

## CHAPTER 30

### RELIABILITY BLOCK DIAGRAMS

#### CONTENTS

	Page
1 Introduction	2
2 The Nature of a Reliability Block Diagram	2
3 Construction of a Reliability Block Diagram	5
4 Quantifying an RBD	9
5 Shortcomings of the RBD Method	10

## 1 INTRODUCTION

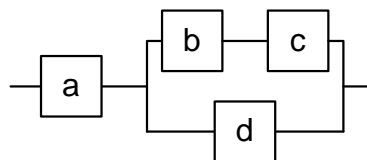
**1.1** Before any reliability analyses can be carried out on a system there must be knowledge of the operational relationships of the various elements comprising that system. The reliability of a system cannot be improved or even evaluated unless there is a thorough understanding of how each of its elements function and how these functions affect system operation. The accurate representation of these relationships is an integral part of this understanding and is particularly important for meaningful predictions, apportionment's and assessments. A Reliability Block Diagram (RBD) provides a method of representing this information in a form, which is easy to comprehend because it is simple and has visual impact.

**1.2** It should be noted that a system or equipment might require more than one RBD to describe it. This is particularly true of equipment, which is capable of performing several functions, or experiences several different operating states during a deployment. An RBD may be required for each particular condition. In fact, the approach should be to produce an RBD for a function in a particular operating state, rather than for a piece of hardware.

## 2 THE NATURE OF A RELIABILITY BLOCK DIAGRAM

### 2.1 The Reliability Block Diagram

**2.1.1** For a system comprising a number of identifiable items of hardware the reliability block diagram is a means of showing the functional relationship between the items, and indicates which ones must operate successfully for the system to accomplish its intended function (or functions). An example of an RBD is shown in Figure 1.



**Figure 1: Example of Reliability Block Diagram**

**2.1.2** It is assumed here that both the system and its elements are in one of two states; either up or down. Hence, in an RBD, each element may be looked on as a switch that is closed when the element is up and open when the element is down. The system will be up only when a path exists between the input and output nodes.

**2.1.3** In the system shown in Figure 1, the system will be down when:

- a) element a is down; or
- b) elements b or c, and element d are down.

**2.1.4** In essence, an RBD is the pictorial representation of a Boolean expression (see PtDCh1). As a Boolean expression may take different forms, so similarly there is not a

unique RBD for a system. There is, however, usually but not always a unique way of expressing an RBD in its simplest form.

**2.1.5** An RBD can always be constructed as connected groups of three types:

- a) Elements in series;
- b) Elements in active redundancy; or
- c) Elements in standby redundancy.

(The groups will not necessarily be independent and elements may be duplicated).

## 2.2 Elements in Series

**2.2.1** The simplest form of a system for reliability analysis is one where the elements are connected in series. In this type of system, if one or more of the elements are down then the system is down. For example, consider the power train of a motor car, comprising engine (e), gearbox and drive links (g), and two wheels ( $w_1$ ,  $w_2$ ). A failure of any element results in failure of the system. The RBD of the system is:



**Figure 2: Example of a Series RBD**

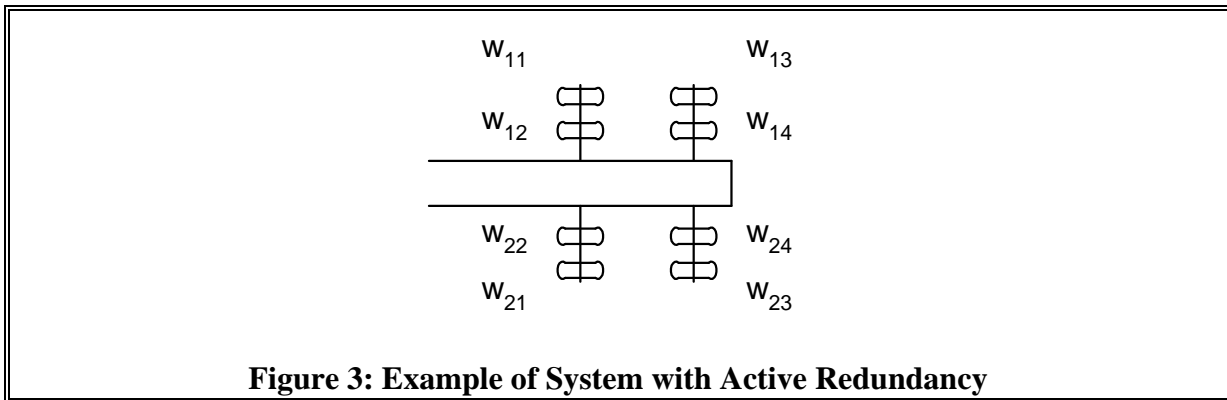
Note that an RBD only depicts functional relationships between elements, so that, although it may be convenient to arrange elements in the same order in which their functions are performed, it is not necessary to do so.

