Procedure

Sydney WATER

Reliability Block Diagram (RBD)

1. Overview

1.1. Objective

The purpose of this procedure is to document the process for generating Reliability Block Diagram (RBD) for Sydney Water's facility assets.

1.2. Scope

All Critical Sydney Waters Facility Assets shall have a representative Reliability Block Diagram (RBD). The level of detail will depend on the tactics used for reliability engineering application. The first RBD shall be initiated at the design stage and updated as and when alterations and modifications are undertaken on the facility.

The diagrams may be developed manually or using standard software.

1.3. Summary

The first facility asset RBD shall initially be undertaken during concept design phase; The RBD will then be used in drawings and process instrumentation diagrams and Maximo hierarchy of equipment. Strategic Asset Management (SAM) shall provide the directions for RBD. Maintenance Engineering, Operation and Asset Solutions will then contribute to further develop the RBD for specific assets.

RBD shall be a part of the Asset Creation Process. All contractors, developers and designers shall be obliged to provide RBD as part of the design.

The RBD shall then be adopted in operation analysis, Process Documentation, Maintenance and Reliability Analysis and other business processes.

2. Procedure

Procedure and explanation for development of RBD for facility assets

Additional theory, application and examples are provided in the companion guide.

Reliability Block Diagram

Reliability block diagrams may be pitched at different levels of disaggregation (indenture level) maintainable component level, maintainable unit level and at system level. Reliability block diagram is initially used at the concept stage of design to record reliability at different levels of disaggregation. This procedure documents various views from well-known authorities in reliability it also addresses the concept of failure rate as a measure of un-reliability

Reliability Block Diagram (RBD) and Design

(Ref Pg 48 - Reliability of Mechanical Systems By John Davidson MEP Institutions of Mech Engg UK Publication)

During the first stage of the design of complex process, engineering plant or facility a block diagram (or flow-diagram) is constructed in this diagram each block represents one of the facilities constituent systems, sub-systems or assets/equipment. A *schematic* block diagram shows how the assets are physically connected, while a *functional* block diagram shows the flow of power, material, etc., through the system, with the relationship between input and output specified for each block. This diagram establishes the conceptual design of the system and needs to be approved before any detailed engineering design is undertaken.

Similarly, the assessment of overall system reliability may be established by the construction and analysis of a Reliability Block Diagram (RBD). In an RBD the connections between the assets, symbolise the ways in which the system will *function as required* and do not necessarily indicate the actual physical connections. A Reliability Block Diagram is usually drawn up using a schematic or functional diagram of the facility or plant as a starting point.

Analysis of a Simple System

(Ref. An Introduction to Reliability and Maintainability Engineering; Charles E. Ebeling)

Components within a system may be related to one another in two primary ways

Series configuration or

Parrel configuration

Series and active parallel RBD are the simplest building blocks for reliability analysis

In series configuration all components must function for the system to function. However in a parallel or redundant configuration at least one component must function for the system to function.

Assumptions

Generally for simplicity in reliability calculation we can assume that the asset/equipment is in a constant hazard rate phase of the bathtub curve; where failure rate λ is constant and the failures are independent of time and will not increase or decrease with the age of the equipment. The failure density function is a negative exponential. Under this phase MTTF = MTBF. Only in the case where the failure distribution is exponential is MTBF constant over time.

Failure rate $\{\lambda\}$ is the arrival rate of failure.

When the Failure distribution is exponential the hazard rate is constant and = failure rate λ

Only in this case when Failure Rate is constant

Cumulative Failure rate, $F(t) = 1 - e^{-\lambda t}$

Reliability, $R(t) = e^{-\lambda t}$

The Inverse of Failure rate is MTTF (mean time to failure). It is an average operating performance for a non-repairable item. This is determined by dividing the asset's cumulative time in service by the cumulative number of failures.

$$MTTF = \frac{1}{\lambda}$$

Non- repairable means we replace the entire asset upon failure.

Similarly for repairable asset we have MTBF (mean time between failure). This is determined by dividing the asset's cumulative time in service by the cumulative number of failures

Series Configuration

(Ref. Pg 84. Reliability and Maintainability Engineering by Charles E Ebeling - McRraw- Hill publication)

In a series configuration, all assets are considered critical in the sense that they need to operate to specification in order for the system to continue to perform its designed function. If any one of the assets in a series relationship fails, the system will fail. The reliability block diagram represents this series relationship.

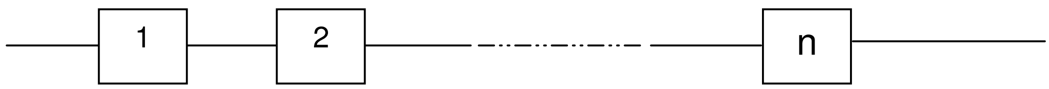


Figure- 1: Reliability Block Diagram for assets in series

Reliability is a probability of success in a given time under given conditions.

A system's reliability R_s may be determined from the asset reliabilities in the following way.

