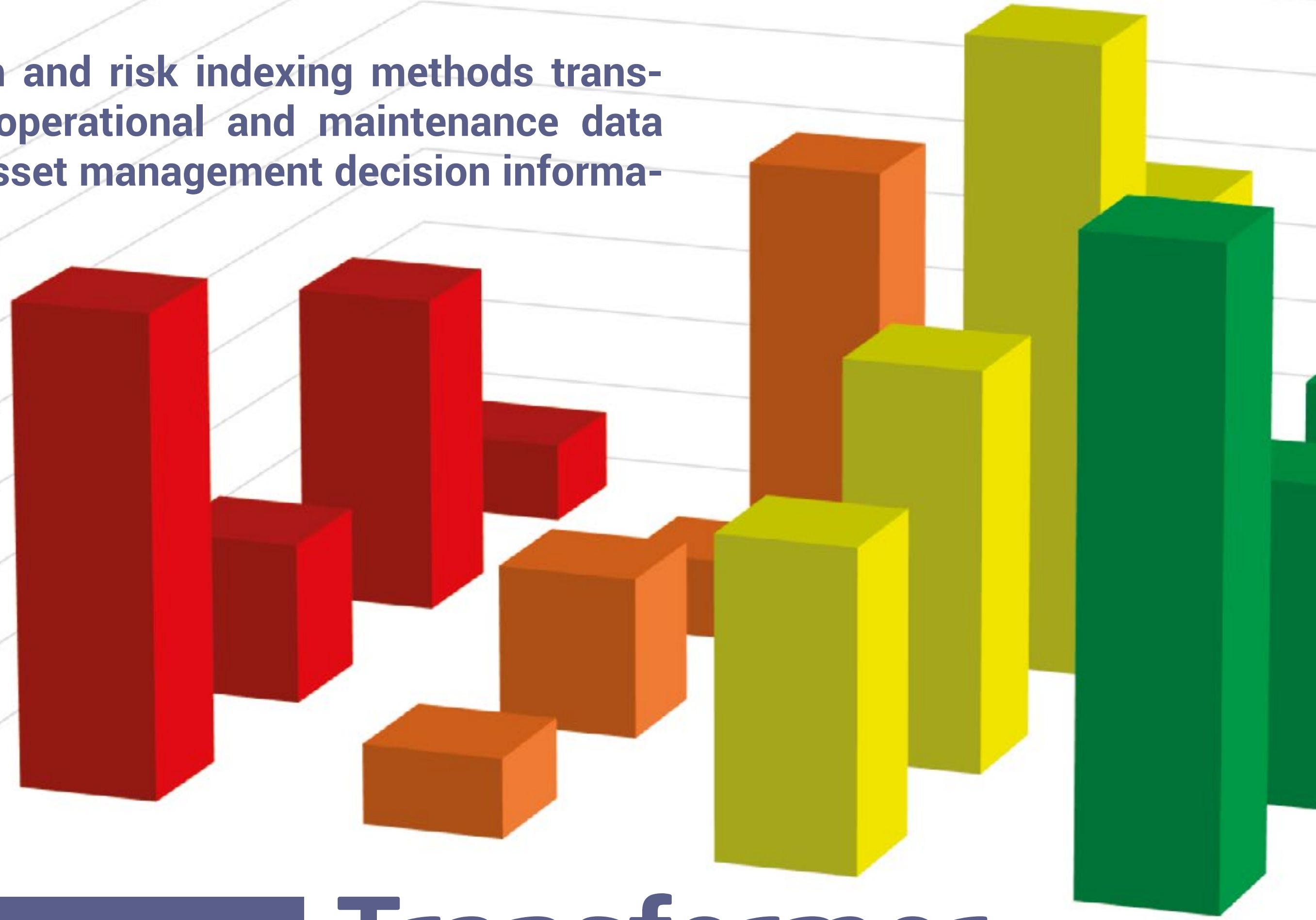
Health and risk indexing methods transform operational and maintenance data into asset management decision information



Transformer health and risk indexing

Transforming asset data into decision-support information

ABSTRACT

Modern asset management systems make use of risk based decision methodologies. This means that not only the frequency or the consequence of an event is regarded, but also the product of both. In order to transform operational and maintenance data into decision information that supports the asset manager in taking well-substantiated decisions, use is made of health and risk indexing methods. A health index is used to represent the condition or health of an asset; a risk index is used to represent the associated risk of a failing or defective asset. Several methodologies are in use to perform health and risk indexing. In this contribution, we will discuss the features and requirements of such methods. In particular, we will discuss some of the key challenges faced when developing and implementing health and risk indexing in asset management decision making.