## 2.3 Elements in Redundancy

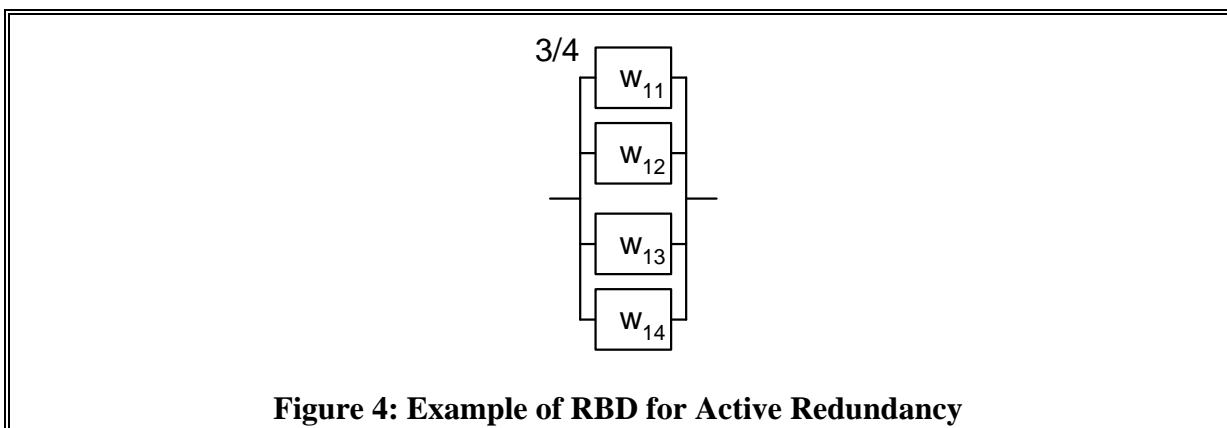
**2.3.1** There is redundancy in a system if not all of its constituent elements are required to be up for successful operation of the system. A 'm/n redundant group' is a group of n items where only (any) m of them has to be up for the group to be considered up. This chapter considers two forms of redundancy, namely active and standby redundancy.

## 2.4 Active Redundancy

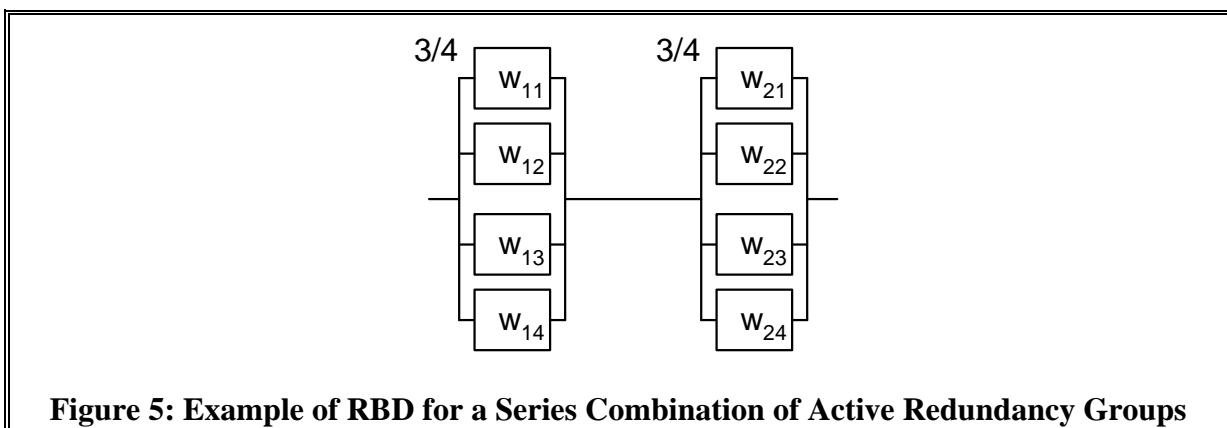
**2.4.1** A group of elements are said to be in active redundancy if all elements in the group are active when the system is operating, but it is not necessary for all elements to be up for the group to be up. Redundancy appears in an RBD as parallel routes. For example, consider the rear suspension of a lorry comprising four wheels on either side as illustrated in Figure 3.



