# Generating Asset Health Indices Which Are Useful and Auditable

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## Abstract

An Asset Health Index (AHI) is an asset score which is designed, in some way, to reflect or characterize asset condition and thus likely asset performance in terms of the asset's role. A number of different approaches to generating an AHI have been proposed, and we review several here, including systems which may be: logarithmic, dynamic, weighted, or binary. Each approach has pro's and con's which are discussed. For a successful AHI we need to link the available raw data– whether condition monitoring or asset history or maintenance and operational data - through to likely failure modes, or issues which will affect asset performance.

We discuss the relevance of particular data sources through to failure modes, and how those can be grouped into logical assessments of an asset or an asset subsystem. Such groupings make sense in terms of users of an AHI system as they deal with, for example, the electrical performance of the dielectric insulation or the thermal performance of the cooling system. Each failure mode can give rise to a likely deterioration rate, which will help direct the actions arising: to gain true value from an AHI, it is necessary to calibrate the scoring system so that similar scores have similar consequent actions and timescales.

As examples of the theory and practice of AHI development we look at some individual systems, to demonstrate their practicality, including how they deal with missing data and erroneous or invalid data. Examples are given for power transformer health, focusing on the failure modes related to winding insulation, to bushings and to thermal performance, but always within an overall AHI.

In each case we look at the need for an AHI to indicate a condition, and how the owner/operator planned actions and scheduled them.

We further discuss the need for calibration of AHI, including both health scoring of the components of a given asset, and between different asset classes. The AHI must provide useful information for intervention: what, and how soon, whether maintenance, refurbishment or planned replacement.

This paper has a practical focus, based on real data from users of AHI's in different locations, with different foci on asset performance. Data from analyses, with actions arising and interventions planned are discussed. The integration of AHI into an overall asset management approach, to make sure that the value of an AHI is realized, is presented

## Introduction

Within an asset management framework, such as described by ISO 55000 (1), the role of asset condition and performance analysis is critical to success. An Asset Health Index (AHI) is an asset score which is designed, in some way, to reflect or characterize asset condition, and thus likely asset performance in terms of the asset's role.

For a successful AHI, we need to link the available raw data – whether condition monitoring or asset history or maintenance and operational data – through to likely failure modes, or issues which will affect asset performance. Diagnosis of the presence of an 'active' failure mode, and an understanding of the timescale associated with that failure mode, allows for intervention planning.

In this discussion, we will use the following definitions:

| | |
|---|---|
| Asset: | an item, thing or entity which has value or potential value (from ISO 55000). |
| Health: | the state of an asset which represents the ability of an asset to meet the function for which it is required for the timescale defined by the 'user' |
| Index: | a number on a scale which represents the health of an asset; this is taken to be the first question we must address: |

"What problem are we trying to solve?"

This means we have to understand what the final AHI will be used for, so that it can be given meaning and value to the user.

A second question, which is often missed, is:

"Is the AHI number auditable?"

That is, can we justify the ranking given, based on the input data, and show that any variations in AHI are driven by identification of failure modes which can be addressed? And if we do it again tomorrow, do we get the same result?

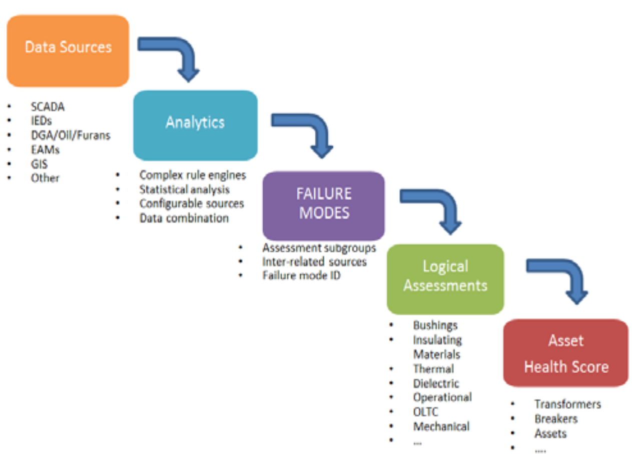
Developing an AHI should mean we can solve a problem, and do it in an auditable manner.

