained.

2.3 Of the list of reasons for undertaking R&M activities only demonstration of performance and satisfaction of the specification match with data flows in Figure 1 (both to Design Acceptance). Improved R&M performance cannot be achieved by R&M activities alone. Design improvement or changes to the operating and support procedures are needed if the real performance is to be improved.

3 DECOMPOSITION

3.1 General

3.1.1 The generalised R&M activity, introduced in Section 2, can be divided into six more specific activities (as shown in Figure 2) plus four data stores (addressed in Section 3.8). These six can then be further divided (see Sections 3.2 to 3.7 to produce a total of 13 lower level activities. It is a selection from these activities that will be undertaken for a particular R&M System Programme. In some cases the engineer knows that a given technique (such as FMEA) will provide the necessary results from the available data and prescribes it directly. The activity still exists however and due consideration of the plan at the activity level is normally beneficial.

3.1.2 These 13 activities vary considerably and are connected only by their interest in failure occurrence and recovery, together with the use of supporting theory. Each is aimed at providing one or more of the output data flows shown in Figure 1 using one or more of the data sources.

[‡] The term ‘in service’ is used to emphasise that we are interested in the real, practical, performance achieved in the field with all relevant factors taken into account. The objective applies equally to new and existing systems.

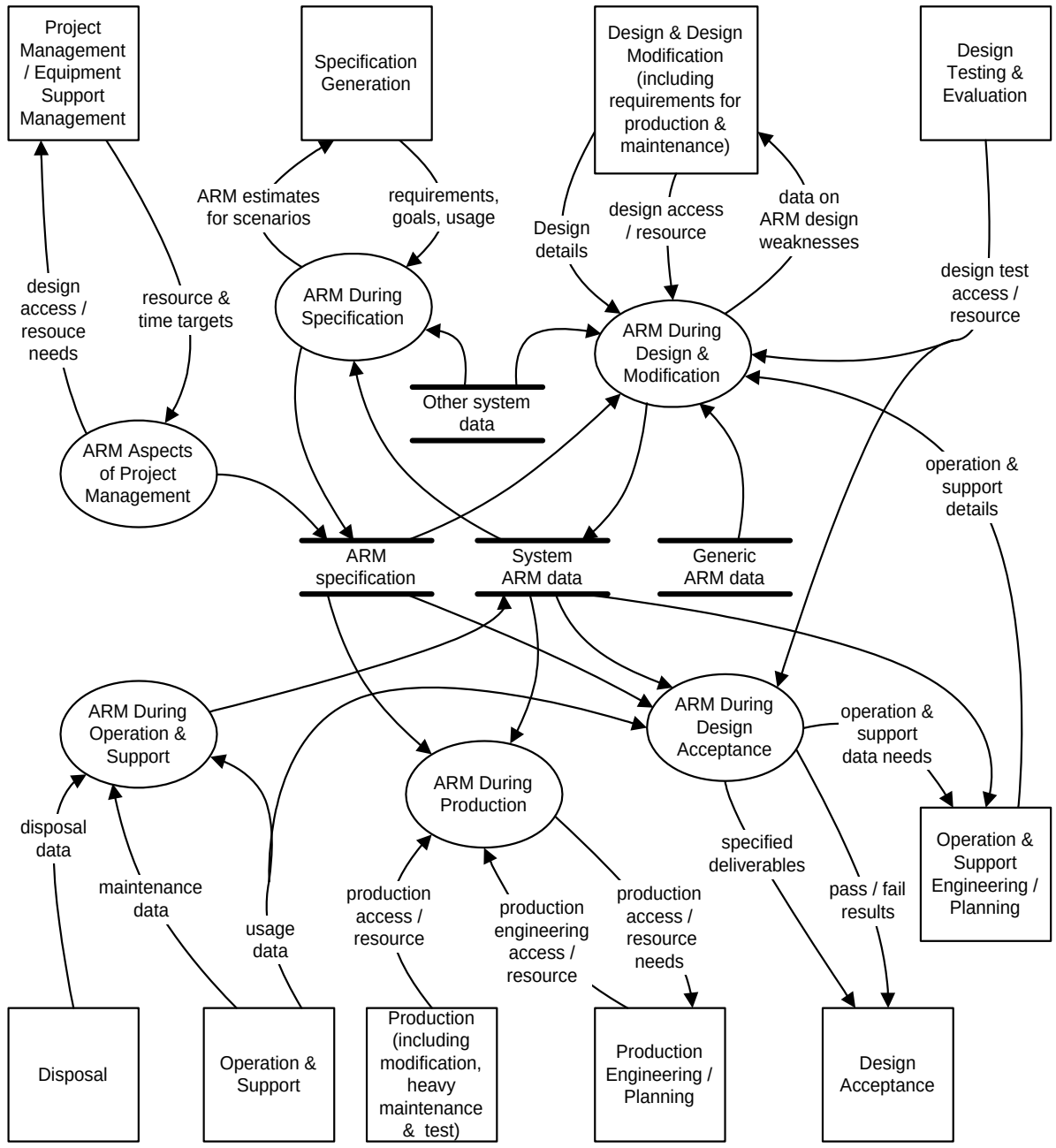


Figure 2: Initial decomposition of the generalised R&M activity

3.1.3 The following sections address the activities divided according to which general system activity they support. The emphasis here is on the division and the interconnections. Each activity is addressed in its own chapter in Part B of the Manual.

3.2 Activities Associated with the Specification of a System or Equipment Type

