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PS3 – Best Practices in Transformers and Reactors Procurement

# Procuring transformers and reactors in a dynamic environment for a sustainable network – the Eskom way.

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## SUMMARY

Eskom Holdings SOC Limited, hereafter referred to as Eskom, is a state-owned company, in South Africa, with a long history of procuring transformers. The conditions under which transformers and reactors were and are procured have been changing over the years and at the same time the need to have a sustainable network has been constantly existing and growing. This combination of these two factors has presented challenges in the procuring organization and compelled several changes in the way of doing things as is detailed in this paper. This rich history is regarded by the authors as a demonstration that procuring transformers is not simply a financial transaction between the purchaser and the supplier, but a call for the two parties to work together to deliver a world class product. It is plausible that CIGRE has given the subject the attention it deserves by producing various technical brochures that cover some of the critical aspects of it and continues to make it part of the preferential subjects.
Revisiting the subject of transformer procurement over a period of about five decades, this paper demonstrates how things keep changing and then requiring new ways of achieving the purpose. It first reflects on the time when the organization procured transformers in a confined market, leading to incompatible units; then reflects on the time of procuring from an open market, bringing lots of learning and improvements, and finally procuring from a regulated market, enforcing consideration of more aspects and change from traditional ways of doing things, as the latter is accompanied by the wake of COVID-19 pandemic. The paper further seeks to call for investing new ways that will advance the current total cost of ownership approach, when qualifying the bids. It concludes that the transformer procurement process has become a complex activity that is beyond technical and commercial aspects, at least for Eskom and South Africa.

## KEYWORDS

transformers, reactors, factory capability, procurement, technical specification

## 1. INTRODUCTION

Transformers and reactors procurement is one of the growing fields within large power utilities and this is confirmed by the fact that CIGRE recognized the need to produce technical brochures [1] and [2] that provide guidelines on the subject's elements. Eskom Holdings, a state-owned power utility in South Africa, is one of the utilities that have and continue to invest significant capital funds in the procurement of transformers and reactors. This demand comes mainly from two main drivers, first the country's electric power network expansion and secondly the need to maintain a sustainable network. The organization is about a century old at the time of writing this paper and has seen three major peaks in the sourcing of transformers. The first one was in the 70s to the 80s, which was mainly on the 400kV and 765kV networks growth and introduction, respectively; and these achieved strong and efficient power transmission across the country. The second peak was in the late 90s coming to 2010 and was driven by the economic growth in the country due to a positive political change. The third and present peak is due to the change in the power regulations, encouraging the emerging of independent power producers and converting to green solutions, plus the aging infrastructure.

The organization has three core divisions, viz. Generation, Transmission, and Distribution, each keeping its own fleet of transformers. For most of the content covered in this paper, these three divisions were using centralized procurement and common specifications; therefore, for the purpose of simplicity and clarity in this paper, more details in terms of the equipment will be confined to the Transmission Division, however, that does not necessarily mean that the other divisions were different. As of today, the Transmission division has a fleet of almost 700 power transformers of between 10 and 800MVA on highest voltages from 22kV up to 765kV. For the reactors, it is mainly the three-phase 100MVAr at 400kV and single-phase 133MVAr at 765kV ones, plus a few others in lower voltages and all tallying to about 130 units. The replacement costs of these units are about ZAR25 billion (1.7 billion USD). The average age of the fleet is 33 years, which is higher than that of the peers [3]. The oldest transformers are 63 years old and are 2 x 30MVA 132/88/22kV and 180MVA 275/88/22kV auto-transformers. From these statistics, asset replacement cannot be overlooked going into the future.

