CHAPTER 10

DATA BASE CONSIDERATIONS

INTRODUCTION

Previous chapters of this text have presented descriptions of, and analytical techniques for, quantitatively assessing system suitability parameters - reliability, maintainability and availability. Topics discussed in these chapters included sample size, test hours, test article configuration, etc., all of which formulate the quantitative characteristics of the data base which supports our assessment.

In contrast, this chapter presents a discussion of qualitative data base characteristics. For example, it is important to conduct sufficient testing on any prototype system, but it is essential that a production decision be supported by a data base composed of production configuration test data. Also, a data base format must be structured before any actual testing is conducted to assure that the required information is collected during testing. Finally, the availability of a meaningful reliability data base, early in production, that reflects early deployment performance can be especially valuable from both a readiness and an economic viewpoint.

These and other qualitative characteristics must be considered on an a priori basis to assure that the data base under development can support the required assessment.

TEST EXPOSURE CONSIDERATIONS

Perhaps one of the most important subjects to be considered in the evaluation of RAM characteristics is the subject of test exposure. The term "test exposure" refers to the amount (quantity and quality) of testing performed on a system or systems in an effort to evaluate performance factors. 'L'he connotation of the term test exposure should include much ❑ore than what is meant by the classical "sample size." When considering single shot devices, test exposure refers to the number of items expended. On the other hand, for non-repairable, continuous operation systems, i.e. , destructive testing, test exposure refers to the amount of time consumed during the test. In this situation, the number of items required for testing is not known until the test is completed, i.e. , the required amount of time on test has been achieved. This results because the actual operating life of each unit is unknown until after the test is completed.

Now consider the case of non-destructive testing on single shot or continuous operation systems. For a single shot system, non-destructive test exposure refers to the number of operating cycles. All cycles could, in theory, be performed on a single item. For a continuous operation system, non-destructive test exposure refers to the amount of test time to be accumulated just as for the destructive testing case. However, with non-destructive testing, the test designer should exercise good judgment in precisely defining the test exposure. Elements to consider are:

- Should the time required be accumulated on one system or several systems?

- Should prototypes or production models be used?

- Should testing be accelerated by eliminating nonoperating time? If so, what is the effect?

- Do we anticipate changes in equipment failure rate due to age effects or design modifications?

- Is the external environment commensurate with the requirements?

One System Vs. Several Systems

Testing one item for 100 hours is, practically speaking, not the same as testing ten items for 10 hours each, although when considering the exponential model, the two tests are theoretically equivalent. The major statistical assumptions involved are a constant failure rate and a homogeneous population. Although the two test alternatives presented are not equivalent for practical evaluation purposes, it is not′ a case of one being "better" than the other. Each alternative has a desirable feature. The test involving ten items has the advantage of using a greater cross-section of the population. This is particularly important if the population quality is inconsistent. On the other hand, the test of one item for 100 hours has the advantage of exploring more fully the effects of equipment age on system reliability.

As a general rule, for evaluation purposes, it is desirable to test a "moderate" number of items for a "moderate" period. This makes the test relatively insensitive to the underlying statistical assumptions of constant failure rate and sample homogeneity. One compromise between sample size and test exposure requires that a minimum of three items will operate for at least 1.5 times the minimum acceptable value (MAV). As another example, MIL-STD 781C recommends for production acceptance testing that 10% of the lot be tested, down to a minimum of 3 items, and up to a maximum of 20 items.

Another recommendation presented in MIL-STD 781C is for each test article to operate at least one half the average operating time of all articles on test. If some of the test articles experience an excessive number of failures there is a natural tendency for them to accumulate little test exposure, simply because of the difficulty of keeping them on test. A constraint of this type should minimize this biasing tendency.

Accelerated Testing and External Environment

Because the operating life of most systems generally exceeds the available test period length, some form of accelerated testing is often performed. The acceleration may consist of merely eliminating standby time from the duty cycle to subjecting the equipment to some sort of overstress conditions. The evaluator should be aware of the impact of accelerated testing on the equipment and how it will influence his analysis.

Circumstances not defined in the mission scenario can significantly impact the results of a reliability test program. Every effort should be made to control these and other effects so that the test environment is commensurate with the intended operational environment.