3.2.1 The activities associated with Specification fall into two groups as shown in Figure 3.

3.2.2 First the modelling of potential scenarios, including their R&M aspects, supports the non-R&M activity which specifies a system. This modelling facilitates the production of a

specific, measurable, balanced and achievable specification. This can include the analysis of the impact of modifications, environmental conditions, and operational and support needs. This is addressed in more detail in PtBCh1.

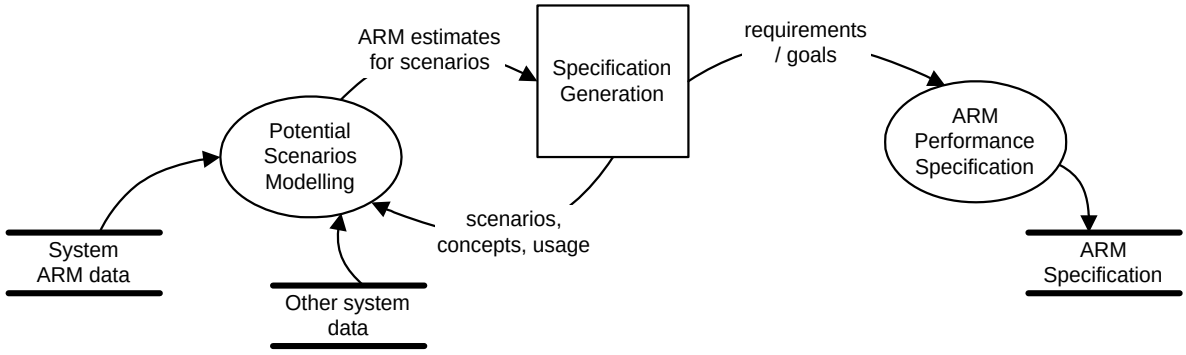


Figure 3: Activities Associated with the Specification of a System or Equipment Type

3.2.3 Secondly the R&M Performance Specification itself should to be created. This must take account of the foreseeable ways in which the system will be used and supported. The appropriate parameters must be chosen and specified to drive the design towards the optimum overall performance. This is addressed in more detail in PtBCh2.

3.3 Activities Associated with Initial Design and Modification of a Design

3.3.1 There are five activities associated with the initial design and modifications thereof. These support the external design process of Figure 1 and Figure 2. Figure 4 shows the data flow associated with these activities.

3.3.2 Design for R&M Performance is the activity which contributes most to the improvement of R&M in service. It is part of the main design and development process and hence is pro-active rather than re-active. The work is also undertaken by design and development staff rather than analysts. Hence the main input is timely allocation of these people to the R&M aspects of the design together with access to the design details and prototypes. The other input of note is the R&M specification. This defines the necessary achievement in terms that are relevant to the item under design. This might include design integrity requirements and derating requirements. This is addressed in more detail in Pt2Ch3.

