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METHODOLOGY FOR ESTIMATING MISSION AVAILABILITY AND RELIABILITY FOR A MULTIMODAL SYSTEM

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Reliability and Operational Availability estimation techniques are developed for systems having several modes of operation and whose Reliability and Operational Availability requirements have been set for a particular mission. An example of the application of these models is also included.

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METHODOLOGY FOR ESTIMATING MISSION AVAILABILITY AND RELIABILITY FOR A MULTIMODAL SYSTEM

1. INTRODUCTION

Developmental Testing constraints sometimes require that a system be tested according to a profile that is different from the mission profile for which the system's reliability requirements were specified. For example, a surface to air missile system whose capabilities include movement, surveillance, and target engagement might, because of accelerated testing requirements, be tested extensively in the target engagement mode (in order to assure that all engagement performance requirements are met) and only minimally in the movement and surveillance modes (Figure 1). However, in the tactical mission profile, surveillance functions might encompass the majority of the mission (Figure 2). It would be incorrect to compare the system availability and mean time between failure (MTBF) demonstrated in the test scenario to the requirements specified for the tactical scenario. This is due to the fact that the engagement mode of operation is more complex and therefore, many more failures associated with it would be expected. Although the rate of failure detections experienced in the engagement mode of the test scenario would remain the same as in the tactical one, the amount of time spent in the engagement mode of the tactical scenario is much less than the test scenario which means that a smaller number of engagement mode failures should be expected on a per mission basis. In this situation, it can be seen that evaluating the system MTBF based on the test scenario would understate the MTBF value. In order to determine if the system meets its reliability specifications, the reliability of the system in the tactical mission must be evaluated from data collected in a test scenario which is entirely different.

This report will develop a methodology that can be used to evaluate a system which is operated in a series of n modes with the i^{th} mode being defined as having a certain number of subsystems operating in it and mode i + 1 consists of mode i subsystems plus additional subsystems operating. That is, subsystems operating in mode i are nested in mode i + 1 (Figure 3).

In addition, the corrective maintenance time and logistics delay time that will be seen in the field are not always known at the time of development testing, either because maintenance procedures are not fully specified at that time or for expediency's sake contractor personnel perform maintenance normally done by the soldier. This report allows for the insertion of maintainability parameters derived from other sources i.e. maintainability demonstrations, logistics simulations, etc.

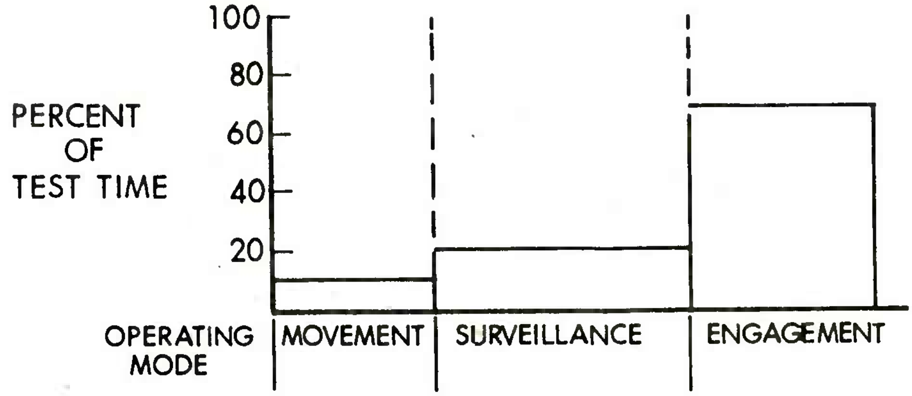

Figure 1. Possible Test Scenario.

