Meeting MTBF Requirements using Allocations

By Lauren Crowe

In some cases, during system design, an overall MTBF or reliability objective is established or known. Even if such an objective is not established, it may be useful to have one in mind so that you can have confidence that your system will meet expectations once production starts. For systems large and small, using allocation methods can aid in setting reliability objectives for key components, or potentially all system components, at the beginning of the design process.

For example, if you are building a system made up of five different subassemblies, and you have a known MTBF goal for the entire system, you can allocate, or split up, the MTBF objectives for each of the five components in a well-balanced way that results in meeting your established overall goal for the system. This may be especially useful in situations where different groups, or even different subcontractors, are responsible for certain subassemblies.

As a system integrator, you can specify the MTBF goals you want each subassembly to achieve. Thus, a key element of the allocation process is to determine how best to allocate MTBF requirements in a well-balanced way across your entire system. This is where reliability allocation methods play a vital role. By considering the various alternatives for computing reliability allocation goals, you can select the method that best suits your needs.

Reliability Allocation Methods

Various reliability allocation methods can be employed to establish MTBF goals. This article will focus on some of the most common methods used. These methods include:

- Equal Apportionment by Component or Subsystem
- Base Apportionment
- ARINC
- AGREE
- Feasibility of Objectives

Lastly, this article will look at an allocation method that can use repair metrics to allocate failure rates of a repairable system.

Equal Apportionment

When the only information available about a system is the number of subsystems, Equal Apportionment methods are appropriate.

The ***Equal Apportionment by Component*** method distributes the failure rate allocation across all components in a system. For a system with a maximum allowed failure rate of λ_S, and the number of components equal to n, the failure rate of each component is calculated as:

$$\lambda_i = \lambda_s / n$$

In the following example, a System has two subsystems: Subsystem A and Subsystem B. Subsystem A contains two components, and Subsystem B contains three components. When the failure rate goal of the System is 100, the allocated failure rate of each component is $\lambda_s / \lambda_n = 100/5$, or 20.

Name	Allocated Failure Rate
System	100.000000
Subsystem A	40.000000
Component A1	20.000000
Component A2	20.000000
Subsystem B	60.000000
Component B1	20.000000
Component B2	20.000000
Component B3	20.000000

Example 1. Equal Apportionment by Component Method

The ***Equal Apportionment by Subsystem*** method distributes the allocations to subsystems in a top-down, recursive way. To apply this method to the example above, first the allocated failure rates of Subsystem A and Subsystem B are computed as $\lambda_s / \lambda_n = 100/2$, or 50 for each subsystem. Then for Subsystem A, $\lambda_s / \lambda_n = 50/2$, or 25 for each component; for Subsystem B, $\lambda_s / \lambda_n = 50/3$, or 16.67 for each component.

Name	Allocated Failure Rate
System	100.000000
Subsystem A	50.000000
Component A1	25.000000
Component A2	25.000000
Subsystem B	50.000000
Component B1	16.666667
Component B2	16.666667
Component B3	16.666667

Example 2. Equal Apportionment by Subsystem Method

The main disadvantage of the Equal Apportionment methods is that all components are viewed as equals. They do not make use of weight factors to take into consideration the degree of difficulty associated with achieving the reliability goal or the varying levels of subsystem complexity. However, Equal Apportionment methods can establish a good starting point for allocating MTBF goals.

Base Apportionment Method

The Base Apportionment method allows each allocated item in the system to be given a weight factor to allow for differences in complexity, environment, manufacturing, or other variables. The weight factors in the system must first be normalized; the normalized weight factor is then multiplied by the failure rate goal to obtain the allocated failure rate.

If W_i is the non-normalized weight factor of Subsystem i, then the normalized weight factor w_i can be determined using the expression:

$$w_i = W_i / (W_0 + W_1 + \ldots + W_n)$$

In Example 3, the weight factors for each item in the system are provided, and the failure rate goal of the system is 100. The normalized weight factors, w_i, are first calculated for each subsystem. The weight factors of the components are then normalized within their subsystems. The allocated failure rates are then calculated as:

$$\lambda_i = \lambda_s \bullet w_i$$

Name	Weight Factor	Normalized Weight Factor	Allocated Failure Rate
System	1	1.000000	100.000000
Subsystem A	60	0.750000	75.000000
Component A1	20	0.400000	30.000000
Component A2	30	0.600000	45.000000
Subsystem B	20	0.250000	25.000000
Component B1	3	0.075000	1.875000
Component B2	12	0.300000	7.500000
Component B3	25	0.625000	15.625000

Example 3. Base Apportionment Method

ARINC

The ARINC method is a reliability allocation technique proposed by Aeronautical Research Inc. It is unique because it uses the predicted failure rates of items in the system to determine weight factors instead of requiring the analyst to determine weight factors. The weight factor is determined by:

$$W_i = \lambda_{PredictedItem} / \lambda_{PredictedAssembly}$$

The failure rate for an allocated item is then calculated as:

$$\lambda_{AllocatedItem} = W_i \bullet \lambda_{AllocatedAssembly}$$

In Example 4, the predicted failure rates are shown. Weight factors for Subsystem A and Subsystem B are first calculated and then used to compute their allocated failure rates. Weight factors and allocated failure rates are then determined for each component.