## Asset Health Indices

A common use for an AHI is to rank assets for proactive replacement in a strategic plan – which units will need to be replaced in which year, and for what reason? More tactical decisions about the viability of an asset may also be managed through an AHI, but it is likely that such decisions are more reactive.

What information should be included in an AHI? The more information that is used, the more reliable and accurate the AHI should be. But if we just take all of the input data, apply a complex function, and come out with a number, we miss the richness available in the original data (2). The waterfall diagram of Figure 1 shows the stages to move from data sources through analytics to failure mode identification, then assessment of logical components of an asset, through to the asset itself. In addition, there is a feedback loop – the sanity check – to make sure the final assessment reflects the root data (3).

**Figure 1:** From Data to Asset




There are many examples of assigning condition codes to raw data. IEEE C57.104 has an interpretation of dissolved gas levels in transformer oil, which allow the user to classify a result as one of four codes. If we wish to have four codes, the C57.104 system could be ideal (4). But how does it help? Certainly, there is a means to prioritize action based on the codes – but what action? And in what timescale? Have we identified what the problem is? That requires more investigation and analysis (3).

Generating an AHI from any single individual piece of condition data should be possible – with less benefit where there is less data. But we can trace the AHI back to the available data and how strongly a failure mode is indicated.

## Getting Started

As far as we can tell, no organization or individual is in possession of perfect data and/or perfect analytics. Improving data quality is a laudable effort, but experience has shown that the most effective approach initially is to analyse and understand the information you have (5). In the context of the problem to be solved, and the route through to good decision making passes through a good analysis of poor data – which may, in fact, be adequate for many problem solutions.

| | | Data Quality | |
|---|---|---|---|
| | | Poor | Good |
| Analytical Ability | Good | Route for success | Target Capability |
| | Poor | Initial status | Avoid this route |

This approach means that useful analysis can take place quickl: an initial view of a 'solution' emerge with confidence. Choose data which has a known 'quality' and use analysis tools which are understood – rank data in terms of the analysis diagnostics in the context of the decision timescale.
In many AHI systems a number of components are scored individually; it is valid to use an initial approach of just one component score – say DGA for transformers – as long as the approach is understood as a 'first step' with more details to be added as confidence in analyses grows.

## Component Scores

Continuing with C57.104, we may be happy with four condition codes for assigning to a population of transformers. But what is the proportion of the population in each code? Does it reflect the nature of the population?

One utility started with a 'Delphic' approach for a transformer population, ascribing each asset to one of four codes based solely on expert considered opinion:

**Table 1:** Delphic Condition Codes

| Code | Description |
|---|---|
| 1 | transformer is expected to last for the foreseeable future, and at least 15 years |
| 2 | transformer is expected to last up to 15 years but may need to be replaced in 5-15 years |
| 3 | transformer is expected to last up to 5 years and may need to be replaced in 2-5 years |
| 4 | transformer is on active list for replacement within 2 years |

The knowledge of the experts meant they knew the transformers, had histories of test and assessment results, and could evaluate the transformers. The sanity check is to review the proportion of transformers in each Code: given a failure rate of 0.5% per annum, say, we would expect a total of 7.5% of the population to fall into codes 2, 3 and 4 (6).

Is there a reason to restrict the number of codes to four? No. But with more codes, it may become more difficult to justify the coding of an individual unit. Do the codes relate to likelihood of failure? Only in that those with a higher code, that have a poorer condition – are in more need of replacement – and, thus, more likely to fail from either internal causes (for example, insulation degradation) or external causes (for example, through fault).