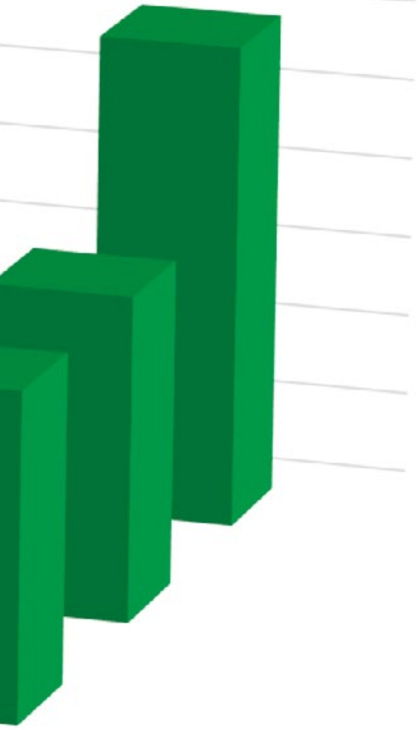
KEYWORDS

health index, risk index, asset management

1. Introduction

In a society, which has become increasingly dependent on electrical energy, we more than ever rely on the reliability of power supply. Power outages may cause major disruptions in both economical activities and social life, let alone lead to unsafe situations and financial losses. On the other hand, grid operators are urged to make effective use of investments and budgets available to ensure a reliable grid. At the same time, modern technology provides a wealth of data through monitoring and digitization. This provides both a challenge and an opportunity, the challenge being to manage the huge amount of data produced and the opportunity being to employ this data for well-informed decision making.

In order to transform data into decision information, we may make use of health indexing methods or, one step further, health and risk indexing methods. Here a health index is used to represent the condition or health of an asset, while a risk index is used to represent the associated risk, and the system is used to provide the grid operator with a dashboard representing the required actions and priorities. Often, this is an integral part of the risk management system that companies use to meet the asset management requirements stipulated by modern standards such as, for example, the Asset Management standard ISO 55000 [1, 2].



BUSINESS VALUE

IMPACT	KPI range	PROBABILITY: Almost impossible < 0,0001/yr	Unlikely > 0,0001/yr	Possible > 0,001/yr	Likely > 0,01/yr	Regularly > 0,1/yr	Yearly > 1/yr	Monthly > 10/yr	Daily > 100/yr	Permanent > 1000/yr
Disastrous	KPI range 1	L	M	H	H	VH	U	U	U	U
Serious	KPI range 2	N	L	M	M	H	VH	U	U	U
Considerable	KPI range 3	N	N	L	L	M	H	VH	VH	U
Modest	KPI range 4	N	N	N	N	L	M	H	H	VH
Small	KPI range 5	N	N	N	N	N	L	M	M	H
Negligible	KPI range 6	N	N	N	N	N	N	L	L	M

RISK APPETITE

- **U** Unacceptable risk
- **VH** Very High risk
- **H** High risk
- **M** Medium risk
- **L** Low risk
- **N** Negligible risk

Figure 1. Schematic representation of a risk matrix

Several methodologies are in use to perform health and risk indexing. In this contribution we will discuss the features and requirements of such methods. In particular, we will discuss some of the key challenges faced when developing and implementing health and risk indexing in asset management decision making.

2. Asset management decision making

Modern asset management systems make use of risk based decision methodologies. This means that not only the frequency or the consequence of an event is regarded, but the product of both. One major event may thus have the same weight as many smaller events. First, hazards or potential risks are identified. Next, the probability (likelihood) and impact (consequence) of these hazards are estimated, and the risk is established. This risk is then measured against the company's risk appetite. The risk appetite is often expressed as a risk matrix, which shows which combinations of probability and impact are regarded as an unacceptable, high, medium, low or negligible risk. Figure 1 gives a schematic representation of a risk matrix. In practice, one risk matrix is being used per individual business value (one for reliability, one for safety, compliance, finance and so on).

