A Testability-Dependent Maintainability-Prediction Technique

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SUMMARY & CONCLUSIONS

Existing maintainability prediction techniques for electronic systems do not directly take into account some important measures of testability. This paper outlines a new mean-time-to-repair (MTTR) prediction technique which is a modification of MIL-HDBK-472 procedure V. The modifications directly relate testability characteristics to maintainability parameters and introduce the influence that different maintenance and repair philosophies have on MTTR. A computerized version of this technique was developed and will also be discussed. Future plans include proposing this technique for inclusion in one of the next revisions of MIL HDBK-472.

INTRODUCTION

The technique outlined in this paper improves on existing maintainability prediction models and relates maintenance and diagnostic parameters to the principle measure of maintainability, mean-time-to-repair (MTTR). Models documented in MIL-HDBK-472 "Maintainability Prediction", were used as a basis for this development. Procedure V of MIL-HDBK-472 was modified to incorporate pertinent testability characteristics, concepts and parameters into the quantification of maintenance actions and maintainability task models.

Specific testability characteristics and concepts incorporated are the: fraction of faults isolatable/detectable, levels of ambiguity, opportunities for secondary fault isolation and troubleshooting concepts, which are pertinent to various levels of system indenture. These are combined with estimates relative to average time required to detect, isolate, disassemble, interchange, reassemble. checkout and start-up which are estimated relative to equipment type and maintenance philosophy.

If desired, this maintainability prediction technique allows for the inclusion of time associated with fault detection. Many maintainability prediction models do not include fault detection time as part of total MTTR. Equation Al in Appendix A of this paper Illustrates the method by which fault detection time is estimated. The modeler has the option of either segregating fault detection and isolation times or of including fault detection as part of fault isolation.

Six different maintenance philosophies are available for consideration when modeling a system. These are explained in detail below. The prediction methodology is based on the assumption that electronic systems are ordered into particular ambiguity groups of replaceable units for the purpose of test, fault isolation, and maintenance. Each ambiguity group is treated as a separate system entity. The portion of time that each ambiguity group contributes to the overall estimated system mean-time-to-repair is computed on a failure rate weighted basis. The contribution of each group is evaluated by taking into account the maintenance philosophy that would be applied in the event of a failure in that group. For example, for each ambiguity group the modeler must determine whether primary fault isolation only or both primary and secondary fault isolation are applicable. Does the removal and replacement policy call for replacing all units within the group at once or to replace the individual units one by one? Is removal at random from the group, or is it based on failure rate or maintenance ease consideration? Are the units or groups all equally accessible? Is checkout performed on the individual units, on the system level, or on both?

The technique is applicable to ground, shipboard and avionic electronics at the organizational, intermediate, and depot levels of maintenance. A prediction can be made on the equipment level, line replaceable unit (LRU) level, or shop replaceable unit (SRU) level.

Assumptions

The following assumptions and stipulations apply to the prediction procedure presented here:

1. Only one failure at a time is considered.
2. Failure rates experienced are in the same proportion to those predicted.
3. Maintenance is performed in accordance with established maintenance procedures.
4. Maintenance is performed by personnel possessing the appropriate skills and training.
5. Inputs to the prediction model are obtained through time standards, prior history, engineering Judgment, or through other analysis techniques. For example. the required testability parameters are obtainable from existing inherent testability analysis techniques.

Notation

The notation used throughout this paper is fully explained as it appears.

MODEL STRUCTURE

The equation for calculating the predicted mean-time-to-repair (MTTR) of a system or equipment is:

$$MTTR = TDET + \sum_{j=1}^{n} TFC_j \qquad (1)$$

where:
TDET = The average time required to detect a fault in the given system or equipment. The equation for computing TDET is found in Appendix A of this paper.

n = The number of ambiguity groups in the given system or equipment.