Each code needs to have a timescale associated with it, and an action. The action is required to address the problem that the AHI is designed to solve. The timescale is appropriate to the action and the problem.

How would we combine the Delphic approach, above, with a coding based on IEEE C57.104? That would be difficult, unless there was a means to calibrate the codes – that a 1 meant the same thing in both systems. This is difficult if we try to reconcile different actions, but relatively easy if we have codes with similar timescales.

We can choose the number of codes and the meaning for each – 1-10 is a common scoring system. But we have to be careful as to what the labels mean: is a 6 twice as likely to fail as a 3? How about a 9, compared to a 6? How accurate is the code – two decimal places? How do we combine codes – say the Delphic score and a C57.104 score to give a meaningful result? Logarithmic scales, where allowable scores are, say, 1-3-10-30-100, allow poor parameters to really stand out both individually and when combined with other parameters.

## Combining Scores

Individual data sources may be scored on a 1-10 scale, or a logarithmic 1-100 scale, and combined to give an overall score for a failure mode. Failure modes may similarly be scored and combined to give an assessment of the bushings, for example. Assessments combine to give an overall asset health score. Each combination is a process by which parameters are combined to give a more complete evaluation. Combination can be done in several ways.

An individual score for dielectric condition may be generated through a table look up:

**Table 2:** Log Scale Dielectric Condition Codes

| Code | Description |
|---|---|
| 1 | No known problems |
| 3 | Slightly unusual dissolved gas signature |
| 10 | Possible arcing/sparking or partial discharge fault |
| 30 | Severe arcing/sparking or partial discharge fault |
| 100 | Very severe arcing/sparking or partial discharge fault, transformer at high risk of failure |

In Table 2 the scales labels are now logarithmic. When combining logarithmic scores, through simple addition, any poor parameter clearly stands out.

We may generate scores for individual, logical, components of a transformer:

- DGA Main Tank Score
- Dielectric Score
- Thermal Score
- Mechanical Score
- Oil Score
- DGA LTC Tank Score
- Operational Score
- Design/manufacturer Score
- Subject Matter Expert Score (Delphic score)
- Other…

And combine them through addition, multiplication, or choose the highest. Averaging or weighting scores can be misleading, as it tends to 'smooth out' variation, and a significant change in a data parameter may provide a small change in AHI. Adding scores is equivalent to providing uniform weighting – this, too, can be misleading, as shown in Table 3.

**Table 3:** Adding Condition Codes

| Factor | Score Range | Trf 1 | Trf 2 | Trf 3 |
|---|---|---|---|---|
| DGA Main Tank Score | 0-10 | 5 | 0 | 0 |
| Dielectric Score | 0-10 | 2 | 10 | 0 |
| Thermal Score | 0-10 | 3 | 0 | 0 |
| Mechanical Score | 0-10 | 1 | 10 | 0 |
| Oil Score | 0-10 | 1 | 0 | 3 |
| DGA LTC Tank Score | 0-10 | 7 | 0 | 10 |
| Operational Score | 0-10 | 3 | 10 | 0 |
| Design/manufacturer Score | 0-10 | 3 | 3 | 10 |
| Subject Matter Expert Score | 0-10 | 8 | 0 | 10 |
| **Sum** | **0-100** | **33** | **33** | **33** |

Each transformer has a similar score, and should have a similar sense of urgency, in terms of action arising. However, it is clear that while transformer 1 is deteriorated, transformers 2 and 3 have serious and specific issues: scores of 10 in several categories implying imminent failure. The simple addition system hides the problem. Further problems arise if there is a significant change in a component score – for example, from 1 to 10. The final overall score may also change by the same amount, which may not be a significant change in terms of the overall score: for example, 33 to 42. On a log scale, anything above 100 would merit investigation within 24 hours, for example – as an individual component score may be above 100.

