# Asset Criticality, Redundancy and Risk of Failure Scores

## Introduction

This document discusses asset criticality, consequence of asset failure and asset redundancy. It shows how they can be combined to calculate asset risk of failure scores that can be displayed in a risk matrix. The document concludes by observing that the recommended method for calculating asset risk of failure scores and determining the assets to be maintained is the method used in **PAM**.

**PAM** uses the Cox proportional hazards model (see the appendix in *Introduction to PAM* in PAM Introduction) to model the risk of asset failure as a dynamic phenomenon. This approach allows asset redundancy to be modelled as a dynamic probability, and an example of how the redundancy of a group of assets is calculated from their survival probabilities is given.

## Asset Criticality

The criticality of an asset is the importance to the organisation of the asset performing as expected. A critical asset is an asset for which divergences from its expected performance, even small divergences, lead to severe consequences. It is determined by three factors: the impact of the asset failing; the cost of the asset; and the time required to repair or replace the asset. Since asset criticality is a key aspect of asset management, it is important that the criticality of each asset is understood and quantified. **PAM** uses asset criticality to define a score for the risk of asset failure (see *Predicted Maintenance Interventions Module* in PAM Modules).

## Consequences of Asset Failure

The consequences of asset failure are the effects of the asset failing. Examples of the consequences of asset failure are safety, environmental and operational impacts. Ideally, all the consequences should be measured on a common continuous scale, for example in monetary units. Unfortunately, this is rarely the case as consequences are usually measured in different units or on ordinal (ranked) scales or qualitatively. The difficulty with using different scales to quantify the effects of different consequences is how to compare the different effects and assign numerical values to them. For example, how should a safety consequence be compared to an environmental consequence? If only one type of consequence is being considered, the problem does not arise but even in this case assigning values to the different effects is subjective and can be difficult.

 

## Asset Redundancy

The redundancy of a group of assets is the survival probability of the group when the number of assets available is greater than the number of assets required. It is calculated from the survival probability of each asset in the group (calculated by **PAM**), the number of assets required and the number of assets available, and is modelled by applying probability theory to the survival probabilities.

Since **PAM** models the risk of asset failure as a dynamic phenomenon, the survival probabilities change as assets are used and maintained, and these changes are reflected in changes in the redundancies.

The following example shows how to calculate the redundancy, i.e. the group survival probability, for three assets.

Let $P_i(t)$ be the probability that $i$ assets are available at time $t$. From probability theory

$$P_0(t)+P_1(t)+P_2(t)+P_3(t)=1 \tag{1}$$

Consider each term in (1) separately. Let $sp_i(t)$ be the survival probability of asset $i$ at time $t$. The analysis assumes that the survival probabilities are independent of one another.

*None of the assets survived (they all failed)*

$$P_0(t)=\left(1-sp_1(t)\right)\times\left(1-sp_2(t)\right)\times\left(1-sp_3(t)\right) \tag{2}$$

*One asset survived and two assets failed*

$$P_1(t)=\left[sp_1(t)\times(1-sp_2(t))\times\left(1-sp_3(t)\right)\right]+\left[sp_2(t)\times\left(1-sp_1(t)\right)\times\left(1-sp_3(t)\right)\right]+ \\ \left[sp_3(t)\times\left(1-sp_1(t)\right)\times(1-sp_2(t))\right] \tag{3}$$

*Two assets survived and one asset failed*

$$P_2(t)=\left[sp_1(t)\times sp_2(t)\times\left(1-sp_3(t)\right)\right]+\left[sp_1(t)\times sp_3(t)\times\left(1-sp_2(t)\right)\right]+\left[sp_2(t)\times sp_3(t)\times\left(1-sp_1(t)\right)\right] \tag{4}$$

*All the assets survived (none failed)*

$$P_3(t)=sp_1(t)\times sp_2(t)\times sp_3(t) \tag{5}$$

It is easy to show that the sum of (2), (3), (4) and (5) is 1.

 

Let $sp_1(t) = 0.8$, $sp_2(t) = 0.7$ and $sp_3(t) = 0.6$. Substituting these values into (2), (3), (4) and (5) leads to $P_0(t) = 0.024$, $P_1(t) = 0.188$, $P_2(t) = 0.452$ and $P_3(t) = 0.336$. The sum of these probabilities is 1, as expected.

If only one asset is available, the redundancy at time $t$ is the asset's survival probability at time $t$. Since the redundancy of a group of assets is greater than the survival probabilities of the individual assets, standby assets increase the availability of the assets to perform the role as required.