Where R_1 = the reliability of asset1

R_2 = the reliability of asset 2

R_3 = the reliability of asset 3

R_n = the reliability of asset n

Assuming that the assets are interdependent (i.e. the failure or non-failure of one asset does not change the reliability of the other assets).

So, in order for the system to function, all asset 1, asset 2, asset 3 and …………………… asset n must function.

Therefore $R_s = (R_1) \times (R_2) \times (R_3) \times ....\times (R_n)$

Generalising to 'n' mutually independent assets in series,

If each asset has a constant failure rate λ_i, the system reliability is given by

$$R_s(t) = R_1 \times R_2 \times R_3 \times ... \times R_n$$

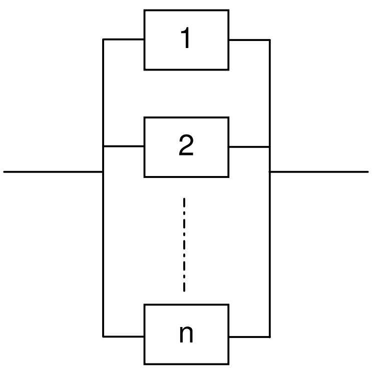
$$R_s(t) = (e^{-\lambda_1 t}) \times (e^{-\lambda_2 t}) \times (e^{-\lambda_3 t}) \times (e^{-\lambda_n t})$$

$$\text{MTTF} = \frac{1}{\lambda_S} = \frac{1}{\lambda_1 + \lambda_2 + \lambda_3 + ... + \lambda_n}$$

<u>Parallel Configuration:</u>

(Ref. Pg 86. Reliability and Maintainability Engineering by Charles E Ebeling - McRraw- Hill publication)

If two or more assets are in active parallel configuration, with 100% or more redundancy, then, all units must fail for the system to fail. If one or more units operate, the system continues to operate. Active Parallel configuration of assets is represented by the block diagram of Figure 2.



<u>Figure- 2 Reliability Block Diagram for assets in parallel</u>

System reliability for ‘n’ active parallel and independent assets is found by taking

1 minus the probability that all n assets failing (i.e., the probability that at least one asset does not fail).

$$R_s\,(t) = 1 - [(1 - R_1)(1 - R_2)(1 - R_3) \ldots\ldots\ldots\ldots (1 - R_n)]$$

(Ref Pg 53 - Reliability of Mechanical Systems By Davidson MEP Institutions of Mech Engg UK Publication)

For a redundant active parallel system consisting of three constant failure rate assets,

$$R_s\,(t) = 1 - (1 - e^{-\lambda_1 t})(1 - e^{-\lambda_2 t})(1 - e^{-\lambda_3 t})$$

From the above result an expression for the system MTBF can be found. However, its form is more complex than that for a series system. For an active parallel system comprising of

two assets.

$$MTTF = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} - \frac{1}{(\lambda_1 + \lambda_2)}$$

For an active parallel system comprising three assets

$$MTTF = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} + \frac{1}{\lambda_3} - \frac{1}{(\lambda_1 + \lambda_2)} - \frac{1}{(\lambda_1 + \lambda_3)} - \frac{1}{(\lambda_2 + \lambda_3)} + \frac{1}{(\lambda_1 + \lambda_2 + \lambda_3)}$$

Combined Series-Parallel Systems:

(Ref. Pg 87. Reliability and Maintainability Engineering by Charles E Ebeling - McRraw- Hill publication)

Generally systems contain assets in both series and parallel relationships. Consider, the example, Figure –3 below, R_i represents the reliability of the i th component. To compute the system reliability, the network may be broken into serries or parallel subsystems; and the reliability of each subsystem is calculated; then the system reliability may be calculated on the basis of the relationship among the subsystems. In the network of Figure –3, the subsystems have the following reliabilities:

$$R_A = [1 - (1 - R_1)(1 - R_2)]$$

$$R_B = (R_A) \times (R_3) \qquad R_C = (R_4) \times (R_5)$$

Since R_B and R_C are in parallel with one another and in series with R_6,

$$R_S = [1 – (1 - R_B) (1 - R_C)] (R_6)$$

If $R_1 = R_2 = 0.90$, $R_3 = R_6 = 0.98$, and $R_4 = R_5 = 0.99$, then

$$R_B = [1 – (0.10)^2] (0.98) = 0.9702$$

$$R_C = (0.99)^2 = 0.9801$$

And

$$R_S = [1 – (1 – 0.9702) (1 – 0.9801)] (0.98) = 0.9794$$

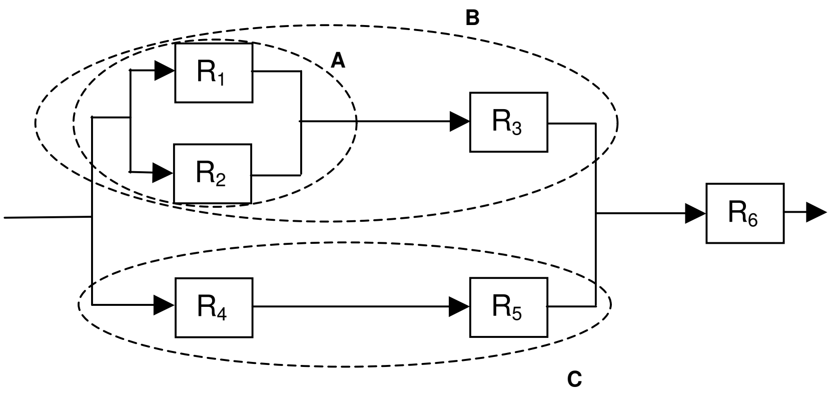


Figure- 3: A system compromised of assets in a combined series and parallel relationship.