In Table 4 there is a comparison of two transformers – transformer 1 with some indicators of a possible problem and transformer 2 with a single severe indicator. The log scale means that the combined score 'picks out' the transformer as having an issue as the score is above 100, and we can also immediately see that the cause is originated in the main tank DGA.

**Table 4:** Comparing Addition of Linear and Logarithmic Condition Codes

| Factor | Score Range | Example 1 | Example 2 |
|---|---|---|---|
| DGA Main Tank Score | 1, 3, 10, 30, 100 | 1 | 100 |
| Dielectric Score | 1, 3, 10, 30, 100 | 3 | 1 |
| Thermal Score | 1, 3, 10, 30, 100 | 3 | 1 |
| Mechanical Score | 1, 3, 10, 30, 100 | 10 | 1 |
| Oil Score | 1, 3, 10, 30, 100 | 30 | 1 |
| DGA LTC Tank Score | 1, 3, 10, 30, 100 | 3 | 1 |
| Operational Score | 1, 3, 10, 30, 100 | 10 | 1 |
| Design/manufacturer Score | 1, 3, 10, 30, 100 | 3 | 1 |
| Subject Matter Expert Score | 1, 3, 10, 30, 100 | 1 | 1 |
| **Sum** | **9-900** | **64** | **108** |

The AHI in Table 4 helps focus our attention and allows for planned intervention.

Dealing with missing or erroneous data is always a challenge; the AHI should generate a score with whatever input values are available: individual DGA or extensive test, maintenance and assessment records. It is up to the user to decide if the final AHI is 'useful'. In Table 4 a logarithmic scale means that we can see the effect of individual sources of data more clearly.

The score change in itself is significant, but it also puts the new AHI over the '100 limit', which signals a rapid response form the user. The table also gives an indication that an individual AHI has value, but the magnitude change and rate of change of the AHI also have a value. Action can be planned and focused. The action planned was more detailed analysis of the winding insulation, and a timescale of 24 hours to make that decision, but given the nature of the problem, a time period of two months in which to perform further testing.

There are a number of organizations which produce strategic plans based on initial AHI values, then use subsequent AHI values and condition monitoring information to modulate the plan.

## Practical Systems

## Insulation Power Factor Deterioration

A dielectric test of a power transformer provides a bulk indication of the insulation status. In Table 5, an offline test updates the AHI, and the condition score deteriorates from 82 to 102.

**Table 5:** Deteriorating Condition Codes

| Factor | Score Range | Initial AHI | Subsequent AHI |
|---|---|---|---|
| DGA Main Tank Score | 1, 3, 10, 30, 100 | 3 | 3 |
| Dielectric Score | 1, 3, 10, 30, 100 | 10 | 30 |
| Thermal Score | 1, 3, 10, 30, 100 | 3 | 3 |
| Mechanical Score | 1, 3, 10, 30, 100 | 10 | 10 |
| Oil Score | 1, 3, 10, 30, 100 | 30 | 30 |
| DGA LTC Tank Score | 1, 3, 10, 30, 100 | 3 | 3 |
| Operational Score | 1, 3, 10, 30, 100 | 10 | 10 |
| Design/manufacturer Score | 1, 3, 10, 30, 100 | 3 | 3 |
| Subject Matter Expert Score | 1, 3, 10, 30, 100 | 10 | 10 |
| Sum | 9-900 | 82 | L02 |

The score change in itself is significant, but it also puts the new AHI over the '100 limit', which signals a rapid response form the user. The table also gives an indication that an individual AHI has value, but the magnitude change and rate of change of the AHI also have a value. Action can be planned and focused. The action planned was more detailed analysis of the winding insulation, and a timescale of 24 hours to make that decision, but given the nature of the problem, a time period of two months in which to perform further testing.