If the first asset is the only asset available, it will be available on average 80% of the time, so that its redundancy is 0.80. Similarly, if the second asset is the only asset available, it will be available on average 70% of the time and its redundancy is 0.70.

If one asset is required at all times and three assets are available, the redundancy at time $t$ is given by

$$redundancy(1, t) = P_1(t) + P_2(t) + P_3(t)$$

$$= 0.188 + 0.452 + 0.336$$

$$= 0.976$$

Thus, at least one asset will be available on average 97.6% of the time. It does not matter which assets are available – it is the survival probabilities of the assets in the group that defines their redundancy.

If two assets are required at all times and three assets are available, the redundancy at time $t$ is given by

$$redundancy(2, t) = P_2(t) + P_3(t)$$

$$= 0.452 + 0.336$$

$$= 0.788$$

Thus, at least two assets will be available on average 78.8% of the time. It does not matter which assets are available – it is the survival probabilities of the assets in the group that defines their redundancy.

## Risk Scores

Risk of asset failure scores can be made more informative by weighting them by the consequences of asset failure. Consequences can be defined by the asset's cost, the effects on the asset's safe operation or the effects on the environment of the failure.

 

If there is one asset, the risk score at time $t$ is given by

$$risk\_score(t) = probability\_of\_failure(t) \times consequence\_score \tag{6}$$

If the assets have redundancy, the risk score at time $t$ is given by

$$risk\_score(t) = (1 - redundancy(t)) \times consequence\_score \tag{7}$$

Since redundancy is defined as the group survival probability, $1 - redundancy(t)$ is the group risk of failure, and so (6) and (7) are equivalent but with different terms.

In contrast to the limited range of the risk of failure, (0,1), the upper limits of (6) and (7) are the maximum values of $consequence\_score$. The minimum value of $consequence\_score$ is 1 and occurs when there are no consequences (it cannot be 0 as $risk\_score(t)$ would then always be 0 irrespective of the value of the probability of failure). Thus, since (6) and (7) consider the consequences of failure, they are better measures than the risk of failure alone for determining which assets should be scheduled for maintenance.

The minimum values of (6) and (7) are not necessarily obtained with the minimum values of $probability\_of\_failure(t)$ and $consequence\_score$ – it is the product of the terms rather than their values that determines the minimum value. The risk of failure can be reduced by adopting a more proactive asset management policy. Indeed, **PAM** helps organisations change their asset management policies from reactive fail-and-fix to proactive predict-and-prevent. This change will also help reduce the consequences scores.

There may occasionally be a temptation to combine different consequence scores, for example one for asset safety and the other for asset cost, into one consequence score by simply adding or multiplying them. This can only be done if the consequences are independent. If they are not independent, the combined consequence score and therefore the calculated risk score will be inflated. As the correlation between the consequence scores increases, the calculated risk score increases artificially.

## Risk Matrices

Risk matrices show the risk score for each combination of likelihood of failure and consequence score. The scores are subjective and usually based on ordinal consequence scores rather than on continuous scores. In addition to the absolute risk scores, risk matrices can also show the risk scores relative to the score of a base case combination of likelihood and consequence.

 

Figure 1 shows a typical risk matrix. The values in the matrix (low, medium, high, extreme) are the risk scores.

**Figure 1**

| Consequence | | | | | |
|---|---|---|---|---|---|
| Extreme | Low | Medium | Medium | High | Extreme |
| Major | Low | Medium | Medium | High | High |
| Moderate | Low | Low | Medium | Medium | Medium |
| Minor | Low | Low | Low | Medium | Medium |
| Insignificant | Low | Low | Low | Low | Low |
| | Very low | Low | Medium | High | Very high |
| | | | | | Likelihood |

The most important cells in risk matrices are the cells with high or extreme risk scores. The conditions that give rise to these scores require most monitoring and therefore procedures for reducing or at least controlling the scores.

In Figure 1 both likelihood and consequence have five categories. If they are made more granular by increasing the number of categories, it becomes harder to define each category unambiguously.

## Determining the Assets Requiring Maintenance

Equations (6) and (7) can be used to calculate the risk score for each asset at each time. The assets can then be ranked in decreasing order of the risk score, and the assets at the top of the list prioritised for maintenance over other assets. Since (6) and (7) consider the consequences of asset failure, it is possible that assets with low risks of failure and high consequence scores are higher up the ranked list than assets with higher risks of failure and lower consequence scores. **PAM**'s Predictive Maintenance Interventions module uses this ranked risk score approach to identify the assets that should be prioritised for maintenance.

 