Using Generic Data to Establish Dormancy Failure Rates

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Abstract: Many hardware items are dormant prior to being operated. The dormant period might be especially long, for example during missions to the moon or Mars. In missions with long dormant periods the risk incurred during dormancy can exceed the active risk contribution. Probabilistic Risk Assessments (PRAs) need to account for the dormant risk contribution as well as the active contribution.

A typical method for calculating a dormant failure rate is to multiply the active failure rate by a constant, the dormancy factor. For example, some practitioners use a heuristic and divide the active failure rate by 30 to obtain an estimate of the dormant failure rate. To obtain a more empirical estimate of the dormancy factor, this paper uses the recently updated database NPRD-2011 [1] to arrive at a set of distributions for the dormancy factor. The resulting dormancy factor distributions are significantly different depending on whether the item is electrical, mechanical, or electro-mechanical. Additionally, this paper will show that using a heuristic constant fails to capture the uncertainty of the possible dormancy factors.

Keywords: PRA, Dormancy, Uncertainty

1. INTRODUCTION

The object of this paper is to develop a distribution for dormancy factors using generic data. In this paper *dormancy* refers to the time an item is inactive after it is last known to be functional. Dormant items are prone to failure, particularly over prolonged periods of inactivity. However, it is intuitive that items have a lower failure rate when they are dormant than when they are being actively used. The *dormancy factor* is a multiplier used to obtain a dormant failure rate given the active failure rate. For example, some practitioners use a blanket factor of 30 to convert an active failure rate to a dormant failure rate. Dormancy distributions will be presented for the following hardware categories: electrical, mechanical, electromechanical, and for all categories combined.

2. DORMANT GENERIC RISK ANALYSIS DATA SET (DGRADS)

2.1. Overview of DGRADS

DGRADS (Dormant Generic Risk Analysis Data Set) is a database developed by JSC Safety & Mission Assurance containing dormancy failure rates. The failure rate data used to develop DGRADS comes from NPRD-2011 [1]. The data in DGRADS can be used to examine the relationship between dormant failure rates and active failure rates. This relationship will be presented as the dormancy factor characterized by a probability distribution.

Each item in DGRADS is a rollup of generic surrogate data and is partitioned into active and dormant failure rates. For example, the item “Actuator” includes the aggregate of all active environments listed for the Actuator entry in NPRD-2011 as well as the aggregate of its dormant failure rates. The aggregated data includes a mean as well as uncertainty parameters.

Most items in NPRD-2011 do not contain information for the dormant failure environment (denoted in NPRD-2011 as DOR). Only items in NPRD-2011 that contain the dormant environment were selected for inclusion in DGRADS. This resulted in 117 records.

Figure 1 shows a front end screen shot of DGRADS.