3.3.3 Theoretical Review of Design for R&M provides feedback on where the design is likely to be weak in terms of meeting the R&M requirements. Often this will be presented as a risk (high, medium or low) of failing to meet the requirement in service, coupled with a list of the items to be addressed in order to reduce that risk to an acceptable level. The design team can then take appropriate action. Such a review needs information on the design, the criteria against which the design is to be judged and the current estimation of the performance. More detail is provided in PtBCh5.

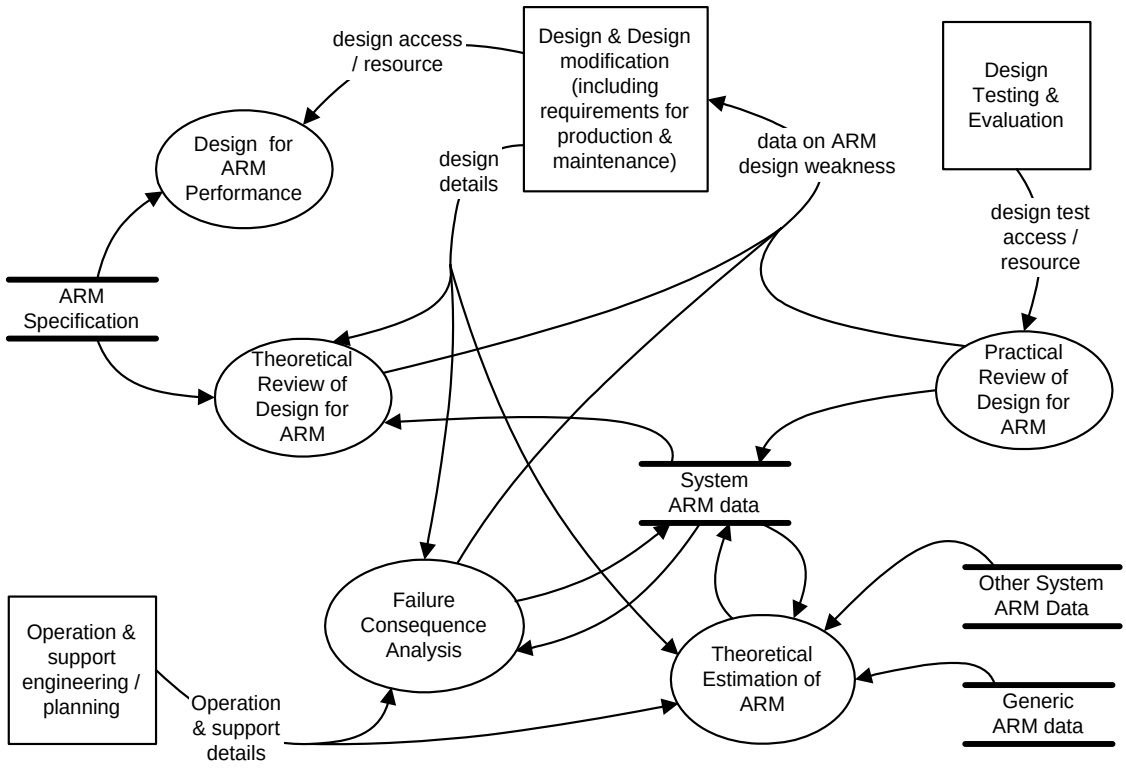


Figure 4: Activities Associated with Initial Design and Later Modification

3.3.4 Practical Review of Design for R&M is a longer process and involves conducting tests and experiments with the aim of identifying weak points in the design for correction as part of the design process. This needs access to equipment in a test environment. At the time when practical review is relevant, the equipment will be in Design Test and Evaluation. The R&M activity needs access and resource provision from this non-R&M specific process. The result of the work carried out, will feed to the Design process and the provide R&M data on the system. This includes Reliability Growth and Test, Analyse and Fix programmes. Further explanation can be found in PtBCh4.

3.3.5 Failure Consequence Analysis establishes the effect of equipment failures on operation, safety, etc. It extends the data on the basic R&M parameters determined by other activities, operational and support intentions and design details. This is where cause and consequence analysis techniques fit into the R&M process. Further discussion is provided in PtBCh6.

3.3.6 The **Theoretical Estimation of R&M** is carried out using data on the design, generic data, data from other systems, practical data (via the System R&M data store) and the established or emerging operation and support details. The results are fed into the system

R&M data store from where they can be reviewed and appropriate action taken. This is a controversial[§] subject and is further discussed in PtBCh7.