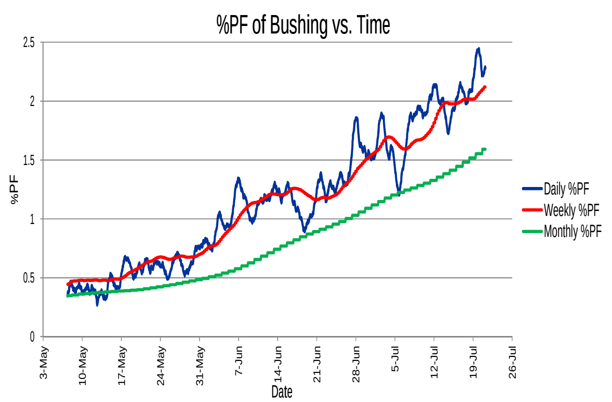
## Bushing Failure Modes

In two decades of bushing condition monitoring, measuring online leakage currents and phase angles, we have identified two general failure modes (6):

- "graceful deterioration", where indication of failure develops over several days to weeks
- "sudden and rapid" onset failures, where deterioration occurs rapidly and may lead to failure in a matter of hours

An AHI is of limited values in either case, as the failure modes are understood and monitoring is targeted at alerting the user that the failure mode has become severe. However, in the case shown in Figure 2, the condition of the insulation deteriorates over several months, and planned intervention can take place. The bushing was left in service and condition monitored before replacing the bushing before failure.

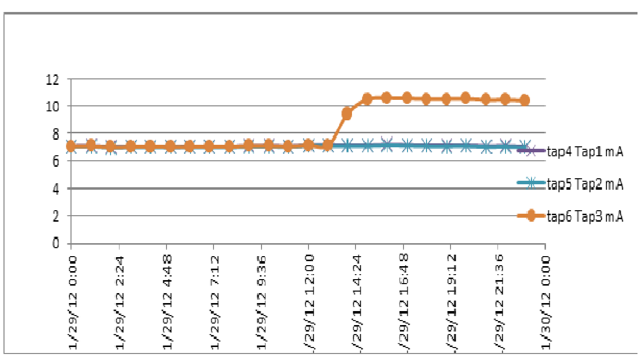
**Figure 2:** Bushing Insulation Deterioration over Several Months




In this case the overall AHI is high, due to the condition of the bushing, and remains high. But the root cause failure mode is known and understood, having been seen in several other locations, and a decision to leave the bushing and transformer in service was justified.

In contrast, the data in Figure 3 shows deterioration of insulation for a type of bushing with a known failure mode – internal insulation breakdown.

Figure 3: Bushing Insulation Deterioration over Several Hours




When the monitoring system went into high level alarm, the transformer was switched out. Note that this is a response previously agreed by engineering, operations and asset management, and there is no need to use an AHI to justify the decision: the failure mode is known, a parameter is used to indicate onset of the failure mode, and the transformer was saved. The transformer was, in fact, switched out of service within 2 minutes of the top level alarm being raised, and a subsequent teardown confirmed the issue.

The key point here is that the condition monitoring data indicated a failure mode becoming more severe, and any AHI activities were performed in parallel to the main task of protecting the asset and the system. The AHI score, which includes condition monitoring, deteriorates and the agreed action plan has a timescale and action: to switch the transformer out in two minutes and investigate.

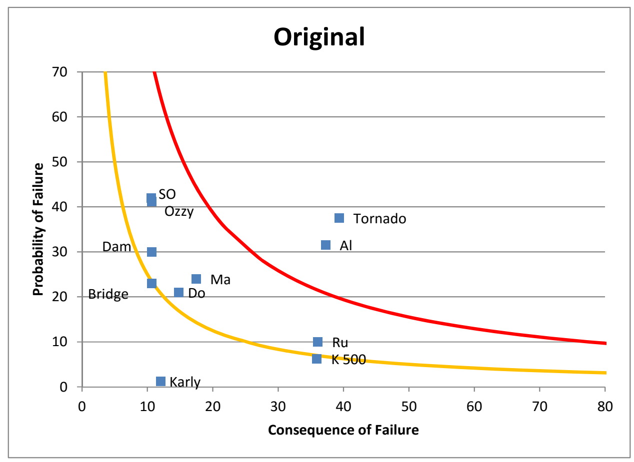
**Weighted System**

In this case, a weighted system which combines several component scores is used to indicate an overall health; this is actually given as a "probability of failure", although the users realized that there was only a tenuous connection between the AHI and the probability. Several power transformers are scored, and ranked.

