RTAMO verification

Report for: Click here to enter text.

Name of client: Internal

Report no.: Document no.

Project no.: Project no.

Revision no.: 1

22 May 2018

Lloyd's Register

Document control

Revision history

Revision No.	Date	Revision
1.0		

List of abbreviations

Abbreviation	Description

Executive summary

The RTAMO software is a suite of modules which allow a user to optimise maintenance tasks. Within RTAMO there are two modules which calculate maintenance intervals (cost module and target module). The cost module allows the user to calculate the maintenance interval at minimum cost. The target module allows the user to identify the maintenance interval which will achieve a specified availability or reliability. This report looks at the theory behind the RTAMO software and verifies the results.

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RTAMO Verification

1. RTAMO target module

If the chosen inspection interval for a component / device is too frequent then effort is wasted with unnecessary work. However, if the chosen inspection interval for a component / device is too long then the component / device could fail between inspections. Thus being able to define the correct inspection interval for a component / device for a given required availability is obviously useful.

The RTAMO target module allows the user to define the ideal inspection interval for a component / device. The user needs information on failure rate and repair time. The user can select to use either reliability or availability as targets. From this an ideal inspection interval is defined. As with other RTAMO modules a sensitivity analysis is carried out so that the user can see a range of suitable inspection intervals within the parameters that have been set (e.g. failure rate +/- 25%, repair time +/- 25% and +/- 25% inspection interval).

1.1 Target module – Reliability

The equation to determine the ideal inspection interval can logically be a function of target reliability and failure rate. Obviously if the failures of the component / device follow a probability distribution then this will form a function of the calculation of the inspection interval. For a constant failure rate the reliability can be given by the following series (see ref [1])

Probability of failure on Demand = $$\frac{\lambda T}{2!} - \frac{(\lambda T)^2}{3!} + \frac{(\lambda T)^3}{4!} - \ldots$$

If the higher order terms are considered to be negligible the equation above could be approximated to

$$\frac{\lambda T}{2}$$

Where λ = failure rate

And T = inspection interval

This simple equation can be re-arranged to determine the inspection interval. However, it should be understood that this is an approximation and the validity of the assumptions need to be corroborated. To reiterate the assumptions are:

i. constant failure rate

ii. higher order terms are considered to be negligible

Looking at the first assumption collection of failure information is obviously difficult. Often the collected information does not allow a probability distribution to be derived. Thus assuming a constant failure rate is reasonable and has been proposed by others in the absence of relevant data (see ref [2]).

The contribution of higher order terms was reviewed by looking at the first 5 terms in several examples. It was found that they contributed less than 10%.

A more accurate model would be

$$R = -\frac{1}{\lambda t}\left(e^{-\lambda t} - 1\right)$$

This ignores the expansion of the terms into a series and hence is more accurate.

1.2 Target module – Availability

Availability can be seen to be a function of repair time, inspection time and failure rate. The equation to determine the availability is given by the following equation (see equation 2.10 ref [3]):

$$A = \frac{1-e^{-LT_2}}{L[T_2+T_c+T_r(1-e^{-LT_2})]}$$

Where :

L = failure rate of component

T_2 = Time interval for tests

T_c = Inspection time

T_r = Repair time

This equation is based on the following assumptions:

a. Failure will be detected when tested;

b. No false alarms occur during test;

c. The system will not fail during a test; and

d. Failures have an exponential distribution.

If the first three of these assumptions are not true then ref 3 gives other equations that can be used to determine availability. But, for most instances these assumptions seem reasonable. The validity of the last assumption has been discussed above.

1.3 Verification of reliability model

Using the simplified formula outlined above the following data was used as inputs:

Reliability	**Unreliability**	λ
0.9	0.1	0.0063

Table 1.3 -1

This data came from the RTAMO case "RTA-MAI-INS-F&G-002". The data was put into an excel spreadsheet. This gave a result of 31.74 months in the excel spreadsheet which compares with the RTAMO value of 33.62 months.

The above was repeated for the RTAMO case "RTA-MAI-INS-F&G-003" the following data was used as inputs:

Reliability	Unreliability	λ
0.9	0.1	0.0104

Table 1.3 -2

This gave a result of 19.230 months in the excel spreadsheet which compares with the RTAMO value of 20.23 months.