TFC, = The average fault correction time associated with the jth ambiguity group. The general equation for computing TFC) follows. The equation for TFC) and models for the maintenance task times contained within the equation are modified for each maintenance philosophy available for selection. The six different maintenance philosophies are described below. Detailed models for TFC) and the maintenance task times are found in reference 2. For illustrative purposes, Appendix A contains the detailed models for maintenance philosophy # 3.

$$TFC_j = \frac{\lambda_j}{\lambda_T}[T_{pp(j)} + T_{pi(j)} + T_{ps(j)} + T_{si(j)} + T_{sr(j)} + T_{d(j)} + T_{cu(j)} + T_{i(j)} + T_{s(j)} + T_{r(j)} + T_{cs(j)} + T_{st(j)}] \qquad (2)$$

where:

λ_j =- The <u>serial</u> <u>failure</u> <u>rate</u> of all units comprising the jth ambiguity group.

$$\lambda_T = \sum_{j=1}^{n} \lambda_j$$

$T_{pp(j)}$ = Time to prepare for primary fault isolation to the jth ambiguity group.

$T_{pi(j)}$ = Time to perform primary fault isolation to the jth ambiguity group.

$T_{ps(j)}$ = Time to prepare for secondary fault isolation to a subgroup of the jth ambiguity group.

$T_{si(j)}$ = Time to perform secondary fault isolation to a subgroup of the jth ambiguity group.

$T_{sr(j)}$ = Time to obtain all necessary spares.

$T_{d(j)}$ = Time to perform disassembly to gain access to the jth ambiguity group or to a subgroup of it.

$T_{sn(j)}$ = Time required to perform checkout on units in the jth ambiguity group or on units in a subgroup of it.

$T_{;(j)}$ = Time required to interchange the jth ambiguity group, a subgroup of it, or the faulty unit in the group or subgroup.

$T_{s(i)}$ = Time required to align the faulty unit in the jth ambiguity group or in a subgroup of it.

$T_{r(j)}$ = Time required to perform reassembly after removing and replacing the jth ambiguity group, a subgroup of it, or the faulty unit in the group or subgroup.

$T_{ds(j)}$ = Time required to checkout the entire system after maintenance is performed.

$T_{st(j)}$ = Time required to start-up/energize the system in order to perform Tom or to restore the system to operational use.

MAINTENANCE PHILOSOPHIES

The term "maintenance philosophy" refers to the method by which fault isolation, repair, and replacement is accomplished. When performing a maintainability prediction, the appropriate maintenance philosophy should be assumed for each ambiguity group of replaceable units within the system. Each maintenance philosophy dictates a method by which the faulty unit is to be isolated, checked out, and removed and replaced. Each maintenance philosophy has its own set of analytical models for computing maintenance task time impact. A number of factors are taken into account for each philosophy. Six different generic philosophies were developed and can be applied in any combination to the groups making up a system or equipment. They are as follows.

<u>Philosophy 1</u>: Group removal and replacement with only primary fault isolation capabilities for the group. The entire ambiguity group would be removed and then replaced with a known good spare group. Philosophy 1 is appropriate for all cases of equipment assembly, it can be used whether or not units are directly accessible. Checkout is performed on the system level after the entire system is buttoned up and energized.

<u>Philosophy 2</u>: Group removal and replacement with both primary isolation used to perform isolation to a group and secondary fault isolation to reduce ambiguity of that group to a smaller subgroup of units within the group. Removal and replacement is accomplished the same way as in philosophy 1 except that it is for subgroups within the primary group of replaceable units. This philosophy is appropriate for all cases of equipment assembly. Checkout is performed on the system level after the entire system is buttoned up and energized.

<u>Philosophy 3:</u> Iterative removal and replacement by randomly selecting replaceable units from the identified group (using only primary fault isolation capabilities). One unit is pulled out at a time until the faulty unit in the group is discovered and replaced. There is no set pattern or order for removing and replacing the units. Philosophy 3 is limited in practicality to ambiguity groups containing units that are directly accessible.

The concept of random replacement would not be used in cases where some units are obstructed by others (since in most cases the obstructing units would obviously be pulled and tested first), or when significant failure rate or corrective maintenance time differences exist among units. Checkout may be performed on the individual units, on the system level, or on both.

Philosophy 4: Iterative removal and replacement by randomly selecting the replaceable units, after both primary and secondary fault isolation has taken place in the group.This is accomplished the same way as in philosophy 3 except that here it is for subgroupswithin the primary group of replaceable units. Philosophy 4 is limited to ambiguity groups containing units that are directly accessible as in philosophy 4. Checkout may be performed on the individual units, on the system level, or on both.