**2.4.2** Suppose the load can be supported by three out of four wheels on each side. Then the RBD for the off-side wheels is as shown in Figure 4.



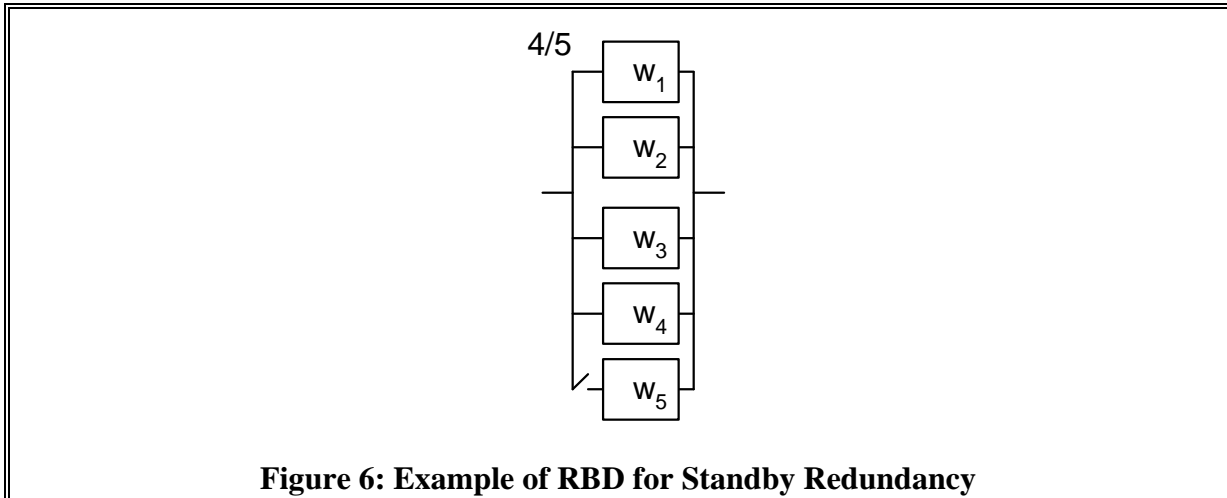
**2.4.3** For all eight wheels considered as a system the RBD is a series combination of active redundancy groups, as shown in Figure 5.



## 2.5 Standby Redundancy

**2.5.1** Elements are said to be in an ‘m/n standby redundant group’ when only m of the elements are required to be in an active state and the remainder are in a passive state. When an active element fails then one of the passive elements is switched on in its place. The failure time distribution of the elements depend on whether they are in an active or passive state (the failure rate of an element in an active state is generally much larger than its failure

rate when it is in a passive state). An example of a standby redundancy group is a car with a spare wheel (assuming that the car with a burst tyre is not regarded as a system failure when there is a working spare). The RBD of this system is shown in Figure 6.



**Figure 6: Example of RBD for Standby Redundancy**

**2.5.2** An important feature of most standby redundancy groups is that failures of elements in the passive state will not be detected until the passive element is required to replace a failed active element. Thus, even elements with a low failure rate in the passive state can have a critical effect on system reliability unless the 'spare' is regularly and comprehensively tested. In addition, if an automatic switching mechanism is used to bring in the passive elements, the mechanism itself may have its own failure time distribution.

### 3 CONSTRUCTION OF A RELIABILITY BLOCK DIAGRAM

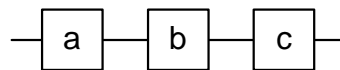
#### 3.1 A Method

**3.1.1** Where a system has a single function, such as in the examples described above, it is generally a straightforward matter to construct the system RBD. Normally such systems will comprise a group of elements in series or, at the most, a number of groups with redundancy themselves connected in series, (e.g. Figure 4). However, where a system has to perform more than one function or where the same function may be performed by more than one set of elements, the construction of the RBD may become much more complex. In these situations, it is advisable to follow a set procedure when drawing the RBD.

**3.1.2** The first step is to define the functions that the system is to perform, and the operating states (e.g. standby, full power, etc.). If the motor car example is taken again, several different functions may be required, e.g.:

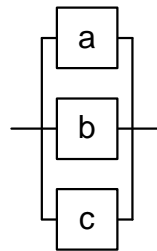
- a) ability to carry two passengers;
- b) ability to carry luggage; and
- c) ability to tow a caravan.