Figure 1: Screen Shot of DGRADS

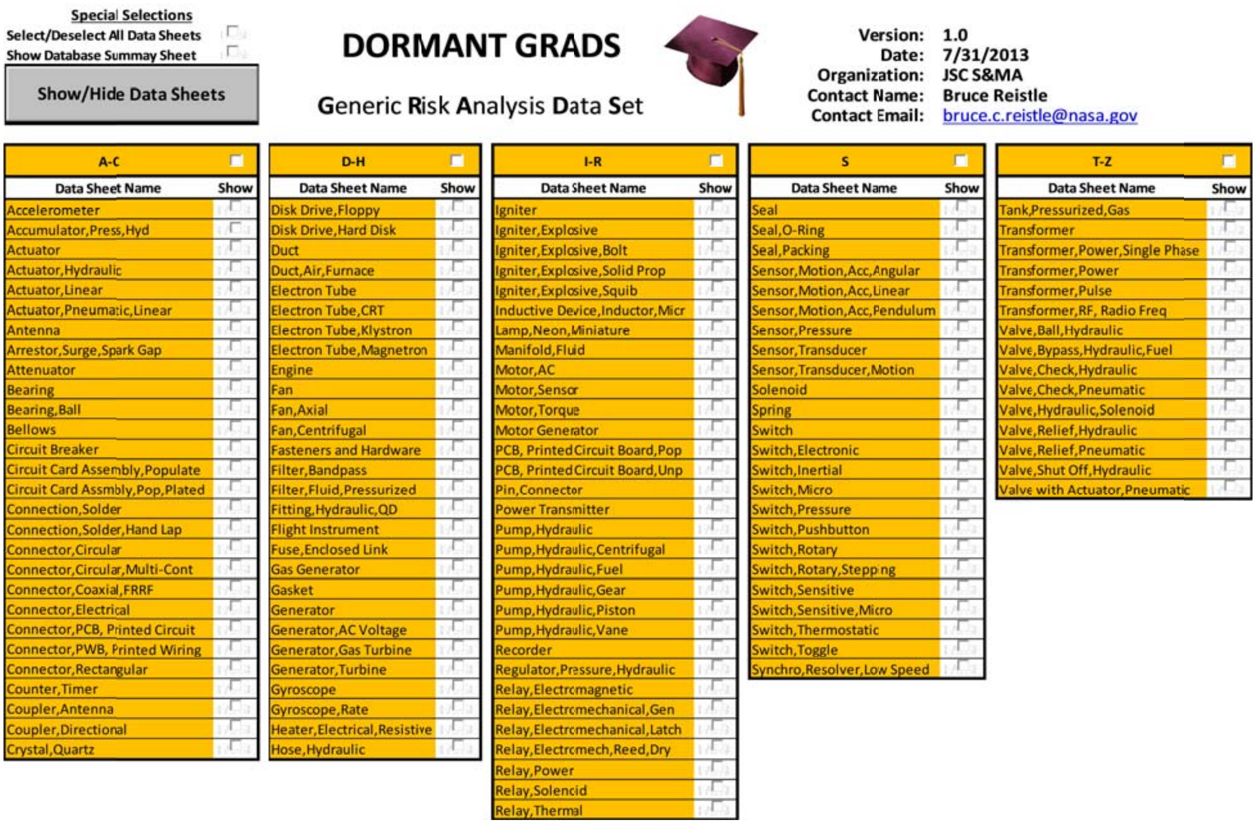


Figure 2 shows the data sheet for Motor, AC:

Figure 2: Motor, AC Data Sheet

Motor,AC **GRADS Rate Based Data Sheet (per hour)**

Environment	Count	Parameters for Lognormal(Mean, EF) and Gamma(α, β)					
		Mean	Error Factor	α	β	SD	Variance
Overall	1	2.2E-05	8.2	2.4E-01	1.1E+04	4.4E-05	1.9E-09
GF	3	1.1E-05	9.5	1.8E-01	1.7E+04	2.5E-05	6.2E-10
NS	2	2.4E-05	4.2	8.6E-01	3.7E+04	2.5E-05	6.4E-10
NSB	2	4.7E-07	5.6	5.0E-01	1.1E+06	6.7E-07	4.4E-13
G	1	3.1E-06	5.6	5.0E-01	1.6E+05	4.4E-06	1.9E-11
GB	1	5.2E-06	5.6	5.0E-01	9.5E+04	7.4E-06	5.5E-11
GM	1	2.8E-05	2.9	2.0E+00	7.2E+04	2.0E-05	3.8E-10
NU	1	1.2E-04	2.4	3.0E+00	2.5E+04	7.1E-05	5.0E-09
DOR	2	2.4E-06	8.6	2.2E-01	9.4E+04	5.0E-06	2.5E-11

3. DORMANCY FACTOR

3.1. Definition of the Dormancy Factor

The ratio of the overall failure rate to the dormancy failure rate will be referred to as the *dormancy factor* and will be denoted *d*. The active and dormant failure rates are denoted F_a and F_d. The dormancy factor is:

$$d = \frac{F_a}{F_d} \tag{1}$$

Note that the dormancy factor does not differentiate the different environments other than as being active or dormant.

3.2. Calculating Dormancy Factors

Dormancy factors were calculated for every item in DGRADS. For example, "Motor, AC" has an overall failure rate of 2.2×10^{-5} and a dormant rate of 2.4×10^{-6}. This results in a dormancy factor of:

$$d = \frac{2.2 \times 10^{-5}}{2.4 \times 10^{-6}} = 9.2$$

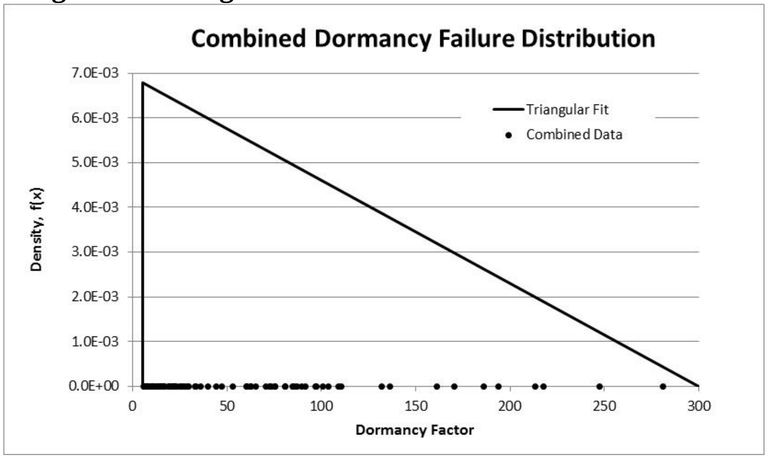
A high dormancy factor indicates less susceptibility to dormancy failures. If intuition is correct, one would expect most dormancy factors to be significantly greater than 1.0.