3. Asset health

When discussing asset condition and health, several definitions are being presented in literature. Commonly, asset condition is defined as the ability of an asset to achieve its required performance. The way to assess the condition depends on the prevalent failure mechanisms: when knowing the failure mechanisms, we may define suitable indicators that may predict failure and monitor these indicators to keep track of the condition.
The parameters used to estimate the condition may result from condition assessment (inspections, measurements, monitoring), or from the known history of use of an asset (accumulated stress, number of operations, lifetime). If no such information is available, statistical data from the asset population may be used instead, be it with less predictive power.
The traditional way of defining an asset health index is by using a simple classification scheme (good, fair, poor), or by taking some sort of weighted average of the available condition parameters. In our view, that is an outdated and sometimes dangerous practice. This is illustrated with a human analogy in Figure 2.

In this analogy, we assume that the health of a human being is governed by its heart, lungs, brain and liver, and that we can assess the condition of each of these organs on a scale from 0 (dead) to 10 (perfectly healthy). Let's take an example that the lungs, brain and liver are in an excellent shape (9), but the heart is in a very bad shape (1). The average score (7) suggests

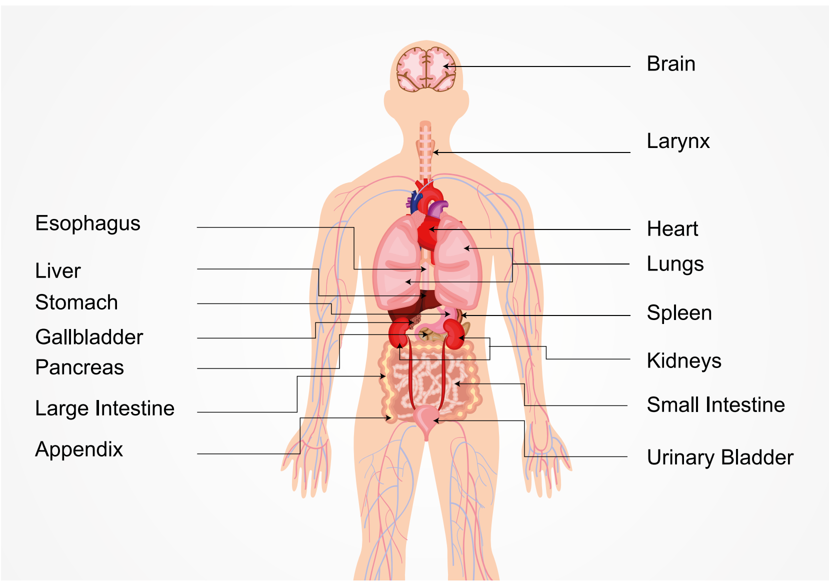


Figure 2. Human analogue

Data abundance poses both a challenge to manage large amount of data, and an opportunity to employ this data for well-informed decision making

that the person is in relatively good shape, whereas in fact he or she needs immediate attention to prevent heart failure. An average score, therefore, is not a good indicator of the actual likelihood of failure. Sometimes weighted averaging is used, so the heart condition may be given a higher weight. However, for a person with a good heart, but imminent brain failure this would be counterproductive. Also, a health definition based on the asset remaining life has been suggested. This is useful for replacement planning, but it does not give the asset manager other options than replacement.
In our view, the concept of asset health should be proactive and action-driven. It should represent the measures needed to maintain the ability to achieve its required performance, given the condition and the present maintenance regime. We, therefore, prefer to express a health index in terms of Remaining Life (RL) combined with Time-to-Additional-Maintenance (TAM). Here additional maintenance stands for the maintenance (or refurbishment) activities on top of regular maintenance, which enable the asset manager to increase the remaining life of the transformer. Also, the health index should provide the level of urgency of the recommended action. In order to make this workable in the asset management practice, time horizons may be defined. A long-term time horizon is used, which may be aligned with the timeline of a multiyear business plan or strategic plan. Also, a short-term time horizon is defined in order to distinguish between plannable action and emergency action. An example of such a health index definition is given in Figure 3.