Prototypes Vs. Production Models

In most cases, there is no choice in this matter. For instance, in development testing there are generally only prototype models available. However, for operational testing and evaluation, production models should be used. In this case, we are trying to evaluate the "final" configuration system as it will actually perform "in the field," rather than evaluating the system's inherent capabilities.

COMPOSING THE RELIABILITY DATA BASE

When we use data analysis techniques that consider the possibility of a changing failure rate, we are acknowledging that there is reason to suspect that the failure rate may not be constant. Two of the most common causes for a changing failure rate are:

- Inherent changes in the equipment as it accumulates more hours of operation, i.e., as it ages.

- Changes in the equipment due to design changes.

There is, at present, no readily usable statistical technique for analyzing system reliability which is affected by two or more of these factors. We cannot define a precise method for evaluating test results which are derived from systems which are improving as a consequence of design modifications and at the same time degrading as a consequence of wear-out. The only guidance for this situation is to perform individual analyses on each of the subsystems for that period of time when they have a fixed configuration. Total system reliability can be obtained by piecing together the subsystem reliabilities in accordance with a system reliability model (series, parallel, etc.). See Chapter 2 for details on the application of this technique. See Case Study 10-1.

Age-Dependent Analysis

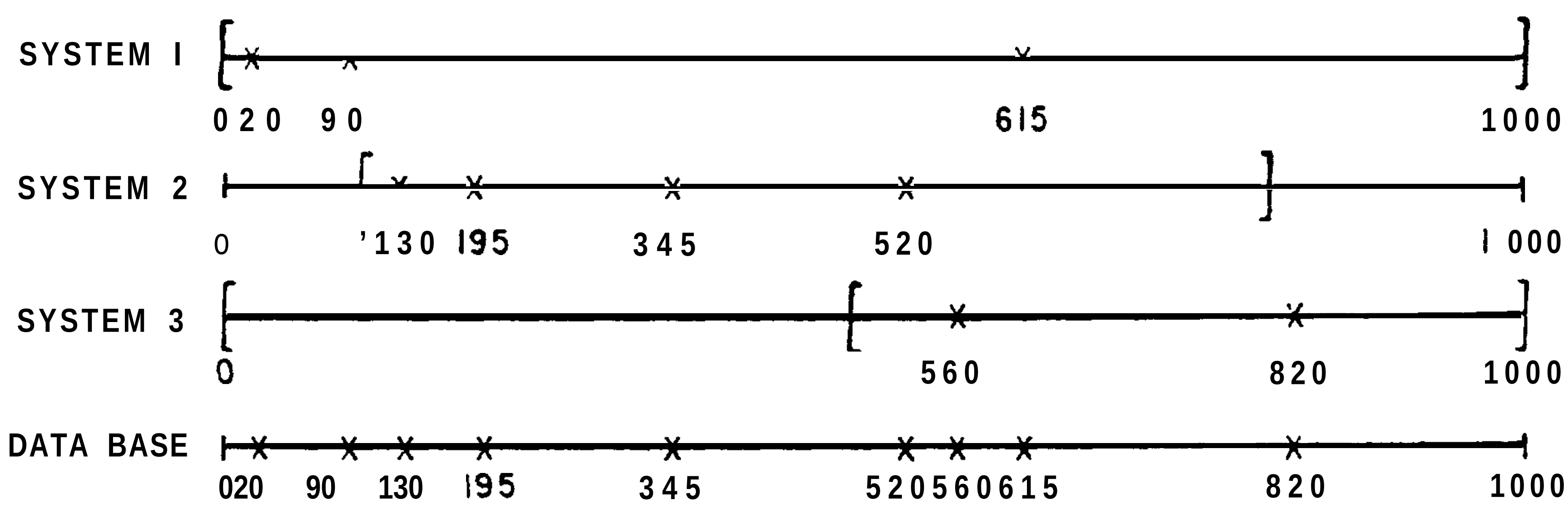
When the configurations of the systems on test are the same and fixed, we may be interested in observing the effects of aging on the failure characteristics. For this situation, we are required to record the actual age of the system when it has failed. Each element of the data base represents the age of the failed system at the time of failure.