Philosophy 5: Iterative removal and replacement by failure rate weighted selection of the replaceable units, with only primary fault isolation capabilities for the group. One unit is pulled out at a time until the faulty unit in the group is discovered. In this case, the units are pulled out in a specific order according to the magnitude of their failure rates. The unit with the highest failure rate is removed and replaced first, the unit with the second highest failure rate second, and so on down the line until the faulty unit in the group is discovered and replaced. This philosophy is appropriate for all cases of equipment assembly where accessibility is not a major problem such that practicality would dictate that the obstructing units be pulled and tested first. Checkout may be performed on the individual units, on the system level, or on both.

Philosophy 6: Iterative removal and replacement based on the fault correction time associated with the replaceable units of the group. Primary fault isolation is only considered (to a group of units). One unit is pulled out at a time until the faulty unit in the group is discovered. In this case, the units are pulled out in a specific order according to the magnitude of their individual active action fault correction times. Individual active action fault correction time here refers to the sum of the units disassembly, interchange, reassembly and alignment times. The unit in the group with the lowest active action fault correction is to be removed and replaced first, the unit with the next lowest active action fault correction time is to be removed and replaced second, and so on until the faulty unit in the group is discovered and replaced. This maintenance philosophy is appropriate for all cases of equipment assembly. Checkout may be performed on the individual units, on the system level, or on both.

The choice of the maintenance concept affects computations for fault correction times accordingly. This can be seen in more detail in Appendix A where the various formulae are shown for maintenance philosophy # 3.

COMPUTER PROGRAM

An automated version of this technique has been developed in-house at the Rome Laboratory. TIME - the Testability Interfaced Maintainability Estimator is available for use in a vax/vms operating system environment. TIME is available to DoD agencies and their contractors through the signature and approval of a statement of terms and conditions for release of Air Force owned or developed software. For more information, contact the authors of this paper.

APPENDIX A MODELS/EQUATIONS

Due to space limitations, models for all six maintenance philosophies are not presented here. The equation for calculating Average Fault Detection Time (TDET) is shown and explained. TDET is used directly in the computation of MTTR (see equation 1). Also shown is the equation for computing Primary Fault Isolation Time ($T_{pi(j)}$). $T_{pi(j)}$ is computed the same way for all six maintenance philosophies. The detailed equations for maintenance philosophy. # 3 are presented to provide an example of what the maintenance task time models look like. Reference 2 includes all models.

Average Fault Detection Time (TDET)

$$TDET = \sum_{j=1}^{I} \frac{\lambda_j}{\lambda_s}[FFD_j FDTA_j + (1 - FFD_j)\, FDTU_j] \qquad (A1)$$

where:

I = The # of replaceable units in the system/equipment.

λ_j = Failure rate of the jth replaceable unit.

$$\lambda_s = \sum_{j=1}^{I} \lambda_j \qquad (A2)$$

FFD_j = Fraction of Faults Detectable in the jth replaceable unit through use of acceptable defined means.

$FDTA_J$ = The average time required to detect a fault in the jth replaceable unit through use of acceptable defined means.

$FDTU_j$ = The average time required to detect a fault in the jth replaceable unit through use of other than acceptable defined means.

Primary Fault Isolation Time To)())

$$T_{pi(j)} = FFI_j FITA_j + (1 - FFI_j)\, FITU_j \qquad (A3)$$

where:

FFI_j = Fraction of faults isolatable in the jth ambiguity group through use of acceptable defined means.

$FITA_j$ = The average time required to isolate a fault through the use of acceptable defined means when the fault occurs in the jth ambiguity group.

FITU, - The average time required to isolate a fault through the use of unacceptable defined means when the fault occurs in the jth ambiguity group.

Equations for Maintenance Philosophy # 3

For this maintenance philosophy, the equation for group fault correction time takes the form:

$$TFC_j = \frac{\lambda_j}{\lambda_T}[T_{pp(j)} + T_{pi(j)} + T_{sr(j)} + T_{d(j)} + K_1 T_{cu(j)} + K_2 T_{i(j)} + T_{a(j)} + T_{r(j)} + K_3 T_{cs(j)} + K_3 T_{sc(j)}] \quad \text{(A4)}$$

S = The average number of events (pulls, etc.) required until the

q = The size of the jth ambiguity group.

$$S = \frac{1 + q}{2} \quad \text{(A5)}$$

faulty unit is discovered in the jth ambiguity group (of size q) when each event takes place sequentially.