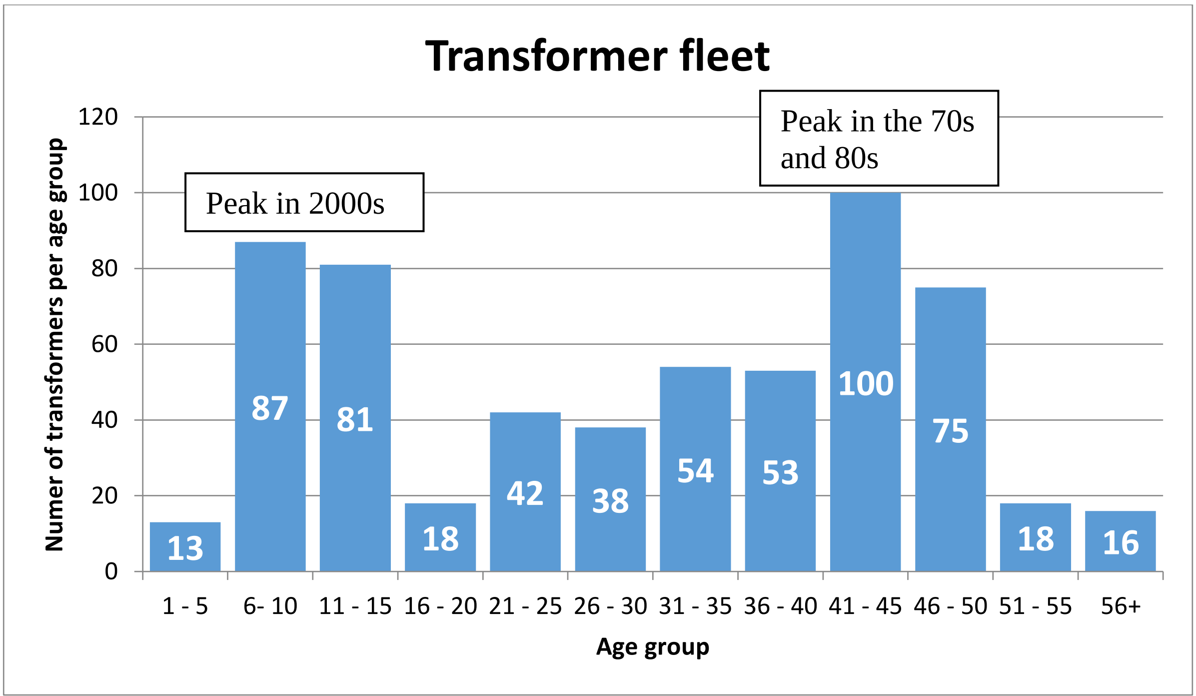


Figure 1 : Transformer fleet presented in age groups

As it is going to be expanded in the next sections of this paper, the procurement of transformers and reactors over the decades has not remained the same. The environment has been changing all the time and in turn, challenging the engineers into new thinking. The factors that have driven these changes include politics, leadership, economy, and now environment as well. These have demonstrated, at least in our organization, that transformer procurement is not merely a technical exercise that is backed up by some commercial rules, but there are other factors that come in and there are various stakeholders with some expectations from the exercise. Despite all these, it is still clear that the major role for an engineer or technical representative is to ensure that his/her company sources the transformers that are fit for purpose, can last for the expected time, and are safe to operate. It can be mentioned that at certain times, technical requirements can be pushed to the back, while the other interests take the front line; it is for the engineer to find a way to protect these.

## 2. TRANSFORMER PROCUREMENT IN THE EARLY TIMES

The early times in the context of this paper refer to the period up to the end of the 90s. It should be appreciated that this period is long and not all information is accurately known about it. The paper, therefore, highlights that which the available history can provide, however, it should not be interpreted as the only truth. Due to the political instability in the country, various countries started to impose sanctions on South Africa, which meant limited trade with some countries. Notably, during the 1970s, there was network expansions due to industrialization, and the technology in the high and extra-high voltage levels was greatly advancing globally. Although the procurement of transformers was massive, it was within a restricted market and lacked standardization. Locally, the country had only one factory that could manufacture transformers rated above 275kV, and additional units were sourced outside the country, including those of above 420kV and HVDC. To a certain and significant extent, the 420kV and below units were mismatched with regards to impedance values, impedance slope, regulation range, and resulted in several components, like tap changers, being from many different OEMs or being under license from classic companies. Many of these major components like bushings, insulating oil and tap changers which could be sourced during this sanctions period were substandard technology, but there were minimum suitable options, these components were also responsible for many unplanned and unpredicted failures. Another downside of this was that the maintenance/technical support became a problem as many of these various companies were no longer in business at the time the organization needed them the most. The attempt to re-engineer the components proved to be detrimental, and some units had to run with limitations, undergo excessive modifications, or be retired in the worst case.

