Total cost of ownership of power transformers

What if the risk matrix had a third axis?

ABSTRACT

Electrical utilities worldwide are tackling the challenge of managing ageing power transformer fleets, which are critical for network reliability. Reliable condition assessment metrics and lifecycle decision models are emphasised, particularly in light of recent supply chain disruptions. A Total Cost of Ownership (TCO) approach is advocated to enhance decision-making in asset lifecycle management.

KEYWORDS:

Risk matrix, total cost of ownership, maintenance, end of life, asset management, automated decisions

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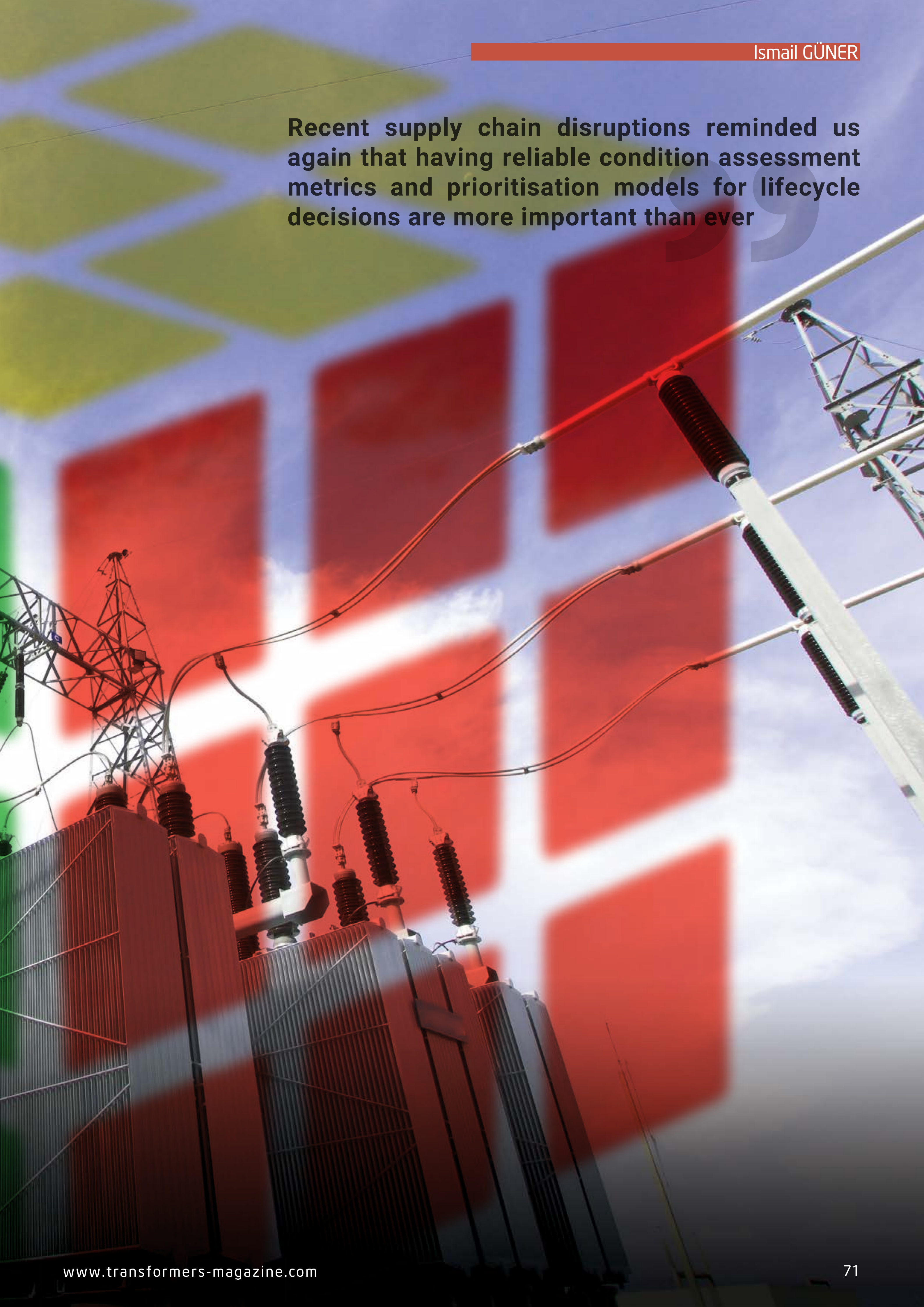