K_j =

1 If each unit can be checked for failure separately at that maintenance level either while in the equipment or through use of a tester after removal.

0 If each unit cannot be checked separately at that maintenance level. To perform checkout the entire system must be buttoned up and energized.

K_t -

1 If each unit can be checked separately at that maintenance level within the equipment.

S If each unit cannot be checked separately at that maintenance level within the equipment.

K_3 =

1 If each unit can be checked separately at that maintenance level (within or after removal from equipment).

S If each unit cannot be checked separately at that maintenance level, but must be reinserted into the equipment and an equipment function test performed to ascertain unit status.

$T_{pp(j)}$ = A predicted or estimated value for the expected time required to prepare the system for primary fault isolation to the jth ambiguity group.

$T_{pi(j)}$ = Computed as above (equation A3).

$T_{sr(j)}$ = A predicted or estimated value for the expected time required to obtain all necessary spares at once.

$T_{d(j)}$ = The expected time required for disassembly to gain access to the faulty unit in the jth ambiguity group.

If the same disassembly action(s) gives access to all units in the jth ambiguity group then:

$$T_{d(j)} = (1-K_1) S T_{d(1,j,q)} + K_1 T_{d(1,j,q)} \quad \text{(A6)}$$

In this case $T_{d(1,j.q)}$ is equal for all q units in the group.
If independent disassembly is required for each unit, $T_{d(1,j,q)}$ may or may not be equal for all q units in the group, then:

$$T_{d(j)} = (1 - K_1) \frac{S}{q}\sum_{l=1}^{q} + K_1 \sum_{l=1}^{q} \frac{T_{d(l,j,q)}}{q} \quad \text{(A7)}$$

$T_{d(1.j,q)}$ = The time required to perform disassembly to gain access to the lth unit in the jth ambiguity group, which is of size q.

$$T_{cu(j)} = S \frac{\sum_{l=1}^{q} T_{cu(l,j,q)}}{q} \quad \text{(A8)}$$

$T_{1(j)}$ = An average estimated value of the time required to perform checkout on units in the jth ambiguity group, which is of size q.

$T_{ds((1,j,q)}$ = The time required to perform checkout on the lth unit in the jth ambiguity group, which is of size q.

$T_{1(j)}$ = An average estimated value for the time required to interchange the faulty unit in the jth ambiguity group, which is of size q.

$$T_{i(j)} = \frac{\sum_{l=1}^{q} T_{i(l,j,q)}}{q} \quad \text{(A9)}$$

$T_{1(1,j,q)}$ = The time required to interchange the lth unit in the jth ambiguity group, which is of size q

$T_{a(j)}$ = A failure rate weighted average value estimating the time required to align the faulty unit in the jth ambiguity group, which is of size q (assumes no realignment required in nonfailed q-1 units).

$$T_{a(j)} = \sum_{l=1}^{q} \frac{\lambda_l}{\lambda_j} T_{a(l,j,q)} \quad \text{(A10)}$$

$T_{a(1,j,q)}$ = The time required to align the 1th unit in the jth ambiguity group which is of size q.

λ_1 = The failure rate of the lth unit in the jth ambiguity group, which is of size q.

λ_1 = The failure rate of the jth ambiguity group.

$T_{r(j)}$= An average estimated value for the expected time required for reassembly after removing and replacing S units in the jth ambiguity group, which is of size q. Reassembly time is estimated the same way as disassembly time.

$T_{ds(j)}$ = A predicted or estimated value for the expected time required to checkout the entire system after removing and replacing ,the "faulty" unit in the jth ambiguity group after buttoning up and energizing the system.

$T_{st(j)}$ = A predicted or estimated value for the expected time required to start-up/energize the entire system in order to perform $T_{cs(j)}$) or to restore the system to operational use.

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Mr. Lyne is a member of the Reliability Engineering Branch of the Rome Laboratory. He has the responsibility for the application of data processing techniques to the development and evaluation of methods for prediction and demonstration of electronic parts and equipment reliability. Mr. Lyne has been employed at RL in the areas of R&M since 1961. He has developed a number of reliability and maintainability evaluation and analysis software packages and is the author of several reports. Mr. Lyne holds a BS in Math from Central Missouri State University and a MS in Systems Information Science from Syracuse University.