**3.1.3** The next step is to decide which of these functions is the minimum required for successful operation of the system. If, in the example above, it is decided that all three functions are required, then the functions should be represented as shown in Figure 7.



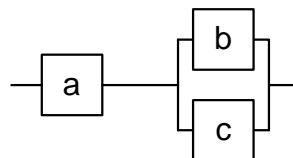
**Figure 7: Representation of Series Function**

If any one of the three functions is sufficient for the operation of the system, then the system should be represented as shown in Figure 8.



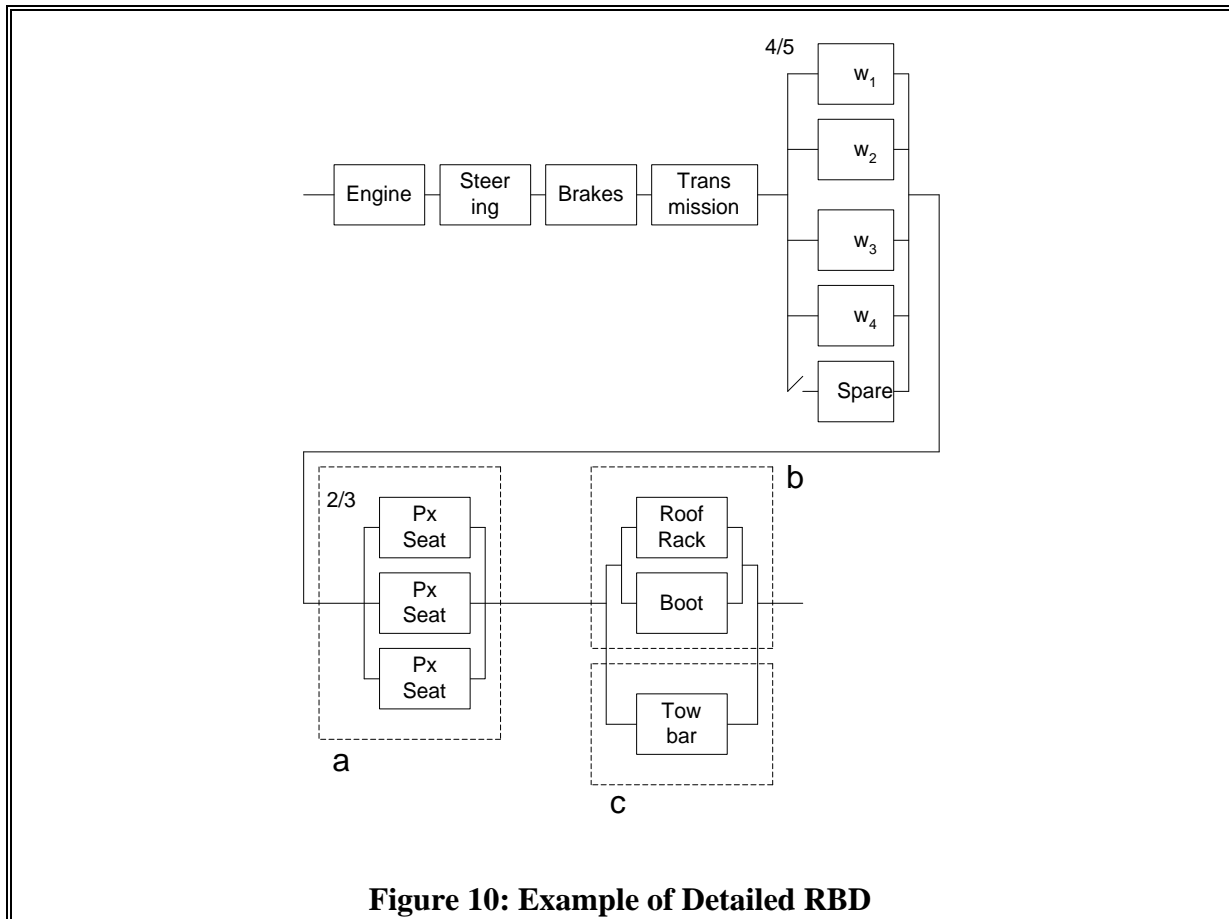
**Figure 8: Representation of Redundant Functions**

**3.1.4** Intermediate configurations are also possible of course. For example, if passenger-carrying was the prime requirement and any one of the other two functions were sufficient for system operation, then the initial RBD would be as shown in Figure 9.