If the asset can survive the long-term time horizon without additional action (i.e. by simply continuing the present maintenance regime), the asset is considered healthy (indicated by the colour green). The remaining life exceeds the time horizon. If the asset may survive this period only when additional action is taken, the condition is regarded repairable and requires attention (indicated by the colour yellow). The time to additional maintenance is shorter than the long-term time horizon, but with maintenance being performed, the remaining life exceeds this time horizon. When the remaining life is shorter than the time horizon, and the defect cannot be repaired, the asset needs to be replaced. We now distinguish between plannable replacement (the remaining life is longer than the short-term horizon) and emergency replacement (the remaining life is shorter than the short-term time horizon).

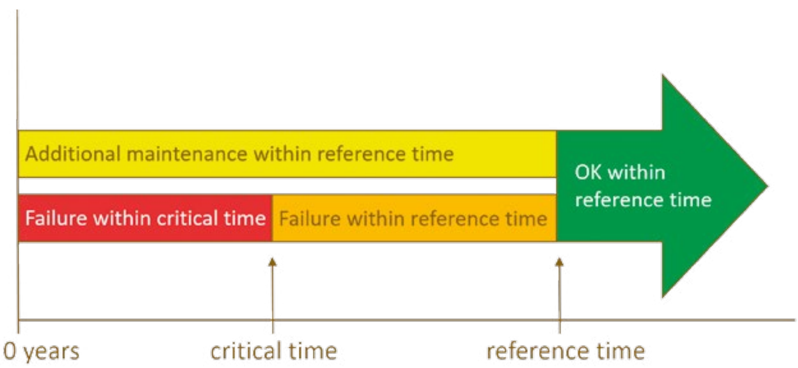


Figure 3. Example of an asset health definition

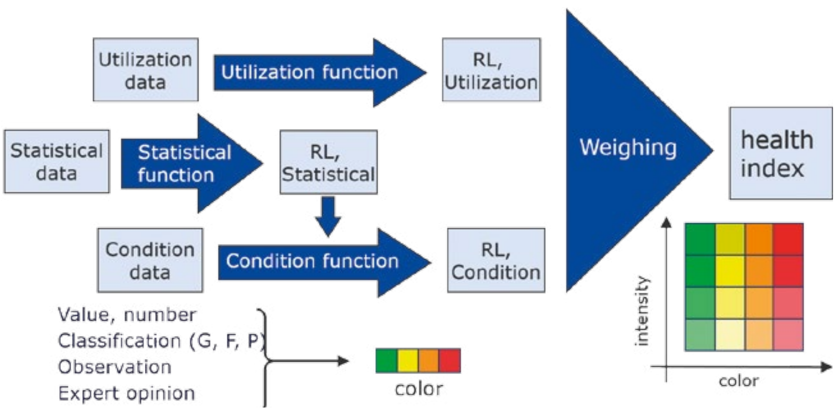


Figure 4. Example of a health index assessment scheme

3.1 Asset health assessment

Using the above definition of a health index, the first technical challenge of health indexing is to translate whatever kind of available data to the remaining life and the time-to-additional-maintenance of a transformer. As a first step, one needs to know the possible failure mechanisms of a transformer, for example by performing a Failure Mode and Effect Analysis (FMEA). Knowing the failure mechanisms and the indicators that provide information on the degradation or defect status, the health may be derived from condition data (inspections, measurements, monitoring), or usage data such as accumulated stress, number of operations or lifetime. This is usually performed on the basis of knowledge of failure mechanisms (FMEA), combined with empirical relationships obtained from laboratory experiments or field experience, and with models such as the transformer loading guide (which translates previous load and ambient temperature to a loss of life). If no condition or usage information is available, statistical data of the asset population may be used instead, be it with less predictive power. Statistical data may also serve as a starting point to provide a first estimate of the remaining lifetime, which may then be further fine-tuned by condition or usage data. Figure 4 shows an example of a health index assessment scheme.