3.4 Activities Linked with Design Acceptance

3.4.1 There are two R&M activities that specifically form a part of design acceptance. However many of the other activities can contribute to design acceptance through the system R&M data store.

3.4.2 There is an activity that provides **R&M Evidence Collation** and documents the satisfactory (or otherwise) nature of the R&M performance. This takes in data from the specification (definition of what is satisfactory) and from the system R&M data (generated by other R&M activities). It also takes the results from specific demonstrations. The results pass to the overall design acceptance activity. Further discussion can be found in PtBCh10.

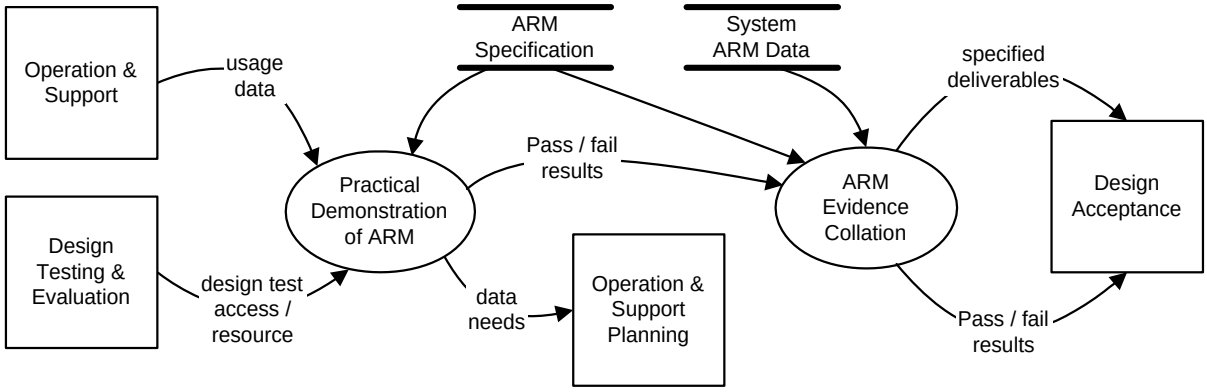


Figure 5: Activities linked with design acceptance

3.4.3 The **Practical Demonstration of R&M** is an activity that is specifically linked with the acceptance process. It can be performed as part of design testing or following entry into service; hence the two inputs shown. The activity is addressed further in PtBCh8.

3.5 Activities Linked with Production

3.5.1 If the intrinsic R&M performance obtainable by the design is to continue to be achieved, it is important that potential fault initiation during production is controlled. This requires the R&M activity to enter the area of production engineering and production itself. To achieve this, the production engineering and production planning processes need to be made aware of the necessary activities during production. These processes, in turn, provide the R&M activity with resource and access to the production process.

[§] Some of the techniques, databases and models used for the estimation of R&M parameters are not well regarded by many people. However this does not invalidate the technique, only require that the results are treated with great care. Indeed, where good databases and models are available, the activity has much to recommend it. Both sides of the argument are presented in Pt2Ch7 so that the reader can judge whether the activity is appropriate in a given situation.

3.5.2 Most of the requirements for producing or maintaining equipment without initiating faults are dealt with by quality techniques. However, techniques do exist that help to reveal such items before delivery. These are considered further on PtBCh11.