As an example, suppose that 3 systems have been on test. System 1 operates from 0 to 1000 hours and failed 3 times. The times of failure were 20 hours, 90 hours, and 615 hours. System 2 operated from 100 to 800 hours and failed 4 times. The times of failure were 130 hours, 195 hours, 345 hours, and 520 hours. System 3 operated from 500 to 1000 hours and failed 2 times. The times of failure were 560 hours and 820 hours. The recorded times represent the age of the system at the time of failure. For an age-dependent analysis, the cumulative operating times are actually irrelevant. The data base for this test is the set of failure times.

{20, 90, 130, 195, 345, 520, 560, 615, 820}

See Figure 10-1 for a graphical portrayal of composing this type of data base.

FIGURE 10-1 SYSTEM FAILURE TIMES



BRACKETS INDICATE WHEN A SYSTEM WAS ON TEST.

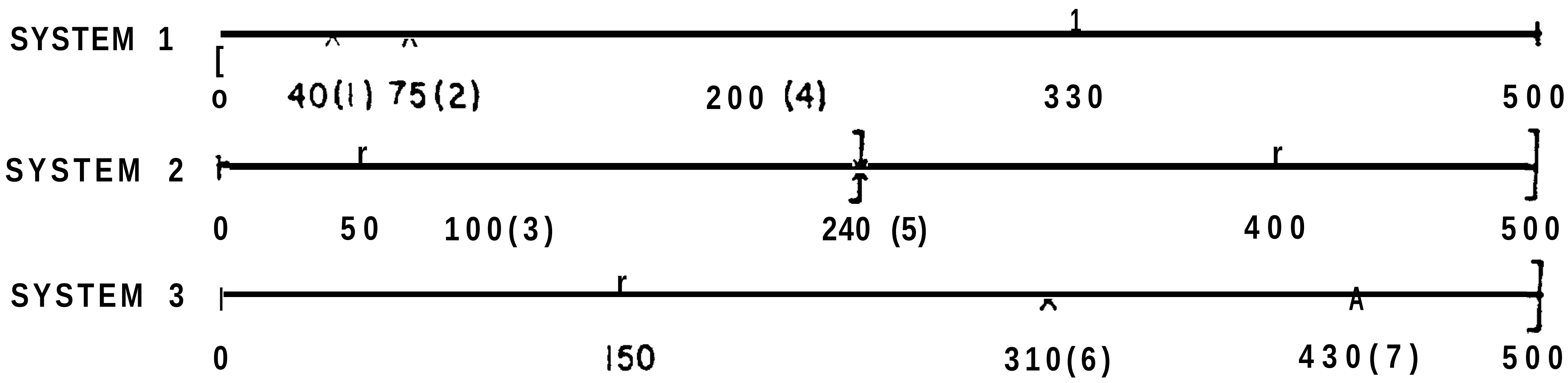
See Case Study 10-2 for another example of composing the data base for an age-dependent analysis.

Growth Analysis

When a system or systems are undergoing a development type test during which design modifications are being incorporated, we may be interested in observing the effects of these design changes on the reliability of the system. In this situation, the systems are being tested so that weaknesses in design will surface as failures. Ideally, when a failure occurs, all testing will stop while the failure is analyzed and a design modification is developed. The modification is incorporated on all test systems and testing is resumed until the next failure occurs. Theoretically, for this type of testing, we are not interested in the age of each of the systems. Rather, we are interested in the cumulative time they have been on test when a failure occurs. Each element of the data base for a reliability growth analysis represents the total test time accumulated by all systems at the exact time a failure occurs.

As an example, suppose that 3 systems have been engaged in development testing. In Figure 10-2 we display the failure patterns of the systems.

FIGURE 10-2 SYSTEM TIME ON TEST



BRACKETS INDICATE WHEN A SYSTEM WAS ON TEST.

NUMBERS IN PARENTHESES REPRESENT THE CHRONOLOGICAL ORDER OF FAILURES.

System 1 was the only one on test for the first 50 hours. System 2 began operating at the 50-hour point and System 3 at the 150-hour point. System 2 was taken off test at the 240-hour point and returned to testing at the 400-hour point. System 1 was taken off test at the 330-hour point and did not return. To compose the data base for this test we must determine how much test operating time has been accumulated when a failure has occurred.