A risk matrix is a widely used tool for identifying, assessing, and prioritising risks based on their likelihood of occurrence and the severity of their impact on the utility's operations, infrastructure, safety, environment, and finances

Electrical utilities all around the world face important challenges in asset management of rapidly ageing networks. Ageing power transformer fleets represent a particularly significant issue for network reliability. Recent supply chain disruptions reminded us again that having reliable condition assessment metrics and prioritisation models for lifecycle decisions are more important than ever.

In the next era of machine learning and reliable big data analysis, utilities are investing in finding the best methodologies for automated asset management decision recommendations based on predicted time to failure and proposed maintenance action options with estimated costs.

The risk matrix is a widely used prioritisation method for many asset managers for any important asset decision, including end-of-life. It is a tool for ranking and displaying risks by defining ranges for consequences and the likelihood of failure of an asset. Past and recent scientific research has pointed out the weaknesses and inconsistencies of using risk matrices as a ranking tool and risk criteria to make a life cycle decision.[1] The foundation is based on an overly subjective character without any scientific principles. Mathematical analysis shows that decisions based on risk matrix ranking could be less efficient than those based on random ranking. Ranking inconsistencies, instability due to input errors, inconsistency with the cost of the solution, range compression, negative correlation of risk acceptance criteria, and ambiguity for non quantitative scales are some of the main issues with the risk matrix.[2] Simple is not always better, especially when it comes down to making major investments.

In the current context of the power transformers market and aging fleet profile, the prioritisation tools must point us in the most optimised and economical direction. Utilities must constantly evaluate and improve the performance of their decision-making process. From a reliability theory and engineering economics point of view, we must consider and implement the total cost of ownership (TCO) approach in the life cycle management decision-making process.

A parameter that is often overlooked is a thorough assessment of costs related to the total life cycle of power transformers, from qualifying a new supplier to end of life decisions. Utilities recognise the considerable upfront costs that come with

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purchasing and project overheads but may not account for the fact that critical energy assets need regular, ongoing, and unplanned maintenance. Maintenance and labor costs that grow over time. A significant portion of maintenance costs is a result of interventions during the last years of a life of a transformer. If we can calculate the TCO at a certain age per transformer and correlate the trend with the rest of its fleet, we would be able to evaluate economical performance of a transformer within a fleet. A tailored TCO modeling may include all operating and maintenance costs, costs associated with interruptions and unplanned downtime, planned condition assessment activities and carbon footprint costs.

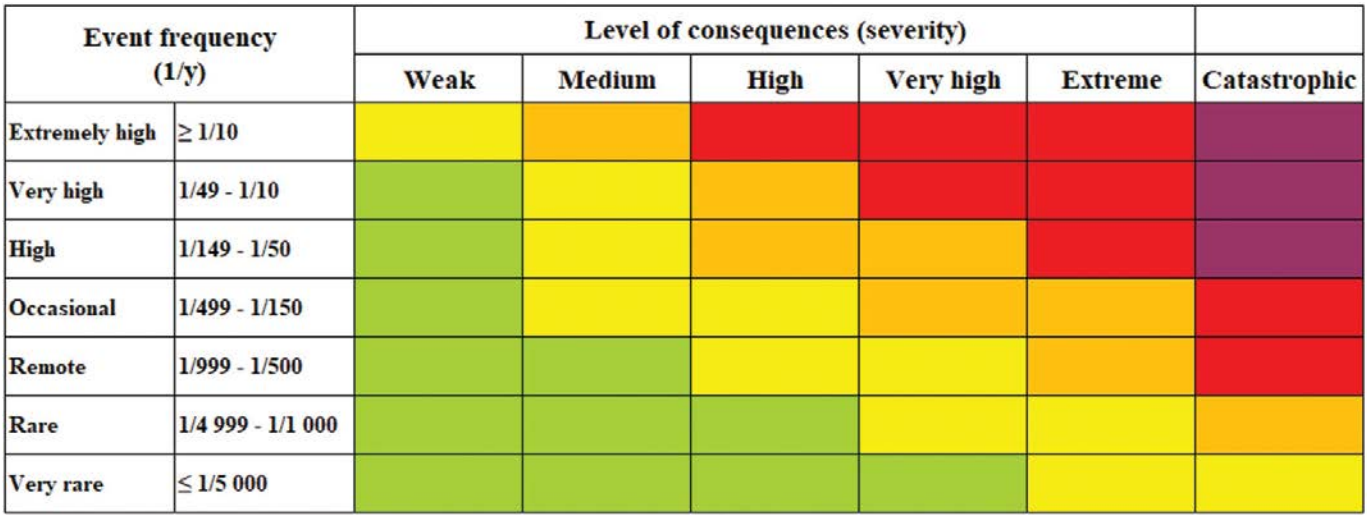
Successful life cycle management of a large fleet of power transformers efficiently involves a combination of strategies to ensure reliability, minimise downtime, and extend the lifespan of the transformers. Life cycle strategies are as good as the utility's ability to execute flexible maintenance and refurbishment actions within its solution portfolio.