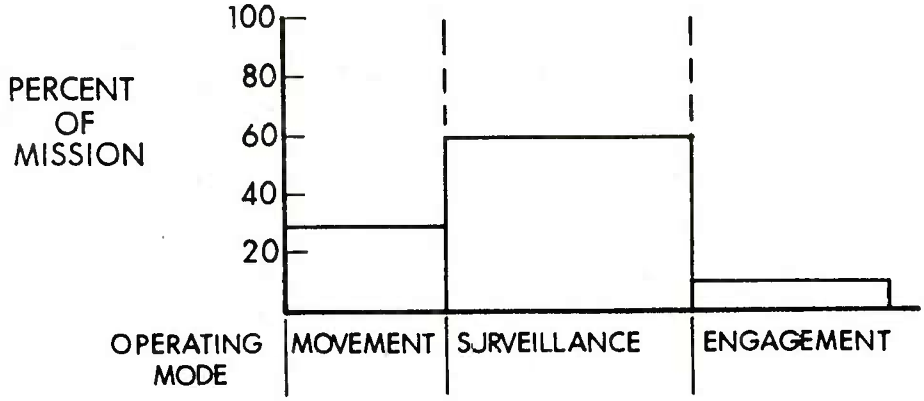

Figure 2. Tactical Mission.

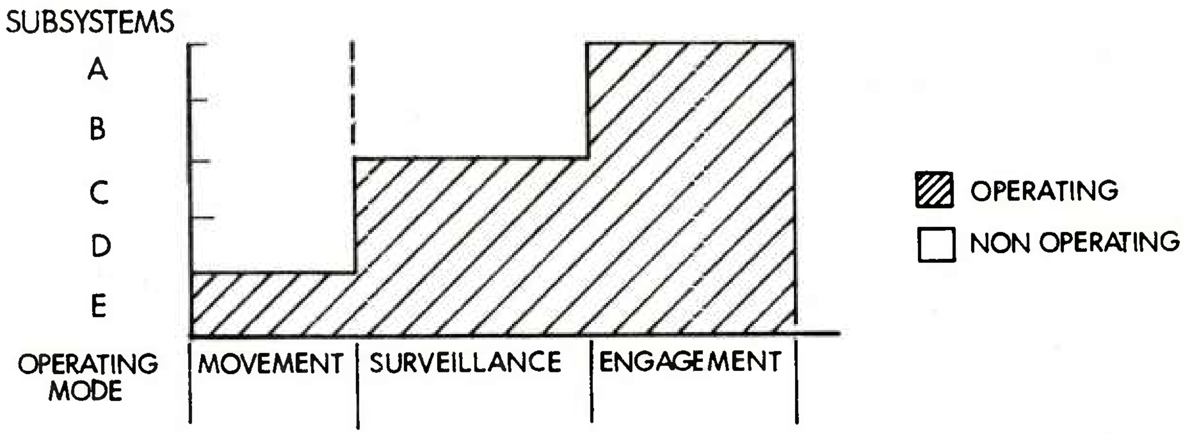

Figure 3. System Operation.

2. DERIVATION OF EQUATIONS

The first step in deriving MTBF and operational availability estimates is to begin with the basic definition of operational availability from which we will derive the mission profile MTBF. It is assumed that estimates of failure rates or MTBFs for each of the operating modes are available. The basic definition of operational availability [1] is given by

$$A_o = \frac{\text{UPTIME}}{\text{UPTIME} + \text{DOWNTIME}} \tag{1}$$

Let us define

k_i = time spent in mode i as specified by desired scenario

$MTBF_i$ = mean time between failure detections of operating mode i (derived from test scenario)

MDT_i = mean downtime including logistics downtime in operating mode i (either specified in tactical scenario or determined by other means - maintainability demonstration, simulation, etc.) If these individual values cannot be determined, use MDT for all values of MDT_i.

MDT = Overall system mean downtime calculated as

$$\frac{\sum \left(\frac{k_i}{MTBF_i + MDT_i}\right) MDT_i}{\sum \left(\frac{k_i}{MTBF_i + MDT_i}\right)} \quad \text{if } MDT_i\text{'s are available.}$$

Otherwise, use an overall MDT from test, simulation, etc.