FIGURE 10-3. CUMULATIVE TEST EXPOSURE/FAILURE HISTORY

Failure Number	Sys tern 1	System 2	System 3	Total Test Exposure
1	40	0	0	40
2	75	25	0	100
3	100	50	0	150
4	200	150	50	400
5	240	190	90	520
6	310	190	160	660
7	330	220	280	830

The data base for this test is the set of failure times:

{40, 100, 150, 400, 520, 660, 830}.

Note that these failure times have nothing to do with the system ages. In fact, the data base is the same whether the systems have no operating time on them at the start of the test or the systems have substantial amounts of operating time at the start of the test. See Case Study 10-2 for another example of composing a reliability growth data base.

COMBINING DT AND OT DATA

One method of obtaining a relatively larger data base at a given time in development is to combine data derived from both Developmental (DT) and Operational (OT) testing into a single, larger "homogeneous" data base. All DoD components have utilized this concept, and expanded use of the aggregated data base concept is anticipated as a direct consequence of DoD policy to execute shorter acquisition cycles supported by comprehensive test programs.

The advantages of a larger data base are clear. It provides the analyst the information necessary to more accurately assess system characteristics and, simultaneously, to be more confident of his results. Likewise, the pitfalls of larger "aggregate" data bases should be apparent. All the assumptions inherent in the various system math models apply to the data base elements. These assumptions relate to failure rate, test article configuration, sample size, test environment realism, etc. Any DT or OT data point that is placed in an aggregate data base must adhere to the applicable assumptions. Therefore, from a practical viewpoint, the development of a meaningful aggregate data base requires that specific ground rules be established prior to data collection and data base development. Further, the developer, user and test organization must jointly review available data and, using the established ground rules, decide what data to place in an aggregate data base. One accepted alternative to a single category data base is the compartmented aggregate data base. Under this concept, various data compartments are established within the aggregate data base. One compartment, for example, would contain DT and OT data which could reasonably support the assessment of the entire system's performance. Another compartment's data would only be used to analyze the performance of specific subsystems, whose configuration may have changed during the final stages of system development.

The key factor in developing an aggregate DT/OT data base is the homogeneity and applicability of the test data. That is, does the larger aggregate data base contain information which supports meaningful performance assessments of the present system, or subsystems, when operated in accordance with current mission scenario requirements? If not, an assessment based on this data will lead to erroneous conclusions.

EARLY DEPLOYMENT DATA

One final aspect of data base development is the timely availability of data required to accurately evaluate system suitability characteristics. It is especially important to obtain timely access to information which describes malfunctions or "shortcomings" which have been observed during early deployment. The availability of this information permits the developer and user to define and implement hardware, software, and training modifications at minimal retrofit cost and in the shortest time. The two methods described below have been utilized to obtain the desired information at the earliest time possible.

Early Field Data Retrieval System

The combination of an on-site developer representative and a structured field-data retrieval system has been used successfully to obtain timely performance information during initial deployment. The developer's representative is responsible for assuring that each malfunction or incident is accurately reported on a real-time basis. Information is collected and analyzed to determine the presence of failure trends which require prompt resolution. The essential feature of this concept is the real-time reporting of data by a trained observer to the developer who can initiate appropriate action. Normal service maintenance reporting systems do not provide the required response time nor the accurate, detailed information.

Lead-The-Force Program

A Lead-The-Force (LTF) program, sometimes referred to as Lead-The-Fleet, has one primary objective. That is, to obtain, at the earliest possible time, information on failure and/or wear-out modes that all units in the force (fleet) are likely to experience at some future time. Of specific interest are those failure or wear-out modes which are unexpected, premature, very costly, or combinations thereof.

For example, it would be cost effective to determine, early in production, that the wing structure of a new cargo aircraft was experiencing premature fatigue, failure, or that a new tank engine was subject to an unexpected failure mode that went undiscovered during testing.

An LTF program provides the desired information by means of accelerated usage of a few systems and by simultaneous in depth reporting of all malfunctions and "incidents."