A maintenance portfolio is a combination of predetermined activities based on multiple parameters. The main types of interventions are:

- Preventive maintenance in scheduled condition assessment and maintenance activities based on industry standards or utility experience, such as routine inspections, oil testing, bushing testing.
- Condition-based maintenance involves performing maintenance actions based on abnormalities observed during inspections, testing or real time condition monitoring.
- Predictive maintenance is also the most efficient method of intervention, involving execution of specific maintenance actions for specific mechanisms of degradation. A certain type of degradation observed in a unit may result in a predictive maintenance action plan on identical or similar units.
- **Risk-based maintenance** includes all maintenance activities that are prioritised based on the probability of failure and its potential impact on operations or the criticality of the transformer. Risk management methodologies such as the risk matrix help allocate resources more effectively, focusing on transformers that pose the highest risk to reliability and safety.
- Corrective maintenance involves repairing or replacing components as issues are detected or failures occur. This reactive maintenance is crucial for the network resilience. The success of the recovery time depends on the availability of spare parts and critical components.

For utility substation applications, the life expectancy of a power transformer active part can vary between 70 to 80 years. However, the average life expectancy of critical components that are essential for the function of a transformer is between 30 to 35 years. Thus, an end-of-life decision is often made due to the condition of these components. A complete refurbishment at an optimum time in the life of a transformer would not only reduce the maintenance costs that are much higher after the age of 30 but also would maximise the use rate of a reliable transformer.

The optimal balance of all these strategies depends on factors such as the fleet profile, operational demands and constraints, environmental conditions, budget considerations and a reliable prioritisation tool that must be tailored to the specific needs and context of the transformer fleet. The risk-based methodologies offer end users a tool to achieve high reliability and operational efficiency if these methodologies can be converted into a reliable prioritisation tool.



Event frequency (1/y)		Level of consequences (severity)					
		Weak	Medium	High	Very high	Extreme	Catastrophic
Extremely high	≥ 1/10	🟨	🟧	🟥	🟥	🟥	🟪
Very high	1/49 - 1/10	🟩	🟨	🟧	🟥	🟥	🟪
High	1/149 - 1/50	🟩	🟨	🟧	🟧	🟥	🟪
Occasional	1/499 - 1/150	🟩	🟨	🟨	🟧	🟧	🟥
Remote	1/999 - 1/500	🟩	🟩	🟨	🟨	🟧	🟥
Rare	1/4 999 - 1/1 000	🟩	🟩	🟩	🟨	🟨	🟧
Very rare	≤ 1/5 000	🟩	🟩	🟩	🟩	🟨	🟨

Figure 1. A typical risk matrix [3]

Risk based life cycle management

A risk matrix is a widely used tool for identifying, assessing, and prioritising risks based on their likelihood of occurrence and the severity of their impact on the utility's operations, infrastructure, safety, environment, and finances. The two typical axes axis of a risk matrix are the probability and the consequence of a potential event of operational disruption. Each utility has its own tailored methodology to calculate the likelihood of a failure and the impact of such an event evaluated as a level of frequency and severity or as a number on a scale (ex. 1 to 5 or 1 to 9).