Name	Predicted Failure Rate	Weight Factor	Allocated Failure Rate
System	150.000000	1.000000	100.000000
Subsystem A	30.000000	0.200000	20.000000
Component A1	10.000000	0.333333	6.666667
Component A2	20.000000	0.666667	13.333333
Subsystem B	120.000000	0.800000	80.000000
Component B1	30.000000	0.250000	20.000000
Component B2	40.000000	0.333333	26.666667
Component B3	50.000000	0.416667	33.333333

Example 4. ARINC Method

AGREE

The AGREE method was proposed by the Advisory Group on Reliability of Electronic Equipment, Office of the Assistant Secretary of Defense, USA. To allocate reliability, it uses a formula based on the number of subsystems, importance factor, and mission time. The importance factor reflects how critical an item is to system operation. This method is best suited for systems that have a three-level hierarchy, such as System, Subsystem, and Element. The equation is:

$$\lambda_i = (n(-\ln(R)))/(N \bullet W \bullet T)$$

Where:

n = Number of elements in subsystem i
R = Reliability goal
N = Total number of elements
W = Importance factor of i
T = Mission Time of i

For Example 5, the reliability goal is 0.995. The system has two subsystems; Subsystem A has two elements, and Subsystem B has three elements. The importance factors and mission times are shown. Using the AGREE allocation calculation, it is determined that the overall system must have a failure rate of 50.125418 or less to meet the reliability goal of 0.995.

Name	Importance Factor	Mission Time	Number of Elements	Allocated Failure Rate
System	1.00	100.000	5	50.125418
Subsystem A	0.75	300.000	2	8.911185
Subsystem B	0.25	100.000	3	120.301004

Example 5. AGREE Method

Feasibility of Objectives

The Feasibility of Objectives method was designed primarily for non-repairable mechanical-electrical systems. It uses weight factors based on a combination of four ranking values. For each subsystem, rankings on a scale of 1 to 10 are provided for Intricacy, State-of-the-Art, Performance Time, and Environment.

- Intricacy is a value determined by the number and complexity of components making up the subsystem.
- State-of-the-Art considers how highly developed the engineering process of the subsystem is.
- The Performance Time ranking is an indicator of how long the subsystem operates in relation to the entire system.
- Environment considers the severity of the environmental conditions in which the subsystem must operate.

These rankings are typically assigned by the design engineer based upon his experience with similar systems.

The four rankings for the subsystem are multiplied together to give an overall rating for the subsystem. The ratings of all subsystems are then normalized. The normalized value is multiplied by the failure rate goal to determine the allocated failure rate of each subsystem.

In Example 6, the system has two subsystems: Subsystem A and Subsystem B. The rankings assigned to each subsystem for Intricacy, State-of-the-Art, Performance Time, and Environment are shown. The allocated failure rate of a subsystem is determined by multiplying its four rankings together. Once this value is normalized, it is multiplied by the failure goal to determine the allocated failure.

Name	Intricacy	State-of-the-Art	Performance...	Environment	Allocated Failure Rate
⊟ System	#	#	#	#	100.000000
⊞ Subsystem A	4	9	5	7	55.555556
⊞ Subsystem B	9	7	8	2	44.444444

Example 6. Feasibility of Objectives Method

Repairable Systems

Unlike the other methods, the Repairable Systems method computes failure rate allocations based on the required availability, MTTR (Mean Time to Repair) values, and number of subsystems, rather than on weight factors. This method is useful for analyzing repairable systems that need to meet a specific uptime requirement. The availability goal is provided for the overall system and then used to compute the steady-state availability of each subsystem using the expression:

$$A_i = (A_s)^{(1/n)}$$

The failure rate of each subsystem is then determined using the expression:

$$\lambda_i = ((1/A_i) - 1) \bullet \mathrm{MTTR}$$

In the following example, MTTR values are used to determine the allocated failure rates for two components.

Name	MTTR	Allocated Failure Rate
⊟ System	#	79.765408
Component 1	0.750000	62.972691
Component 2	0.200000	16.792718

Example 7. Repairable Method

Summary

Establishing reliability goals during system design is critical to ensuring that your overall reliability objectives will be achieved. It is important, therefore, to appropriately allocate MTBF goals across all your system components in the most effective manner. Selecting the appropriate reliability allocation technique is a critical part of this effort. The technique you employ should be selected based on the information available about your system and your overall requirements.