Now, total time is uptime plus downtime, or uptime equals total time minus downtime. From the definitions it may be noted that total mission time, T, is given by

$$T = \sum_i k_i$$

In determining downtime, it may be noted that

$$\frac{k_i}{MTBF_i + MDT_i}$$

is the expected number of failures in operating mode i and multiplying this by the expected downtime for mode i, MDT_i, gives the expected downtime in mode i. Therefore,

$$\text{UPTIME} = \sum_i \left[k_i - \left(\frac{k_i}{MTBF_i + MDT_i} \right) MDT_i \right] \qquad (2)$$

and thus, it follows that

$$A_o = \frac{\sum_i \left[k_i - \left(\frac{k_i}{MTBF_i + MDT_i} \right) MDT_i \right]}{T} \qquad (3)$$

It may be shown that A_o is a weighted average of the mode availabilities. On rearranging (3), we have

$$A_o = \frac{\sum_i \frac{k_i \left(MTBF_i + MDT_i \right) - k_i \; MDT_i}{MTBF_i + MDT_i}}{T}$$

$$= \frac{1}{T} \sum_i \frac{k_i MTBF_i}{MTBF_i + MDT_i}$$

$$= \sum_i \left(\frac{k_i}{T} \right) \left(\frac{MTBF_i}{MTBF_i + MDT_i} \right)$$

$$= \sum_i W_i \; A_{oi}$$

Now, we may also view A_o as

$$A_o = \frac{MTBF_{sys}}{MTBF_{sys} + MDT} \qquad (4)$$

where $MTBF_{sys}$ is the system MTBF. Equating (3) and (4) we have

$$\frac{MTBF_{sys}}{MTBF_{sys} + MDT} = \frac{\sum_i \left[k_i - \frac{k_i}{MTBF_i + MDT_i} \; MDT_i \right]}{T}$$

Rearranging and solving for system MTBF yields

$$MTBF_{sys} = \frac{T}{\sum_i \frac{k_i}{MTBF_i + MDT_i}} - MDT \qquad (5)$$

3. EXAMPLE OF APPLICATION

Consider a surface to air missile system which is characterized by three modes of operation - travel, surveillance and target engagement. A system MTBF requirement of 100 hours and an operational availability requirement of 0.90 have been set. The typical 24 hour scenario for which the requirements were set is as follows:

	Time (hours)
Travel	1
Surveillance	21
Engagement	2

During the test program the following failure detection rates were observed:

	$MTBF_i$
Travel	1000
Surveillance	500
Engagement	50

Overall mean time to repair was determined to be 6 hours and mean logistics delay time was found by a logistics simulation to be 14 hours. No other information is available.

The question is then, has the system demonstrated requirements? Using equation (5) we have

$$MTBF_{sys} = \frac{T}{\sum \frac{k_i}{MTBF_i + MDT_i}} - MDT$$

Therefore $MTBF_{sys} = \dfrac{24}{\dfrac{1}{1000 + 20} + \dfrac{21}{500 + 20} + \dfrac{2}{50 + 20}} - 20$

$MTBF_{sys} = 323$ hrs.

Using Equation 3, we have:

$$A_o = \frac{\sum_i \left[k_i - \left(\frac{k_i}{MTBF_i + MDT_i} \right) MDT_i \right]}{\text{TOTAL TIME IN MISSION}}$$

$$A_o = \frac{\left[1 - \left(\frac{1}{1000 + 20}\right) 20\right] + \left[21 - \left(\frac{21}{500 + 20}\right) 20\right] + \left[2 - \left(\frac{2}{50 + 20}\right) 20\right]}{24}$$

$A_o = .94$

Therefore, the system requirements have been demonstrated.

REFERENCE

1. AMCP 706-132, ENGINEERING DESIGN HANDBOOK, Maintenance Engineering Techniques, pp 4-12.

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