Next to the actual failure probability, an asset management decision depends on the rate of change of a failure mechanisms, as this provides relevant information on the expected time-to-failure. Therefore,

Apart from representing the current condition, a health index should also reflect the measures needed for continued safe operation, as well as the urgency of these measures

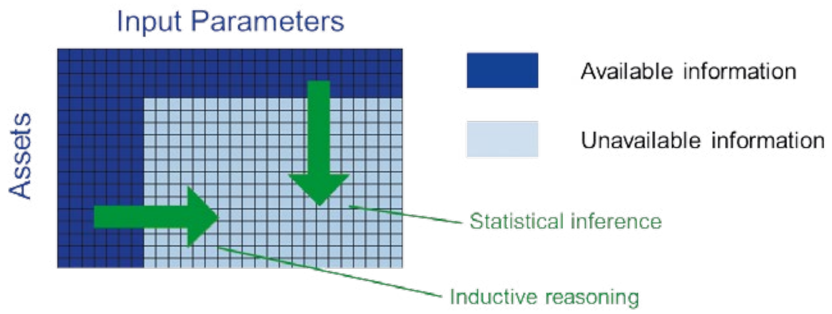


Figure 5. Methods for managing missing information

trend analysis of condition indicators and failure modes are a valuable contribution to health indexing systems.
In terms of a software solution, data is transformed into decision information (RL, TAM) by means of algorithms that incorporate the above knowledge, empirical relations and models. In practice, each type of asset requires a set of rules, and a library is established, which contains the sets for each asset type.

3.2 Health indexing requirements

In order for a health index concept to support the asset manager in an effective way, it needs to fulfil a number of requirements.

Predictive and actionable
In order for a health index to provide decision information in a risk based system, it needs to be predictive and actionable. The index needs to be representative not only for the present condition but for future defects and failures. Also, the outcome needs to provide possible actions to be taken by the asset or maintenance manager, as well as the impact of such measures on asset health.

Data availability and quality
Early health index concepts prescribe which data must be available for the model to work, and assume that this data is of sufficient quality. Considering that missing data is a common issue for many network operators, as is the data quality, this is not a practical concept. In our view, a health index concept should be able to work on any set of available data, be it condition-based, usage-based or statistical. On the other hand, the availability and quality of data has an impact on the accuracy and confidence level of the outcome. Next to the actual outcome, the confidence level also provides important information for the decision maker. He or she may take immediate mitigating actions on results with a high confidence level, but may decide to collect more information in case the accuracy of the prediction is questionable (low confidence level).
Therefore, modern health index models need to involve features to overcome data unavailability and quality issues. Best estimates for missing data may be generated by various methods. Using statistics, missing values may be estimated from population information. If, for example, the age of asset is unknown, it may be estimated from the surrounding population. Also, input values may be estimated from available data by means of induction. For example, if humidity data is missing, it may be estimated by using information on weather conditions, structural properties and environmental conditions.
The methods for generating estimations for missing data are illustrated in Figure 5.

The confidence level of such estimates is lower than that of measured or documented information, but less accurate estimates provide more reliable results than missing information. The impact on accuracy or confidence level is discussed below.

3.3 Data quality and health index accuracy

As mentioned above, the quality of data may differ, causing different levels of confidence in the outcome. For an asset manager, who is responsible for making the right decisions, the confidence level of health index results is of vital importance. Therefore, the health index model needs not only to provide estimates for the remaining life or time-to-additional-maintenance, but also on the confidence level of the estimations. In modern health index methods, this is solved by adding probability distributions to the input values, and performing a Monte Carlo simulation to provide a probability distribution of the remaining life or time-to-additional-maintenance.

3.4 Some examples

Figure 6 shows some typical histograms produced with the health indexing model, whereas Figure 7 shows an example of a replacement wave calculation.