A third case was also reviewed "RTA-MAI-INS-F&G-004" the following data was used as inputs:

Reliability	Unreliability	λ
0.9	0.1	0.0015

Table 1.3 -3

This gave a result of 133.3333 months in the excel spreadsheet which compares with the RTAMO value of 144.24 months.

1.4 Verification of availability model

Using the formula outlined above a spreadsheet was created using the following data as inputs:

Variable	Value
lambda	0.0056
Time to repair (hours)	48
Time to inspect (hours)	4
Time to repair (months)	0.066667
Time to inspect (months)	0.005556
Target availability	0.9

Table 1.4 -1

For a range of test intervals the following plot was created:

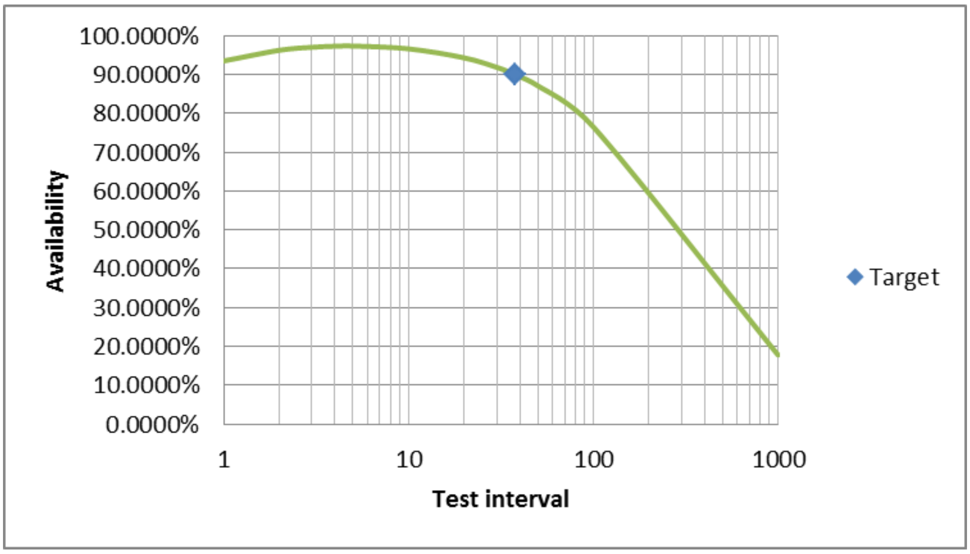

Chart 1.4 - 1

As can be seen for an availability of 90% the test interval is around 35 months. This is of course very approximate. The data above was taken from the RTAMO case "RTA-MAI-INS-F&G-001 " which gave the test interval as 38.47 months for an availability of 90%. The spreadsheet gave 90.0354% for a test interval of 37.5 months. The error between the RTAMO value and the Excel value is probably due to rounding errors. But, the error is not that significant.

Using the formula and spreadsheet outlined above the following data was used for a second verification:

Variable	Value
lambda	0.0104
Time to repair (hours)	48
Time to inspect (hours)	4
Time to repair (months)	0.066667
Time to inspect (months)	0.005556
Target availability	0.9

Table 1.4 -2

For a range of test intervals the following plot was created:

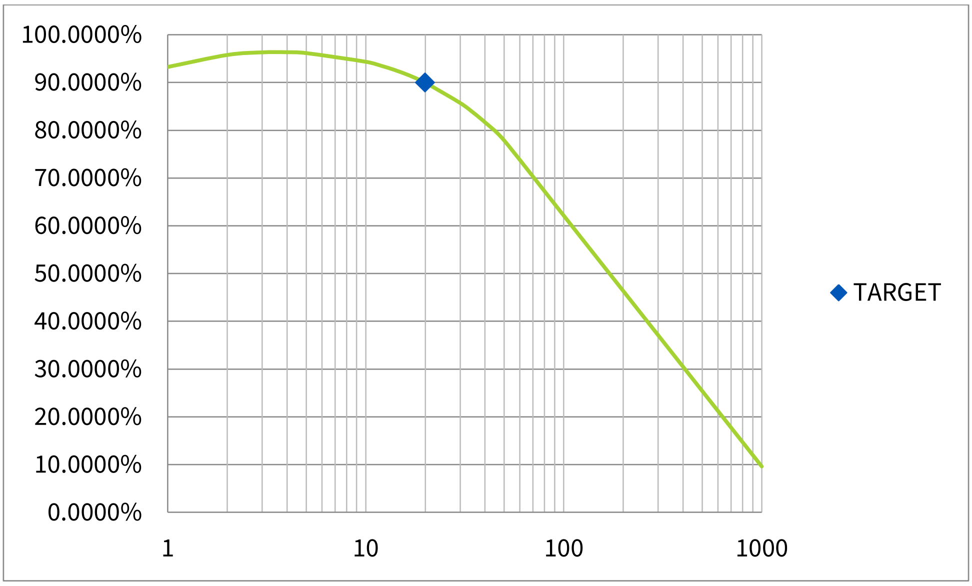

Chart 1.4 - 2

As can be seen for an availability of 90% the test interval is just under 20 months (19.955). The same date was used in RTAMO which gave the test interval as 20.42 months for an availability of 90% (see screen shot below). The spreadsheet gave 90.0001% for a test interval of 19.955months. The error between the RTAMO value and the Excel value is probably due to rounding errors. But, again the error is not that significant.


Intervals
Current Interval
6.00
months
Optimum Interval
20.42
months
Selected Interval
9.00
months
Target v Interval
100%
95%
90%
80%
0%
1
10
100
1000
Availability
Target
Current Interval
Optimised Interval
Selected Interval

Fig 1.4 – 1

2. RTAMO cost module

The RTAMO cost module uses the time delay model which will be outlined in more detail below.

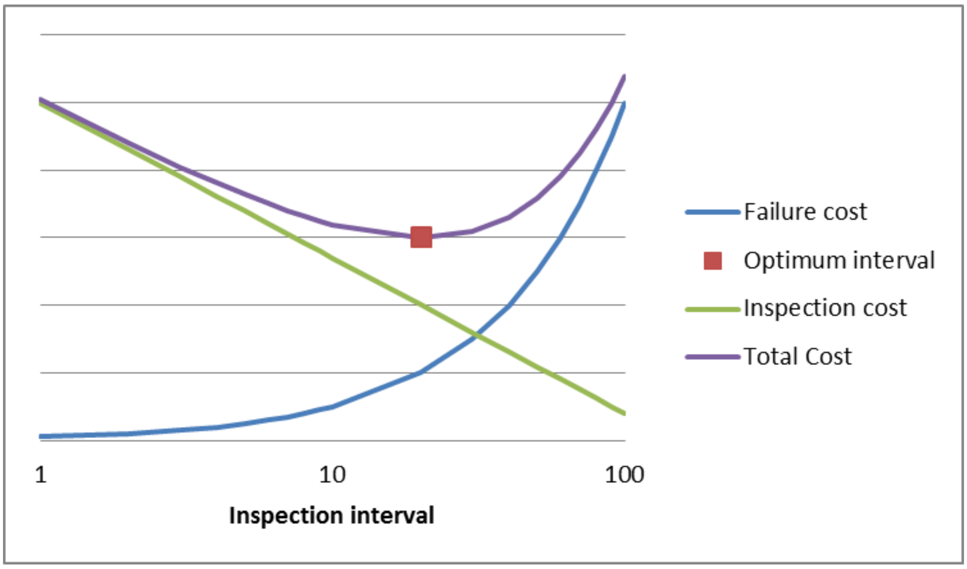

Fig 2.0-1

The delay time model is a mathematical model which aims to minimize costs by optimizing the inspection interval. The figure above plots cost of inspection which varies with inspection interval and cost of failure which also will vary with inspection interval. Total cost is the sum of failure and intervention. The plot further shows the optimum inspection interval will be when total cost is minimized. The delay time model has been outlined in several papers. Some of the papers on this are listed below:

Neil Arthur paper (ref [4]) - Outlines an application of the delay time model in selecting time intervals for maintenance tasks in offshore oil and gas industry. One example sited has a 83% reduction in inspection costs.