**Figure 9: Representation of Series and Redundant Functions**

**3.1.5** The next step is to associate with each function those elements that are required to perform the function. It may be that there are some elements which are common to all functions and they should be separated out first, e.g. in the example above, the engine, steering, brakes, transmission and four wheels are clearly necessary for all three functions. Function a could be stated as requiring two out of three passenger seats, function b as requiring either a roof rack or boot, and function c as requiring a towbar. The full RBD for the case shown in Figure 9 would then be as shown in Figure 10.

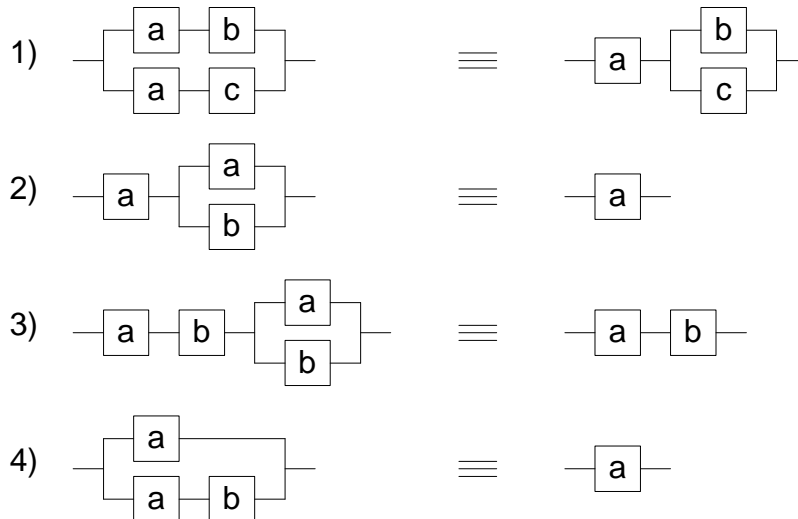


**Figure 10: Example of Detailed RBD**

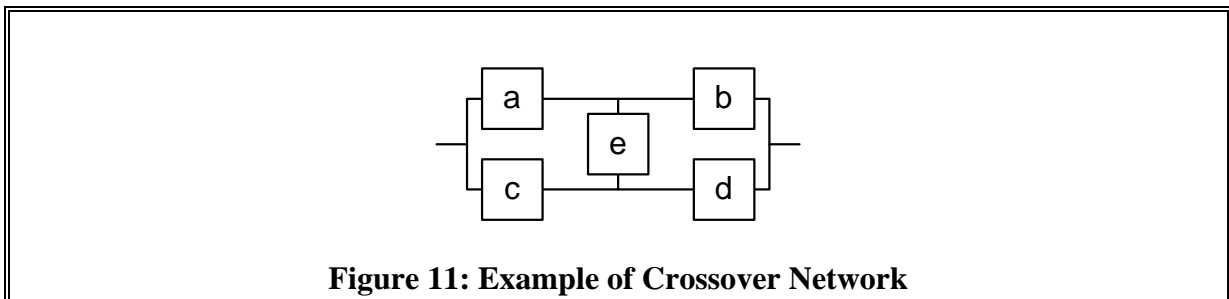
### 3.2 Simplifying an RBD

**3.2.1** The above system provides a straightforward example of RBD construction. In practice, however, a system may be more complicated particularly if some elements are required for more than one function but not all. In these cases, a rigorous procedure should be followed when constructing RBDs. A suitable procedure, based on Boolean Algebra, is described in PtDCh1, and the analysis of complex redundancy is discussed in PtDCh6.