4. Asset risk

Modern asset management standards such as ISO 55000 are based on risk based decision making, risk being defined as the

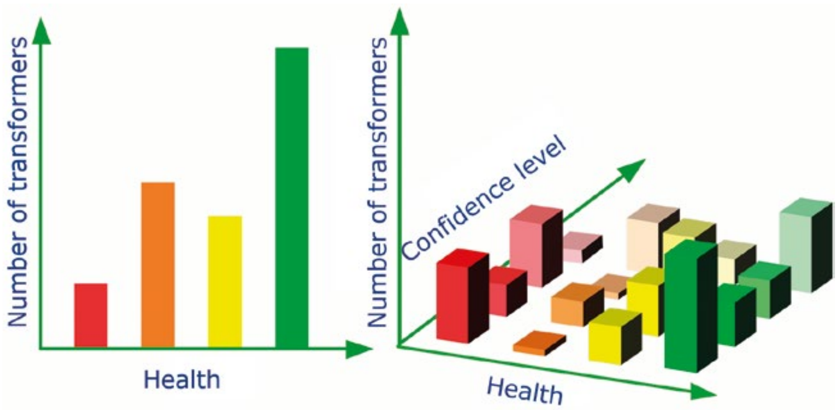


Figure 6. Health index histograms without (left) or with (right) confidence level

Modern health index models overcome data unavailability and quality issues, for example by using features based on statistical inference or inductive reasoning

combination (product) of the likelihood of an event and the associated consequences of that event. The consequence of an event is regarded for the different business values defined. Common business values include reliability (or quality of service), safety, finance, compliance, sustainability, reputation, customer satisfaction and similar.
The health index provides information on the likelihood of an event. In order for a health index model to be extended to a risk index model, one needs to determine the impact of an event on the individual business values defined. For example, in case of a certain probability of a transformer explosion, we may determine the impact on safety, reliability and so on. This requires:

- that the business values are clearly defined
- that KPIs are defined to measure them by
- that a risk framework or matrix is present to classify the risk of failure

An example of a health and risk indexing framework is given in Figure 8.

4.1 Asset risk indexing

As mentioned, risk indexing builds on a set of business values and KPIs, and requires a risk management framework such as a risk matrix with well-defined risk appetite. In practice, network companies are using different business values and KPIs, and different risk frameworks. As a result, a risk indexing model needs to be sufficiently flexible to adjust to the company's choices.
Once the risk management framework is established, risk indexing consists of assessing the impact of a failure or defect on each individual business value, followed by assessing the risk and confronting the risk with the risk appetite.

4.2 Some examples

Figure 9 shows two examples of resulting risk plots: left, an example where each asset is placed in a risk matrix; and right, an example where each square in the matrix contains the number of assets with that particular risk.

5. A case study: the DNV GL AHRM model

Based on the above-mentioned principles and requirements, DNV GL has developed a decision support model named AHRM (Asset Health and Risk Model). It combines a Health Index model and a Risk Index model.

The Health Index design is inspired by human analogy of remaining lifetime estimations. As a start, the statistical behavior of the asset populations is analyzed using survival analysis in order to determine the most likely failure probability distribution curve of the asset population. This provides a statistical expectation of the population, but no information on individual assets. Based on a FMEA analysis, we have designed additional assessment functions, which can be categorized into two groups: utilization functions and condition functions. Utilization functions assess the asset degradation of relevant transformer parts, based on the way the asset has been operated. The condition functions assess the actual asset condition based on inspections, measurements and monitoring, and diagnosis. The underlying principle is that poor or bad condition indicators show that an asset is performing worse than the average asset, and hence result in a reduced expected remaining lifetime compared to the statistical expectation. Similarly, when all relevant condition indicators show good results, the asset is performing better than an average asset, therefore increasing the asset's expected remaining lifetime. Over the last decade, a library of utilization and condition functions has been developed and implemented in health indexing systems. The health indexing scheme was earlier shown in Figure 4.
The assessment scheme determines different remaining life estimations for each relevant transformer subsystem, dependent on the failure modes and indicators involved. A folding function is used to arrive at one overall health index per transformer. This function does not use a weighted average because that would potentially mask essential transformer defects, as discussed earlier. Instead, it uses the weakest link approach, which identifies any problem in the asset. This approach is valid, because only the critical failure modes have been included in the health index design. In addition, the health index differentiates between reversible and irreversible degradation processes. Reversible processes may lead to maintenance whereas irreversible processes eventually lead to replacement.