Not only these were the barriers; the organization was almost passive with regards to the asset creation phase and the transformer specifications were minimal in terms of the requirements details. As indicated above, this introduced mismatched transformers which meant that after a failure, it sometimes became the only option to run the network with split busbars as the transformers could not be paralleled and some replacements required significant plinth modifications, adding to the recovery time and cost. The major sanctions of 1986 had a strong negative impact on the economy of the country as it entered a recession, and the transformer demand declined accordingly and the few transformers that were needed could all be sourced locally, and there was no appetite nor compelling circumstances to procure transformers offshore. These restrictions somehow isolated the organization from the global trends as it was inward focused and local capacity was sufficient.

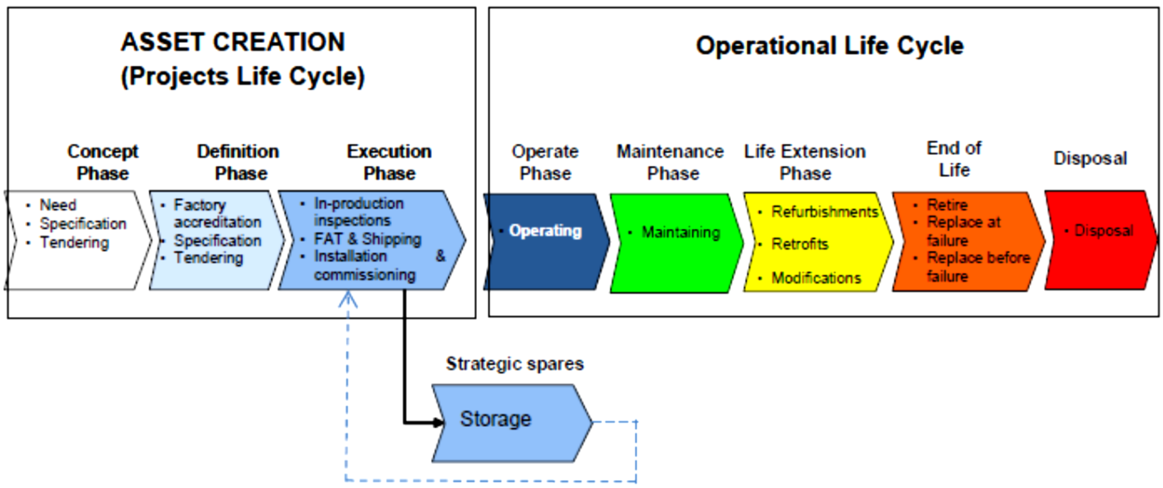


Figure 2: The phases of asset management

The major lessons from this period were that a weak procurement structure for such a critical commodity is detrimental as it opens the network to many limitations in a long run. Many units were of designs that make engineering sense, but they were not geared for the operational environment of our organization, this pointed to a need for a detailed specification and customer involvement in the design review process to ensure that the company's requirements are correctly interpreted by the appointed suppliers. It would be fair to say, to a certain extent, the company was buying a black box because there were no strong measures to ensure that quality was built-in to the product. As the exposed network expanded, the frequency and the magnitude of the through faults increased and many of these units could not last, and they failed. This was because the earlier designs had assumed a system impedance value that fast diminished as the network grew. In attempts to repair, it was discovered that the country did not have the skills or equipment to handle some of the repairs and the units had to be scrapped.