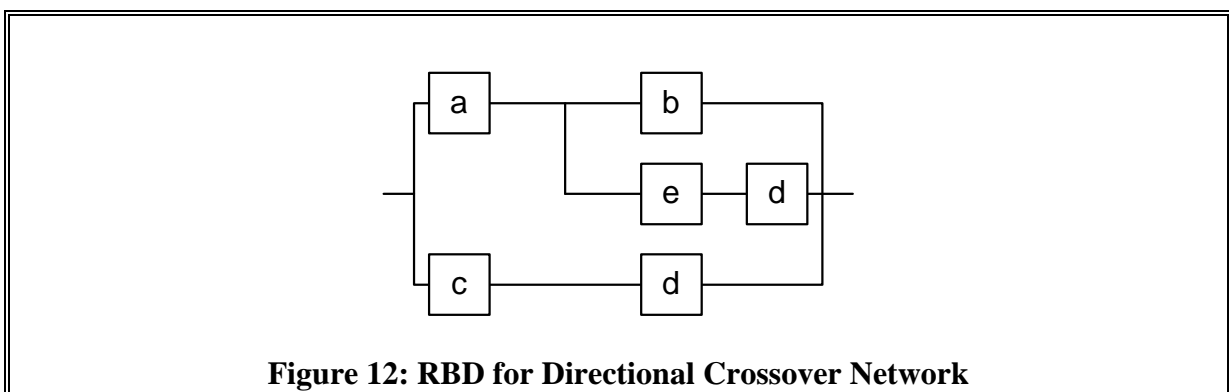
**3.2.2** When developing RBDs it is not always a matter of simple inspection to determine the conditions that represent successful operation of a system, the system up states, or alternatively the system down states. In these cases, techniques such as Truth Tables or Boolean Algebra should be used. The Boolean analysis in PtDCh1 shows how to construct and simplify an RBD. For simple systems the following results are useful when minimising an RBD.



**3.2.3** When simplifying an RBD take care to ensure that the routing conditions in the diagram are preserved. This problem arises because the node-block-node construction is not directional. It is possible to have routes in both directions through blocks not connected to the input or output node. An example of this is the crossover network shown below in which routes pass through element 'e' in both directions.

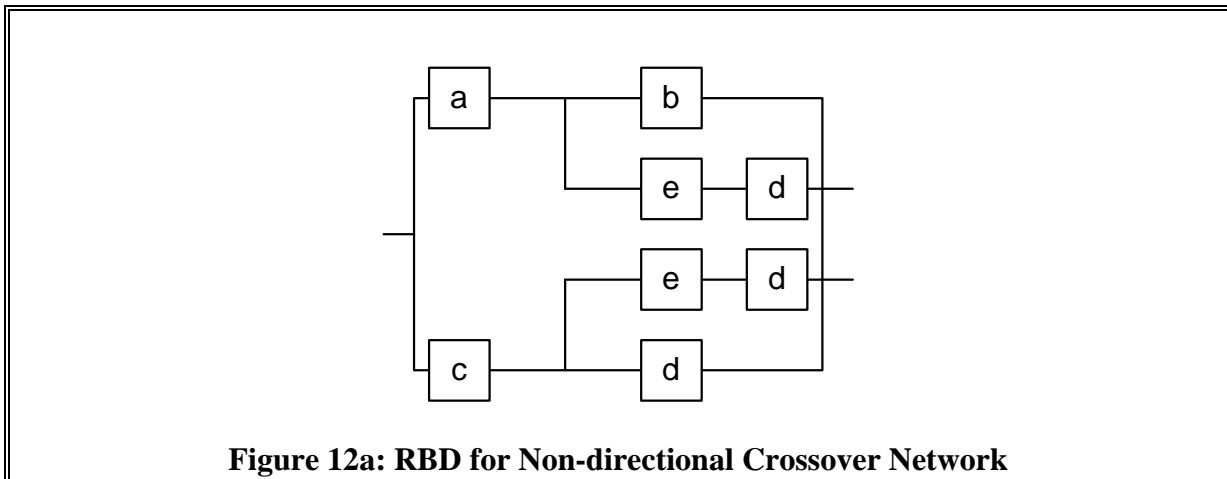


**3.2.4** If the 'e' block is directional, i.e. 'ceb' is not a system up state, then the RBD must either have a downward arrow on the 'e' route or, preferably, be drawn as:



**3.2.5** If the 'e' block is non-directional, i.e. either 'aed' or 'ceb' is a system up state, then the RBD must either have a bi-directional arrow on the 'e' route or, preferably, be drawn as:





**3.2.6** The process of constructing an RBD for a complex system may be summarised as follows:

- a) Specify the function(s) to be analysed, and the operating state (e.g. standby, full power, etc.).
- b) Specify the minimum requirements for the system to operate successfully in terms of the functions of the system.
- c) Draw a system RBD in terms of the system functions.
- d) Specify the elements that comprise the system functions.
- e) Draw a system RBD in terms of the system elements.
- f) Simplify the RBD but if in doubt leave it; the analysis will still be correct.

## 4 QUANTIFYING AN RBD

### 4.1 General

**4.1.1** RBDs can be used to evaluate the system availability or system reliability given the availability, reliability etc. of the individual elements.