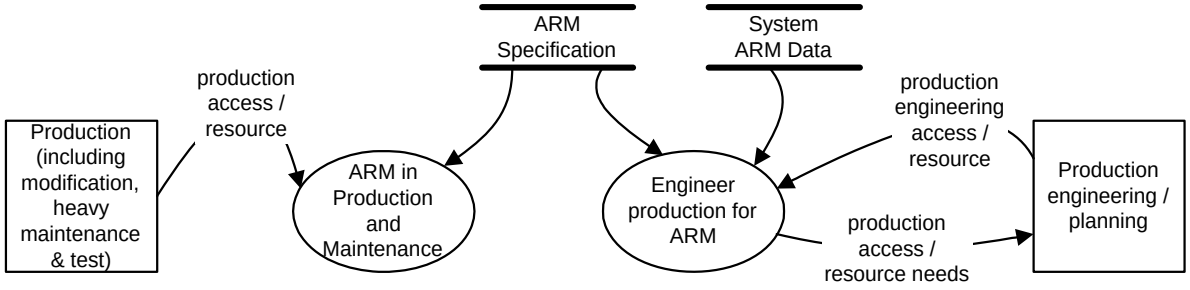


Figure 6: Activities linked with production

3.5.3 To prevent systematic faults[**] being initiated during production and maintenance, requires production engineering to address the ways in which they may be introduced. This requires R&M activities to be undertaken as a part of production engineering. Further explanation is given in PBCh9.Activities during operation and support.

3.6 Activities During Operation and Support

3.6.1 There are two R&M activities during operation and maintenance (the R&M achievement side of maintenance is best considered under production, see para 3.5).

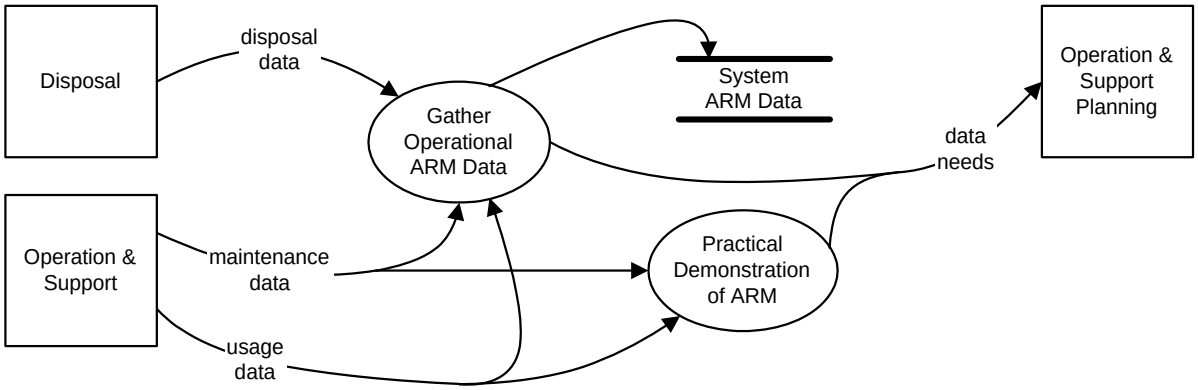


Figure 7: Activities during operation and support

[**] Systematic faults are latent faults or design weaknesses waiting to be revealed. They are built into every instance of the systems during specification, design, production or maintenance. Examples include lack of immunity from likely electrical impulses and inadequate material strength. In theory it should be possible to test for these faults but, often such extensive testing is not practical. If a systematic fault is revealed by a sequence of events in a given environment, then that sequence and environment will always reveal that fault.

3.6.2 The main item is the gathering of data on the system performance for current and future use. This data, suitably analysed, should be held in the system R&M data store. It must be identified to the operation & support planning activity, if data is to be collected. The gathering of data and its analysis are addressed in PtBC12.

3.6.3 Practical demonstration of the R&M achievement (see para 3.4.3.) is often carried out during actual operation. Further explanation can be found in PtBCh8.

3.7 R&M Aspects of Project Management

3.7.1 The management of any system development must include the management of the associated R&M activities. The particular needs of R&M management are addressed in PtBCh13.

3.7.2 Two areas of project management are considered to require particular attention when addressing R&M and are addressed as techniques in this Manual. These are:

a) the **sub-contracting** of areas of the system design and the considerations associated with reflecting the overall R&M requirements down (see PtCCh47); and

b) the preparation and content of **R&M plans and programmes** (see PtCCh48).

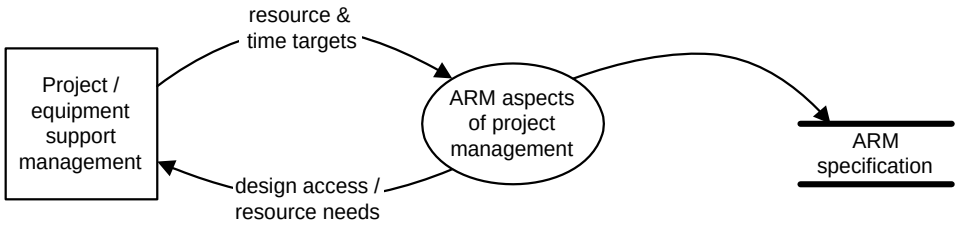


Figure 8: R&M Aspects of Project Management

3.8 Data Stores

3.8.1 The initial decomposition (para 3.1) identified four data stores. These provide a library function and save each activity from having to specifically pass information to all potential users. PBCh14 considers the management of system R&M data and R&M specification requirements in more detail.