An example of an LTF program will prove helpful. Suppose we are starting to deploy a new light-armored vehicle and the engine/drive train subsystem is expected to have a usable service life of 60,000 miles. During training, the average vehicle will be driven 300 miles per month. At this rate it would require over 16 years before the first vehicle drive trains will require depot maintenance. An LTF program for the drive train subsystem would require that a selected number of production configuration vehicles accumulate mileage which is at least 3 to 6 times the average. This added mileage must be accumulated under typical conditions of speed, terrain, maintenance, etc. Assuming the planned LTF program is executed at 4 times the average mileage, we will be able to obtain a preliminary view of the fleet's drive train life cycle performance in just over four years. This information is valuable because: it permits us to more accurately plan future depot maintenance requirements; we are able to predict the occurrence of major mechanical problems that could potentially affect fleet-wide mission readiness; we can start now to implement changes in production models and to manufacture retrofit kits or spares which can be installed because major breakdowns occur.

In summary, an LTF data base provides information required to assess long term system reliability and maintainability characteristics in a significantly shortened time period. The primary benefits are linked to our ability to execute timely, cost effective actions which maintain desired readiness levels.

CASE STUDY NO. 10-1

Background

A system is composed of four primary subsystems. The system has been undergoing development testing during which time two of the subsystems have received substantial design modifications. The other two subsystems are relatively mature and have not been modified. One of these subsystems has experienced wearout failures; the other, has not. The following information on the subsystem is available.

Subsystem	Information
1&2	Modifications incorporated MTBF estimates θ_1 = 450 hours θ_2 = 200 hours
3	Wearout failures MTBF estimate θ_3 = 300 hours
4	No wear out failures MTBF estimate θ_4 = 800 hours

Determine

1. If the subsystems are in series, what is system mission reliability for a 100-hour mission?

2. If subsystems 1 and 2 are in parallel (active redundancy), what is system mission reliability for a 200-hour mission?

Solution

In order to determine system reliability, we first compute subsystem reliability using the reliability function,

$$R(t) = e^{-t/\theta}.$$

Subsystem	Reliability 100-Hour	Reliability 200-Hour
1	$e^{-100/450} = 0.80$	$e^{-200/450} = 0.64$
2	$e^{-100/200} = 0.61$	$e^{-200/200} = 0.37$
3	$e^{-100/300} = 0.72$	$e^{-200/300} = 0.51$
4	$e^{-100/800} = 0.88$	$e^{-200/800} = 0.78$

1. Since the subsystems are all in series, the system reliability is

(0.80)(0.61)(0.72)(0.88) = 0.31.

2. Since subsystems 1 and 2 are in parallel and then together are in series with subsystems 3 and 4, the system reliability is

$$R_{system} = \left[1 - \prod_{i=1}^{n} (1 - R_i)\right]_{\substack{\text{parallel}\\ \text{systems}}} \times \; {R_{1-n}}_{\substack{\text{series}\\ \text{systems}}} \quad \Bigg\} \text{See Equations 2.1 and 2.2}$$

[1 - (1 - 0.64)(1 - 0.37)] (0.51)(0.78)

= [1 - (0.36)(0.63)](0.51)(0.78)

= (1 - 0.23)(0.51)(0.78)