**4.1.2** The quantitative use of RBDs to derive R&M parameters is detailed in PtDCh6, which provides formulae and methods for calculating the System Reliability (R), Availability (A), Mean Time To Failure (MTTF), Mean Time Between Failures (MTBF), and Mean Time To Repair (MTTR), when the Reliability and/or MTBF and/or MTTR (as appropriate) of the items comprising the System are known.

### 4.2 Computational Programs

**4.2.1** The assessment of Availability, Reliability and Maintainability (R&M) parameters for complex RBDs is a difficult task and is generally beyond the scope of manual or analytical calculation in all but the simplest situations. For example, if queuing for repair occurs or if it is required to assess the sensitivity of the system R&M parameters to the reliability and repair time characteristics of elements of the system, then the mathematical difficulty and computational load will be such that help from a computer program is essential.

**4.2.2** Computer based analytical aids, such as RAM4<sup>8</sup>, provide the solution to this problem.

### **4.3 Facilities provided by Computational Programs**

**4.3.1** Programs such as RAM4 are designed to be capable of assessing a variety of systems of mixed repairable and non-repairable elements, including those with standby redundancy. They may include the capability to model logistic delays, common mode failures and repair teams with specific skills, and may also perform two common types of R&M study, sensitivity analysis and apportionment.

**4.3.2** For a system under specified mission conditions RAM4 calculates the mean and distributions of the following system parameters:

- Availability.
- System Failure Rate.
- Mean Time Between Failures (MTBF).
- Mean Time To Repair (MTTR).
- Mean Time to First Failure (MTFF).

**4.3.3** In addition to producing overall single figure measures of these system reliability parameters, RAM4 also produces the distributions about and confidence intervals about the calculated means. RAM4 also produces:

- an analysis of R&M parameters for elements of the system and for sub-systems (groups of elements).
- a repair queue analysis giving statistics for waiting times and queue lengths.
- an automatic Sensitivity Analysis.
- distributions of the main system R&M parameters displayed graphically as histograms.
- a graphical display of results by colour shading of the RBD in a Criticality Analysis.
- detailed results tabulated in an output file which can be viewed and output to a printer.

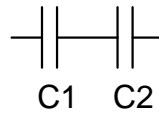
**4.3.4** These outputs enable the factors influencing the overall system reliability to be identified. It must however be recognised that the R&M assessment of a complex system will always produce results which require careful study.

## **5 SHORTCOMINGS OF THE RBD METHOD**

**5.1.1** There are some assumptions in the RBD method of representing complex system which mean that some systems analyses are less straightforward than indicated previously. Problem areas resulting from these assumptions are described below.

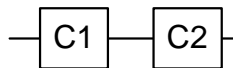
**5.1.2 Failure Modes.** An item of equipment might have more than one mode of failure in which case the effect on the system of a failure in that equipment will depend upon which failure mode occurs.

**5.1.3** To clarify this point, consider two electronic capacitors in a circuit connected in series, as shown in the following schematic.



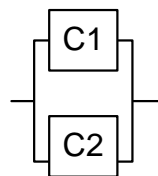
**Figure 13: Electronic Circuit**

**5.1.4** Two failure modes are possible for each capacitor, namely open circuit and short circuit. Considering the open circuit case first, output will be lost if either one of the capacitors goes open circuit, so a series configuration will be shown for this case, see Figure 14.



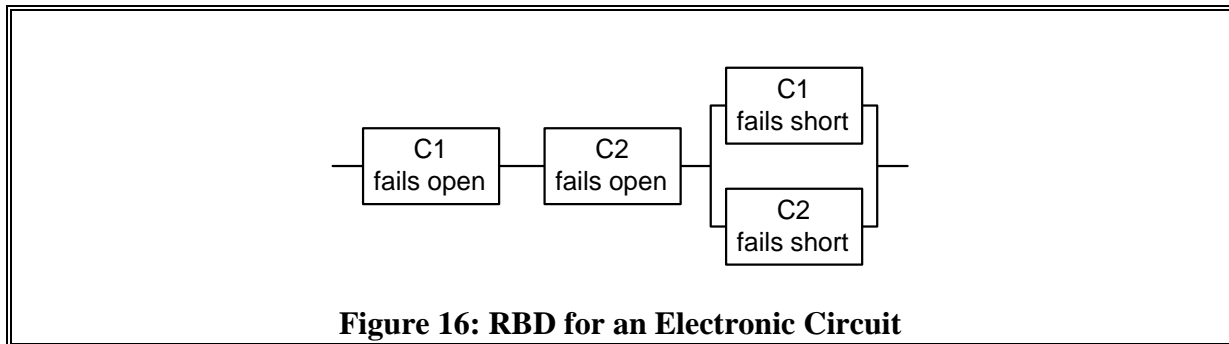
**Figure 14: Representation of Capacitors Open Circuit**

**5.1.5** However, the system can still function with one capacitor failed short circuit (assuming some output is available with a single capacitor operational) so the RBD will show them in parallel, see Figure 15.