Philip A Scarf paper (ref [5]) - This paper outlines the same method as the paper by Neil Arthur. However, one of the equations is different. But, the solution for inspection interval is the same. The paper notes that if "the rate of occurrence of defect arrivals is increasing then the optimal inspection frequency must decrease with age"

R.D. Baker and W. Wang paper (ref [6]) - This paper discusses developing the "time delay" method. For example when failure rates increase or decrease with the age of the machine. This is further explored in another paper by R.D. Baker and W. Wang paper (ref [7]). Where an extension of the simple delay time model for dealing with the optimum maintenance interval for systems with wear out failures is discussed.

The simple delay time method has the following assumptions:

1. Inspection costs are less than failure costs. If the impact (and therefore the cost) of a failure of a component is not significant then it might be easier to run to failure. In other words if the inspection costs are NOT less than failure costs then it is not worth doing the inspection. But, these failures will be in the minority and for most failures it is worth doing some maintenance task to prevent the failure.

2. Inspections will find defects. It would be hoped that the maintenance tasks chosen will identify failures. This would normally be the case if all the failures and the associated mitigation tasks have been identified.

3. Repair times are negligible. If repairs can be carried out before a failure has caused significant consequences the repair time should be relatively short.

4. The simplified delay time model assumes defects are randomly distributed. Moubary (ref 2) in his paper comments that in the absence of detailed information assuming random failures is a conservative assumption. The NASA RCM guide (ref[8]) reports on different failure distribution patterns across several studies it states that "random failures are between 77 and 92 percent of the total failures".

2.1 The formulas used in the time delay model

To be able to calculate the optimum maintenance task interval certain information is needed such as:

a. Cost of inspection and repair (This is c1 in the formulas below)

b. Cost of failure (This is c2 in the formulas below)

c. Mean Time Between Failures (MTBF)

The formulas are for the delay time model are outlined in the paper by N Arthur (ref 4) which are repeated below for easy reference:

The defects are assumed to be a Poisson process with a defect arrival rate of α with exponentially distributed delay times with a mean 1/γ.

$$\breve{\alpha} = \frac{n}{T}$$

Where n = total number of defects observed in time, T.

In other words $\breve{\alpha} = {}^{1}/_{MTBF}$

$$\sum_{i=1}^{k} \frac{\breve{\gamma}\tau_i}{e^{\breve{\gamma}\tau_i} - 1} + \sum_{i=1}^{n-k} \frac{\breve{\gamma}\Delta}{e^{\breve{\gamma}\Delta} - 1} = n - k$$

Where:

k failures are observed at time τ_i

n-k defects are found at inspections

Δ = inspection interval

$\breve{\alpha}$ and $\breve{\gamma}$ are estimates of α and γ respectively

The optimum inspection interval, Δ^*, satisfies the expression:

$$(1 + \gamma\Delta^*)e^{-\gamma\Delta^*} = 1 - \frac{\gamma c_1}{\alpha c_2}$$

The paper by Scarf (ref 5) gives helpful formula for cost per unit time:

$$D = \frac{c_1}{\Delta} + \alpha c_2(1 - P_D)$$

Where $P_D = {(1 - e^{-\gamma\Delta})}/{\gamma\Delta}$

2.2 Alternatives to the simple time delay model

If there is sufficient detail on failure distribution patterns it might be useful to incorporate this data. Methods have been outlined which extend the simple delay time model (see for example ref 7). However, a simpler approach would be to use the method outlined in (ref[9]). This method is similar to the delay tome model in that total cost is the sum of maintenance costs and failure costs. And the optimum maintenance cost is when the total cost is minimized. The optimum interval is given by:

$$T = m\theta + \delta$$

Where

m = is a function of the ratio of the failure cost to the preventive maintenance cost and the value of the shape parameter.

θ = the scale parameter of the Weibull distribution

δ = the location parameter of the Weibull distribution

2.3 Verification of RTAMO cost module

Using the cost per unit time equations given above it is possible to derive the costs for a range of time intervals. It is then possible to iterate towards the minimum cost. The following examples came from (ref 3).