The intuitive design of risk matrices is simple to understand. However, risk matrices have several weaknesses that can limit their effectiveness in some contexts, especially if not used carefully or supplemented with other profiling and prioritisation tools. The main weaknesses of the risk matrix methodology are subjectivity, oversimplification, resolution limitations, neglect of risk interdependencies, false sense of precision and, of course, scaling. IEC technical committee TC123 working group members are currently evaluating the very definition of risk of failure and the efficiency of the risk matrix methodology.

The decision-making process needs to be improved, and TCO offers us a starting point. The total cost of ownership of a power transformer refers to the comprehensive calculation of all direct and indirect costs associated with procurement, installation, commissioning, operations, maintenance, outage time, monitoring, diagnostics, asset management, performance tracking, refurbishment, upgrade, recycling or disposal and environmental impact. The advantage of the TCO approach would be the possibility to project the overall life cycle cost of an asset based on the unit TCO at a specific age and the historical data on identical or similar units, therefore identifying possible deviations in the performance of an asset.

The most efficient method of integration of the TCO into the life cycle management process would be creating groups or classes of transformers in a fleet based on voltage levels, MVA rating, type of cooling system and number of phases. The complexity of the active part weight could also be considered if carbon footprint calculations need to be covered by the TCO. Comparing each asset within its group would be beneficial to identify correlations and outliers. Each TCO per asset must be converted to a unit cost per year for trend analysis. In the example shown in Figure 2, a targeted intervention is necessary for the outlier unit TrA. The TCO of a transformer may also include a fixed cost to represent the lack of a reserve or logistics if it is in a remote location. Using end user's scaling methodology, the TCO performance of an asset can be modeled into an existing matrix, evolving it into a unit cube. This 3D view would be more representative of the fleet profile and the real impact of any life cycle management decision on an asset.

As transformer purchasing and operating costs continuously increase alongside the average age of critical infrastructure, new and efficient approaches to optimise all life cycle decisions are becoming the focus of electrical utilities. Introducing TCO trend analysis combined with artificial intelligence capabilities may significantly reduce the overall cost of ownership.

References

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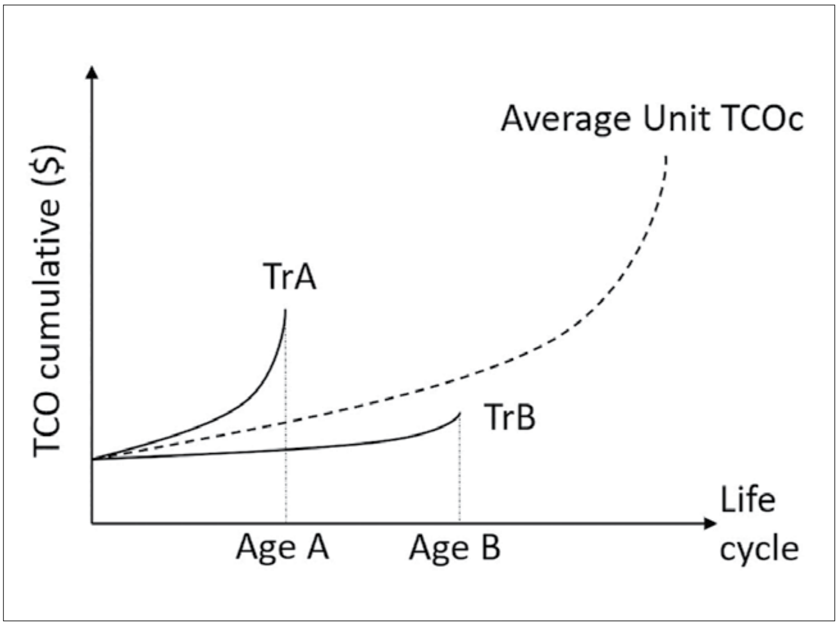

Figure 2. An example of TCO trend analysis

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