**Figure 15: Representation of Capacitors Short Circuit**

**5.1.6** From a reliability point of view the RBD for this system might be drawn as shown in Figure 16 and the failure rates by mode assigned to each element.



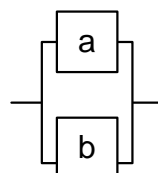
**5.1.7** However, it can be seen that because C1 and C2 both appear twice in the figure the elements are not independent of each other; the operation and failure of each element is conditional. For instance, the failure of C1 due to a short is conditional upon there being no failure due to an open circuit.

**5.1.8** To evaluate an RBD there must be only one failure mode represented for each element. For elements with more than one failure mode, separate RBDs must be drawn using each failure mode.

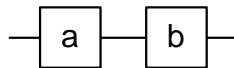
**5.1.9 Active Redundancy.** In practice, if an element fails in a m/n active redundancy group, the failure time distributions of the remaining elements are altered. The failure of an element may mean, for example, that additional stress is placed on the remaining elements, which reduces their MTBF. This would be the case for the lorry example described in section 2.4.

**5.1.10 Multi-mode Missions.** Often the requirements of a system change in successive phases of mission although the basic physical configuration of the system remains the same. Some system components may not operate during every phase of the mission. Thus component failures may or may not affect system failure, depending on phase and operational requirements at the time. The consequence for the RBD is that different phases might represent different reliability configurations, elements in series might become redundancy items and vice versa, furthermore, functional definitions may change. This situation cannot be depicted accurately using RBDs and approximations may have to be made.

**5.1.11** Consider the case of a system power supply consisting of two batteries. If in the early phase of the mission the power demands are light, either one of the batteries is sufficient. However, if in the latter stage of the mission demand is heavy both batteries must be operational to meet the demand. The RBD for the battery sub-system in the early mission phase would appear thus:



While for the latter phase when both are required a series arrangement is required:



**5.1.12** Obviously both configurations cannot be included in the same RBD, so which one can be used as the best approximation for the whole mission? From a consideration of the mission requirements it is clear that the failure of either battery in the early phase will subsequently result in system failure in the later phase due to insufficient power, so the series arrangement would be the better one. (This conclusion assumes that repair action during the mission would be either impossible or very lengthy. If repair times were short it would complicate the situation further). In many cases approximations such as this may be possible without significantly affecting the analysis results, whereas for other cases it may prove necessary to construct a separate RBD for each mission phase.

**5.1.13 Common Cause Failures.** Due allowance for the effect of common cause failures should be allowed for in the RBD. When such failures occur all the elements affected by the common mode event fail. A discussion on common cause failures is presented in PtCCh28.

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### RELATED DOCUMENTS

1. DEF STAN 00-40 (Part 1)/Issue 2 (R&MP-1). 14 December 1994. *Reliability and Maintainability Part 1: Management Responsibilities and Requirements for Programmes and Plans*.
2. DEF STAN 00-40 (Part 2)/Issue 1 (R&MP-2). 14 December 1994. *Reliability and Maintainability Part 2: General Application Guidance on the Use of Part 1 (R&MP-1)*.
3. DEF STAN 00-41 Issue 3. 25 June 1993. *Reliability and Maintainability MOD Guide to Practices and Procedures*.
4. Patrick D T O'Connor. *Practical Reliability Engineering*. John Wiley & Sons.
5. D J Smith. *Reliability Maintainability and Risk*. Butterworth Heinemann. 1993.
6. *The Mathematical Analysis of Logic*. George Boole, (dated 1874).
7. BS 6548: Part 6: 1995. *Maintainability of Equipment Part 6. Guide to Statistical Methods in Maintainability Evaluation*.
8. SSP 41 Issue 4. *Project Availability, Reliability and Maintainability (R&M) Handbook, Part 8, User's Guide to the Reliability, Availability and Maintainability Analysis Program 'RAM4' (Version 3)*. MOD(PE).

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