a. Motor Bearing Analysis

b. Gearbox Bearing Analysis

The results from RTAMO are shown below for the Motor Bearing Analysis

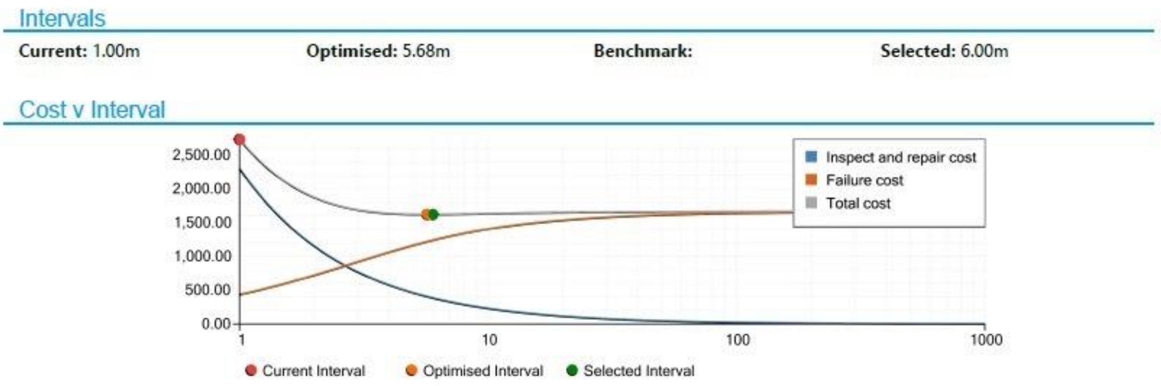

Fig 2.3-1

Using the same data as RTAMO a spreadsheet was created for the Motor Bearing Analysis. The plot is shown below:

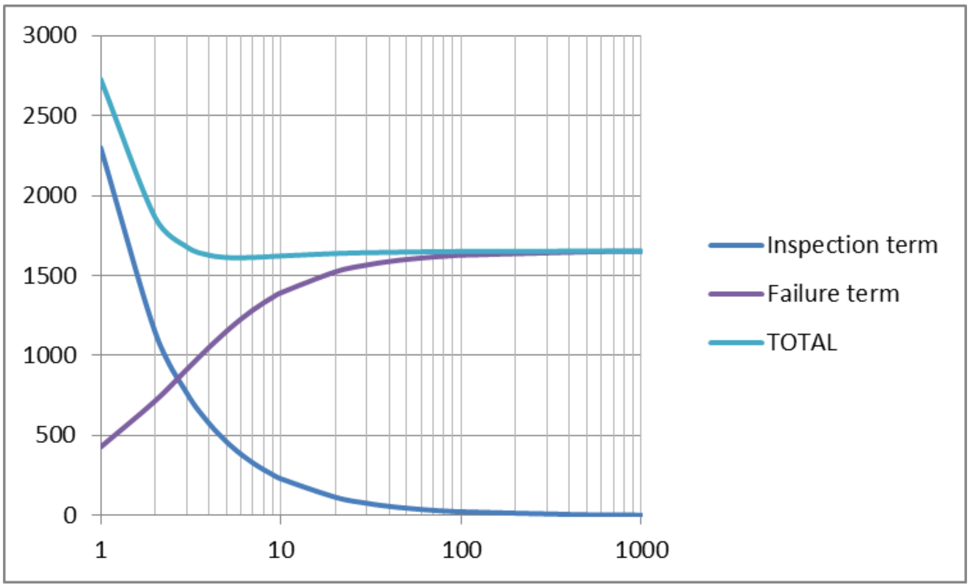

Fig 2.3-2

The minimum cost was found as being £1,610.96 at 5.8 months. This compares with the value from RTAMO of 5.68 months. The error is probably due to rounding errors.