Reliability Data

Standard failure data is available from:

OREDA – Offshore Reliability Data

RAC - Reliability Analysis Centre

Process Equipment Reliability Data AICH

It is better obtain data from the CMMS (Maximo) as it is based within the operating context of the organisation.

3. Context

3.1. Definitions

Term	Definition
Criticality	A relative measure of the consequence and frequency of occurrence of a failure mode.
Equipment	A general term designating an item or group of items capable of performing a complete function.
Failure	The event, or inoperable state, in which any item or part of an item does not, or would not, perform as previously specified.
Failure mode	The consequence of the mechanism through which the failure occurs, i.e.,short, open, fracture, excessive wear.
Failure rate	The total number of failures within an item population, divided by the total number of life units expended by that population, during a particular measurement period under stated conditions
Failure, random	A failure, the occurrence of which cannot be predicted except in a probabilistic or statistical sense.
Life cycle cost (LCC)	The sum of acquisition, logistics support, operating, and retirement and phase-out expenses.
Maintenance	All actions necessary for retaining an item in or restoring it to a specified condition.
Mean time between failure (MTBF)	A basic measure of reliability for repairable items. The mean number of life units during which all parts of the item perform within their specified limits, during a particular measurement interval under stated conditions.
Mean time to failure (MTTF)	A basic measure of reliability for non-repairable items. The total number of life units of an item population divided by the number of failures within that population, during a particular measurement interval under stated conditions.
Mean time to repair (MTTR)	A basic measure of maintainability. The sum of corrective maintenance times at any specific level of repair, divided by the total number of failures within an item repaired at that level, during a particular interval under stated conditions.
Mission reliability	The measure of the ability of an item to perform its required function for the duration of a specified mission profile. Mission reliability defines the probability that the system will not fail to complete the mission, considering all possible redundant modes of operation.
Redundancy	The existence of more than one means for accomplishing a given function. Each means of accomplishing the function need not necessarily be identical. The two basic types of redundancy are active and standby. Active Redundancy - Redundancy in which all redundant items operate simultaneously. Standby Redundancy - Redundancy in which some or all of the redundant items are not operating continuously but are activated only upon failure of the primary item performing the function(s).

Reliability	(1) The duration or probability of failure-free performance under stated conditions. (2) The probability that an item can perform its intended function for a specified interval under stated conditions. (For non-redundant items this is equivalent to definition (1). For redundant items this is equivalent to definition of mission reliability.)
Repairable item	An item which, when failed, can be restored by corrective maintenance to an operable state in which it can perform all required functions.
Reliability block diagram (RBD)	A reliability block diagram shows the interdependencies among all elements (subsystems, equipments, etc.) or functional groups of the item for item success in each service use event. The purpose is to show, by concise visual shorthand, the various series-parallel block combinations (paths) that result in item success. A complete understanding of the item's mission definition, and service use profile is required. Each reliability block diagram will have a title including identification of the item, the mission identification or portion of the service use profile addressed, and a description of the mode of operation for which the prediction is to be performed. Each reliability block diagram should include a statement of conditions listing all constraints, which influence the choice of block presentation, the reliability parameters or reliability variables utilized in the analysis, and the assumptions or simplifications utilized to develop the diagram. Once established, these conditions are observed throughout the analysis.

3.2. Responsibilities

This procedure will be implemented by SAM.

FMECA shall be conducted at

- Concept stage by the designers and planners
- Detail design stage by designers.
- Commissioning stage by the contractor.
- Operation stage by the operators, planners and maintainers to review the maintenance requirements

Position	Responsibility
Manager - Strategic Asset Management (SAM)	Procedure owner
Maintenance Strategy Leader – SAM	Procedure development and review
Planners, Designers, Contractors & Operators	Procedure implementation
Management System Administrator	Policy publishing (in BMIS); initiating scheduled policy review cycles and incorporating of amendments

3.3. References

Document type	Title
Legislation	Occupational Health & Safety Act
Other documents	US MIL-HDBK-338B, Electronic Reliability Design Handbook

4. Document control

Procedure title: Reliability Block Diagram procedure		
Effective date: 24-09-2010	**Review Period:** As Required	**Registered file:** N/A
BMIS file name: AMQ0036		
Procedure Owner	Manager, Strategic Asset Management (SAM)	
Prepared by:	SAM - Maintenance Strategy Leader	
Approved by:	SAM - Asset Strategy Manager Wastewater	