The Risk Index is designed to be flexible and capable of coping with different types of risk frameworks. Before configuring the model, the company's business values, KPIs, risk framework and risk appetite are identified. The impact of asset failure is then computed per KPI using risk impact functions. These functions are tailor-made per KPI, company network structure and environment. Using the health index' remaining lifetime and probability of failure, the probability axis of the risk matrix is populated per asset. The risk impact function's result populates the impact axis of the risk matrix. As such, all assets can be plotted per KPI in a risk matrix.

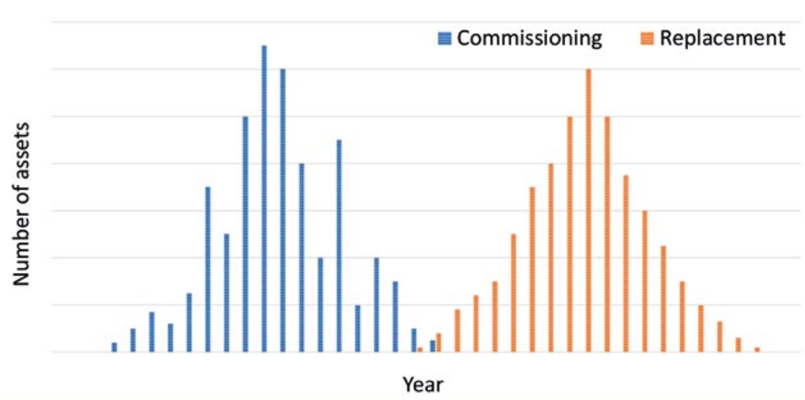


Figure 7. Example of a replacement wave calculation

Conclusion

As stated earlier, the purpose of health and risk indexing is to support the asset manager in taking well-substantiated, risk based, decisions. There are numerous types of decisions for which such a model may be applied. These include, among others:

- Being prepared for future risks
- Reduction of unplanned downtime
- Managing the replacement wave
- Planning and prioritization of replacement, refurbishment and investments
- Portfolio management
- Maintenance improvement
- Planning of maintenance activities and manpower
- Prioritization of data quality improvement
- Transparent decision making

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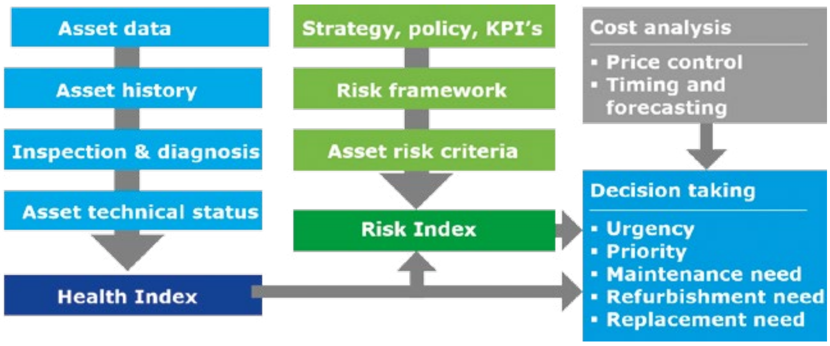
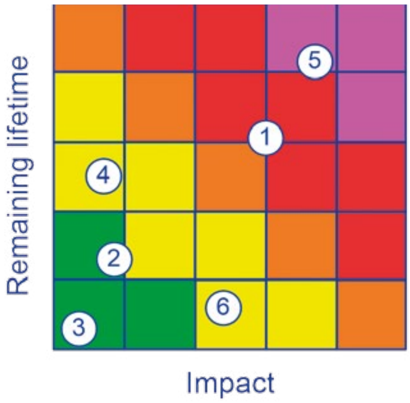


Figure 8. Example of a health and risk indexing framework



Rem. lifetime \ Impact	Negligable	Small	Moderate	Severe	Catastrophic
0-2 years	0	1	3	0	0
2-3 years	0	2	2	0	1
3-7 years	1	0	7	8	2
7-15 years	8	14	5	4	6
> 15 years	17	29	36	0	1

Figure 9. Two examples of risk plots (note that in these examples the remaining lifetime is used instead of the likelihood of failure)

In order to take substantiated decisions, the asset manager needs to be aware of the confidence level of decision-support information

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