The results from RTAMO are shown below for the Gearbox Bearing Analysis

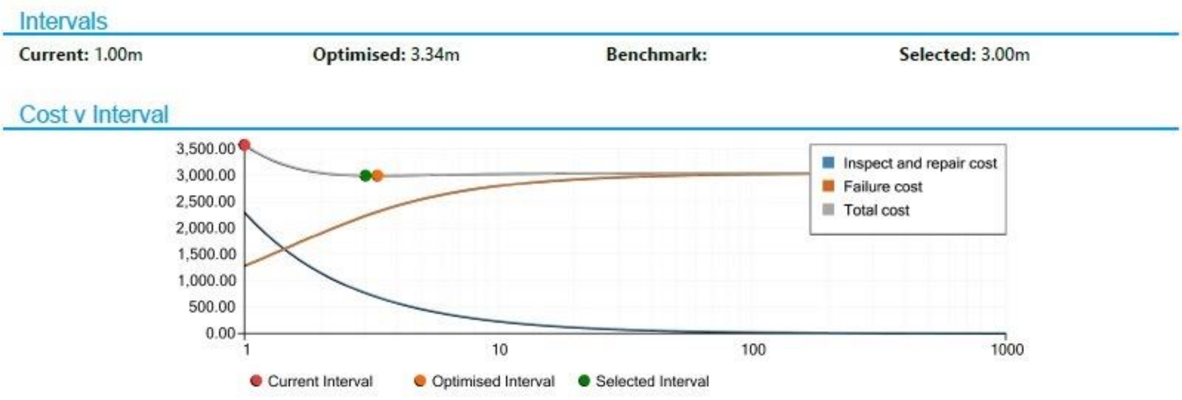

Fig 2.3-3

Using the same data as RTAMO another spreadsheet was created for the Gearbox Bearing Analysis. The plot is shown below:

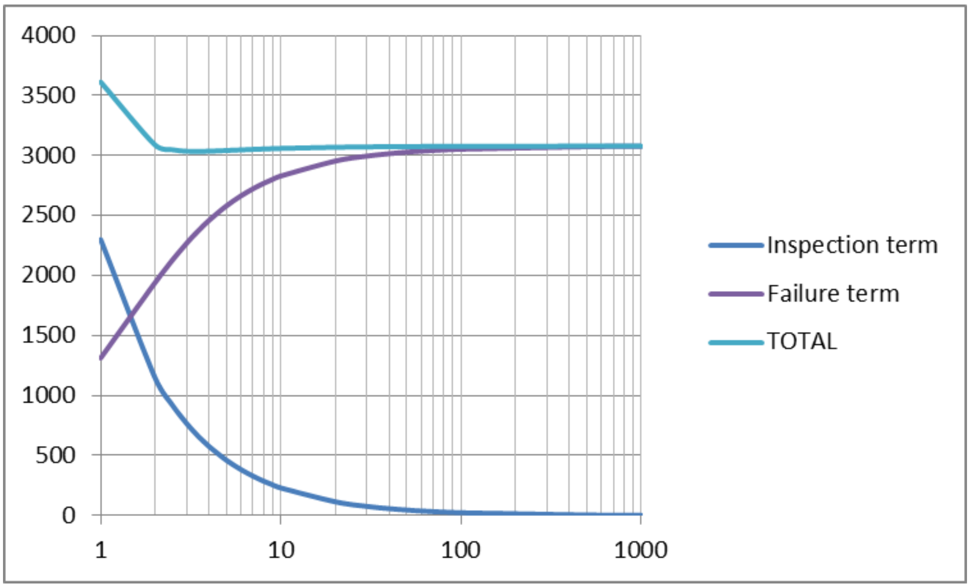

Fig 2.3-4

The minimum cost was found as being £3,034.31 at 3.4 months. This compares with the value from RTAMO of 3.34 months. The error is probably due to rounding errors.

3. Summary / Conclusions

The RTAMO software is a suite of modules which allow a user to optimise maintenance tasks. Within RTAMO there are two modules which calculate maintenance intervals (cost module and target module). This report has reviewed the theory behind the RTAMO software cost and target modules. Then the output has been verified by comparing results from RTAMO with simple spreadsheets. There was some difference in the results but the difference was not significant in practical terms.

References

[1] "Methods for determining and processing probabilities" Publication Series on Dangerous Substances 4 (PGS 4)
[2] John Moubray "Maintenance management – new paradigm"
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[4] N Arthur, "Optimization of vibration analysis inspection intervals for an offshore oil and gas water injection pumping system" , *Proc. IMechE Vol. 219 Part E: J. Process Mechanical Engineering*
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[7] R.D. Baker and W. Wang, "Developing and Testing the Delay-Time Model" J. Opi Res. Soc. Vol. 44, No. 4, pp. 361-374
[8] RCM GUIDE -RELIABILITY-CENTERED MAINTENANCE GUIDE For Facilities and Collateral Equipment - National Aeronautics and Space Administration, September 2008
[9] "Using statistics to schedule maintenance" Engineered Software, Inc. 1999

Appendix A Click or tap here to enter text.

A.1 Appendix 2

A.1.1 Appendix 3

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