= **(0.77)(0.51)(0.78) = 0.31.**

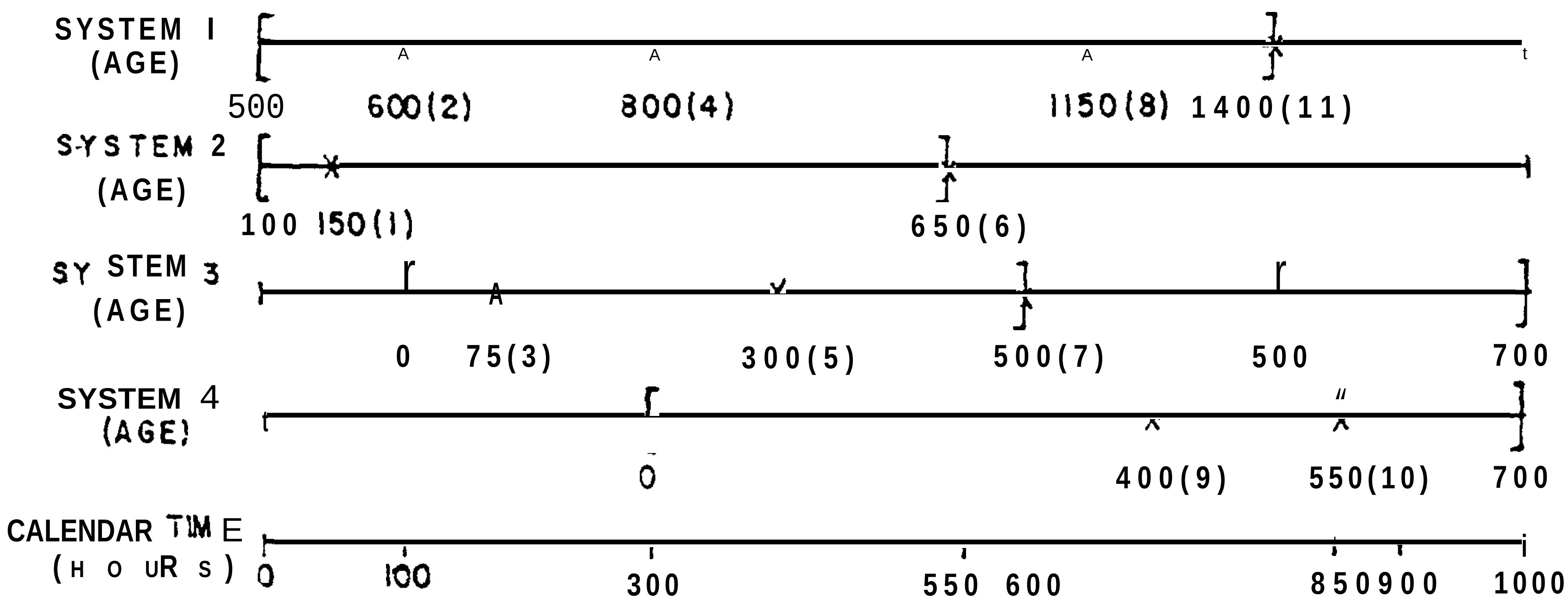
Commentary

In the background, we have given the MTBF estimates for each subsystem. In order to obtain such estimates, analysis should be done on failure data for each subsystem. In particular, a reliability growth analysis should be performed on subsystems 1 and 2. (See Chapter 9 for details on this analysis.) For subsystem 4, an exponential analysis would be appropriate. (See Chapter 7 for details on this analysis.) An analysis using a non-homogeneous Poisson process would no doubt be necessary for subsystem 3. (See Chapter 7 for a description of when this type of analysis is required.) The primary purpose of this case study i. to show how the concept. in Chapter 2 can be used to obtain an estimate of system reliability using estimates of subsystem reliability. The essential utility of this procedure is for the situation where different methods of analysis for different subsystems are necessary. The fact that the two system reliabilities are 0.31 is coincidental.

CASE STUDY NO. 10-2

Background

Four different systems have been operating at one time or another over a test period. The failure times for each system have been recorded and are presented graphically below.



Determine

1. Compose the data base for an age-dependent analysis.

2. Compose the data base for a growth analysis.

Solution

1. For an age-dependent analysis, failure times for each system are recorded as system age at the time of failure.

System 1 failure times : 600, 800, 1150, 1400

System 2 failure times: 150, 650

System 3 failure times: 75, 300, 500

System 4 failure times: 400, 550

The data base is the set:

{75, 150, 300, 400, 500, 550, 600, 650, 800, 1150, 1400} .

2. For a growth analysis, failure times for each system are recorded as accumulated test exposure at the time of failure.

Failure Number	System Test Hours 1	2	3	4	Accumulated Test Time
1	50	50	0	0	100
2	100	100	0	0	200
3	175	175	75	0	425
4	300	300	200	0	800
5	400	400	300	100	1200
6	550	550	450	250	1800
7	600	550	500	300	1950
8	650	550	500	350	2050
9	700	550	500	400	2150
10	850	550	500	550	2450
11	900	550	550	600	2600

The data base is the set:

{100, 200, 425, 800, 1200, 1800, 1950, 2050, 2150, 2450, 2600}.

Commentary

For comparative purposes, this case study composes the data base two ways: as a function of age, which is appropriate for a-fixed-configuration test; and as a function of accumulated test exposure, which is appropriate for a test with design changes. It must be emphasized that this is done for illustrative purposes only. An actual data base is composed one way or the other depending on the nature of the test.