3.8.2 The first requirement is to record all the R&M requirements placed on the system. This starts with the initial requirements associated with the function of the system. Other requirements emerge as the system develops. For example the safety requirements may require a certain Availability or Reliability from functions that were not recognised as important at the requirements specification stage. The development process may also identify production and maintenance requirements that must be enacted if the required Reliability is to be achieved.

3.8.3 Secondly, R&M data should be recorded centrally as it becomes available. This record should include all derived data such as estimates of relevant R&M parameters. It should also include (by reference if appropriate) the documentation associated with the

activities carried out, since this may become part of the R&M Case and be delivered to the customer. This differs from the specification data store in that the specification store contains requirements; R&M data is actual data arising from tests, analyses, and other activities.

3.8.4 Data from other systems is referenced since this can make a major contribution, particularly in the early stages of development. This store is the same as that addressed in the previous paragraph but for systems other than the current one.

3.8.5 Generic R&M data is also useful in the early stages of development although its value can be controversial, as discussed in PtBCh7.

4 TECHNIQUES

4.1 Having identified:

a) the activities to be undertaken;

b) the output required; and

c) the data / data sources available.

it is necessary to consider how the input will be converted to the required output. This requires one or more techniques.

4.2 There is a large range of R&M techniques. This Manual addresses the most common and useful and aims to provide a reasonably complete set. However new techniques are emerging all the time and there are countless variations used. Hence the Manual cannot be totally comprehensive. The practitioner should always ask whether the technique in use is providing the results in an effective manner or whether another approach would be more appropriate. Similarly, the customer should be prepared to accept results using a different or varied technique, provided the method used is sound and rigorous.

4.3 In this Manual the chapters on activities identify relevant techniques and vice versa. The connectivity is also summarised in Table 1 of this Chapter and the figure in PtACh1.

5 SUPPORTING THEORY

5.1 Most of the techniques are based to some extent on mathematics. It is not always necessary for the practitioner or the customer to understand the background mathematics but it can be useful in certain circumstances. This is particularly so when a technique is being used outside its normal area of application or extended in a novel manner.

5.2 As with the links from activities to techniques, the links from techniques to supporting theory are summarised in the relevant chapters, the table below and the figure in PtACh1.

6 SUMMARY

6.1 The variety of tasks undertaken in pursuit of R&M performance can be grouped into one general activity. This activity has interfaces with many non-R&M activities.

6.2 The general R&M activity is divided into thirteen lower-level activities and four data stores (whose management requires a fourteenth activity).

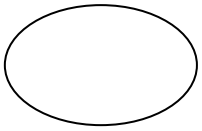
6.3 Each of these activities is supported by techniques and those techniques by supporting theory.

6.4 The decomposition and linkage is summarised in Figure 1 of PtACh1.

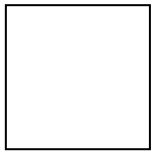
LEAFLET A4/1

DATA-FLOW DIAGRAM CONVENTIONS

The figures in PtACh4 and the first figure in most chapters of Pt B of the Manual use a form of data flow diagram based on the techniques developed by Yourdon and others to record the analysis and partitioning of systems. Although originally developed in support of software design, they provide a good aid to understanding of how the R&M activities relate to each other and to the rest of the world. The following is a brief description of the symbols and their meaning.



Ellipse - activity (descriptively named in the ellipse) within the scope of consideration.



Square - activity (descriptively named in the square) outside the scope of consideration but relevant as the source or destination of data to or from activities inside that scope.

Line with arrowhead - data or other object (descriptively named close to or over the line) which flows between activities in the direction of the arrow.

Rectangle with heavy top and bottom but no sides - data store (named in the rectangle), data flowing in or out is shown as an arrowed line without a name as the name would be the same as the name of the store.