3.3. Fitting the Data

The goal is to characterize the central tendency of the data. Among the 117 items there were extremes on both ends (e.g., ratios less than 1.0 and greater than 8,000). While it is possible these values are valid, they are certainly extreme cases and are possibly due to anomalies in data collection and recording. To avoid catering to the extremes, the data between the 20th and 80th percentiles was used.

Figure 3 shows the triangular distribution for the combined data set (the combined data set includes data from all categories). The data points are plotted on the *x*-axis (as opposed to being binned like you might see in a histogram).

Figure 3: Triangular Distribution for Combined Data Set



As seen in Figure 3, there are significantly more values on the lower end (e.g., near 5) than on the higher end (e.g., near 300). A right-triangular distribution provides a good model for characterizing the data. To be clear, this distribution is a heuristic selection and is not obtained by a rigorous goodness-of-fit methodology. It is the author's opinion that using more rigorous fitting techniques and more sophisticated distributions will result in a false impression of increased precision. Using the triangular distribution ensures that small values (e.g., less than 1.0) will not be modeled. It also ensures that unreasonably large numbers are not modeled. Hence, the range of possible dormancy factors is bounded.

One could possibly obtain a "better" fit with a different distribution; for example the exponential distribution gives reasonable goodness-of-fit measures. However, the exponential distribution needs to be truncated or shifted to ensure that values less than 1.0 are not sampled. Some software cannot do such modifications and the added complications come with minimal gain.

3.4. Fit Results

A triangular distribution is characterized by three parameters: the minimum, the mode, and the maximum. Table 1 shows the recommended triangular distribution parameters for electrical, mechanical, electro-mechanical, and combined categories. It should be noted that each of these triangular distributions are right triangles; that is, the minimum is equal to the mode. (The values in the table have been rounded to avoid the appearance of a false sense of precision.)

Table 1: Triangular Parameters

Hardware Type	Minimum	Mode	Mean	Maximum
Electrical	2	2	50	150
Mechanical	10	10	310	900
Electro-Mechanical	10	10	110	300
Combined	5	5	100	300

Table 2 shows the corresponding statistics. The mean of the triangular distribution can be compared to mean of the data by looking at the two shaded columns.

Table 2: Statistics

Hardware Type	Data Points	10th	Mean	Data Mean	90th
Electrical	45	10	50	50	100
Mechanical	33	60	310	300	620
Electro-Mechanical	39	20	110	90	210
Combined	117	20	100	100	210

It is evident from the Table 2 that the Electrical components are more susceptible to dormancy failures than the other environments.

4. PRACTICAL APPLICATIONS

4.1. Determine the Dormant Failure Rate

Using a dormancy factor requires that the active failure rate distribution is known. To find the dormant failure rate, determine whether the component being modeled is electrical, mechanical, or electro-mechanical and select the corresponding triangular distribution. If no determination can be made, then use the combined triangular distribution. To find the point estimate of the dormant failure rate, $\lambda_{Dormant}$, divide the active failure rate, λ_{Active} by the mean dormancy factor, d_{Mean}:

$$\lambda_{Dormant} = \lambda_{Active} / d_{Mean} \qquad (2)$$

However, the author recommends including uncertainty by using the dormancy factor triangular distribution as well as the uncertainty distribution associated with λ_{Active}. This would in all likelihood involve using Monte Carlo sampling to sample values from the triangular distribution and values from the λ_{Active} distribution and then dividing. For example, in SAPHIRE the dormancy factor would be parameterized by entering the mean failure rate with its uncertainty terms being the mode and the maximum value. (The minimum value doesn't need to be entered because it can be calculated from the other values.)

4.2. Determine the Dormant Failure Probability

Modeling a dormant failure *probability* requires combining the dormant failure rate distribution with the dormant time. The *dormant time* needs to be carefully considered. Dormant time should be taken to be the entire time that the item has been dormant since it was last known to be functional. To be clear, this does not simply mean the beginning of a mission. If an item has been determined to be functional immediately before launch, then that is when the dormant period begins. However, many items cannot be checked immediately prior to launch (e.g., most pyrotechnic devices) so the dormant time might start days or even months prior to launch.

Once $\lambda_{Dormant}$ has been determined (whether it be the point estimate or a sampled variate) along with its corresponding dormant time, $t_{Dormant}$, then the dormant failure probability, $p_{Dormant}$, is:

$$p_{Dormant} = 1 - \exp\left(-\lambda_{Dormant} \cdot t_{Dormant}\right) \qquad (3)$$

This assumes an exponential time-to-failure distribution.

5. CONCLUSIONS

The dormancy distributions presented here should be used only if better information is unavailable. If a dormancy failure rate is available for a particular component then it should be used rather than the generic factor presented in this paper. Whatever dormancy rates are used, careful consideration should be given to the dormant time. Also, since dormant failure rates are leveraged off active failure rates, it is imperative to have quality data for the active environment.

References

[1] NPRD-2011, Reliability Information Analysis Center, 100 Seymour Rd, Suite C 101, Utica, NY