Each factor is scored on a scale of 0 to 5, where 0 is good and 5 is as bad as it can get.

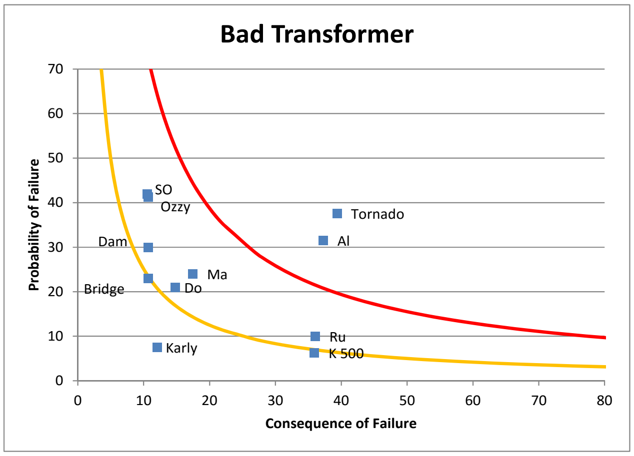
The data is plotted as a risk vector, with iso-risk lines for warning and action noted, with the original data as shown in Figure 4.

Figure 4: Bushing Insulation Deterioration over Several Months




It is instructive to review the data for one transformer with a change in a single factor – say DGA or Bushing Power Factor going from it's current value to the worst possible. Such a sensitivity analysis has been carried out for several factors.

Figure 5: Main Power Factor has deteriorated from 0 to 5 for a single unit




The unit Karly has deteriorated, but it is not necessarily clear from the chart. This is a disadvantage of weighted systems; we must stress that such a system is not 'wrong' – it is tuned to do what the users wish it to do, and helps them solve a problem.

## Getting the Value from an AHI Score

To get value from an AHI, it is necessary to have a clear, stated and agreed statement of:

- The aim and purpose of the AHI – the problem(s) it is to solve
- Timescales for actions associated with individual scores and ranges of scores
- An ability to audit scoring decisions and actions via failure mode analysis

## Making Use of an AHI

It should not be necessary to have 'complete' information for an asset – this is unlikely to be the case in many organizations. What should be required is that it is not 'difficult' to generate an AHI with a subset of data. In fact, there is much to support the idea of starting with a small and well understood subset of data and 'sanity check' the results of the AHI analyses and ranking.

The AHI must address the initial problem – timescale, action, justification, auditability.

In our opinion it must also be easily understood and flexible to respond to changing data.

## Conclusions

When we are reviewing asset health we must take into consideration all available data and apply best engineering judgment. However, when we consider the viability of an asset, we must also consider the function which the asset must perform – this can be a far more complex consideration as we must consider the consequence of failure to determine risk.
This analysis becomes more complex as we must consider interconnected assets – such as breakers, cables and transformers – which provide an overall function. The collation of data for such interconnected assets is similar to that for the sub-components or sub-assemblies of the individual assets: when one sub-asset deteriorates, the condition of the whole assembly deteriorates as a result. Management of the system of assets is similar to the management of individual assets.

## Further Work

The analysis of asset health index systems available is far from complete; there are numerous systems in operation around the world, and the first test is whether they provide value to the organization using them. Some benchmarking studies of such systems have begun, and should be continued. It is often the case that clearly 'good' assets and clearly 'bad' assets are given appropriate scores, but it is the journey and rate of travel between the two states which is of interest.

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