## 3. TRANSFORMER PROCUREMENT IN THE RECENT PAST PERIOD (2000 – 2015)

Post the 1994 political turnaround in the country, the economic growth exceeded the forecast, and it was accompanied by massive electrification projects. Doubtless to mention that this was going to trigger a rise in transformers and reactors demand. By the early 2000s, it was evident that the country's peak demand was getting very close to the power system capacity and accelerated network expansion was non-negotiable. At the same time, transformer reliability levels were dropping with many units highly and actively gassing and others reaching a catastrophic state, especially 400kV and 765kV reactors. The required delivery times and engineering changes were too sudden and massive for the local transformer manufacturing capability and there was no way it could meet the new demands on time. This compelled the procuring organization to establish relationships with various offshore suppliers and started doing factory capability assessments and that opened the doors to accelerated learning regarding best practices and technologies. Contacts and relationships were made and formed, respectively, with internationally renowned experts from different continents who assisted in various aspects, including the review of the technical specifications, performing design reviews, and assisting with in-production inspections.

During this time, the organization developed a specific procuring function that focused on the group's procurement of the high voltage equipment, and with a specific function for transformers and reactors. The main goal was to source units that were fit for purpose, could last the expected time, and were efficient to operate. Referring again to figure 2 above, lots of effort was put into the asset creation phases in the following manner:

3.1 The need

This is a critical stage in ensuring that the units can last the expected lifetime. It involves the power ratings, taking into consideration the future demand growth. This again became an input towards standardizing the units, unlike in the previous times where you found that in each voltage transformation, there were various sizes that were a few MVAs apart, these were grouped to form few standard sizes, which in turn simplified the spares holding requirements. The network performance was also studied in detail to understand the voltage regulation requirements.

3.2 The specifications

As stated above, this was the engine of all the procurement exercises. For each division, the document itself was influenced by internal and external experts to ensure that it harnessed the global experience while remaining relevant to the intended network. The external experts were brought from different continents to ensure that the organization's exposure is not limited to a certain zone. In cases where the opinions of the experts differed, which was very seldom, the organization had to make a call based on what is more relevant to the local environment. There were also various lessons that came from failure root cause analysis and other operational experience and they contributed to the changes that were made. One typical example was the revision of the winding arrangement as older designs were exhibiting a particular failure mode, which was traced back to the winding configuration. The upgrading of the specification documents introduced various technological changes like dry bushings, air-cells in conservator tanks, vacuum on-load-tap-changers and thermally upgraded paper, to count the few.

Earlier challenges in the implementation of the specifications were mainly on the auxiliary components which are the protective and indicative devices which in some cases were not suitable for local conditions, but this improved as the years of relationship with suppliers increased. The custom was also to hold annual contract reviews with each transformer supplier in order to integrate modern and better technologies and overcome non-compliances. This practice proved to be fruitful in reducing the deviations.

3.3 Tendering

The tendering phase followed a defined internal process based on an open-tender strategy, this was done to increase competition and spread any potential risks. This was important given the fact that many of the supplier-customer relationships were going to be new, and therefore, with limited product performance background. The cross-functional teams comprising mainly of technical, commercial, project management, quality, and end-user facilitated this process. Adjudication of tenders was based on the total cost-of-ownership rather than the direct tender price, and this practice allows bidders to "focus on submitting the most efficient design possible within the given limits of the economic loss values" as stated in [4]. It is known that designing for a more efficient transformer is more costly as well, which means that a procuring body pays a higher premium to derive efficiency-based cost savings when the asset is utilized. This is, however, a gamble because it assumes that the transformer will last for the expected life span, which is not always the case. An efficient transformer is not necessarily a reliable transformer, and therefore these evaluations should better take into consideration other factors like in-service-failure rates or average age at failure for a certain make of transformers to better guide the procuring organizations. The order awarded on the total cost-of-ownership will be a sunk cost if the transformer does not last to the expected life. Although the new fleet is currently performing exceptionally well, the cases of premature failures were experienced in our history and some of those units were already out of the warranty time.

## 3.4 Factory assessments

In the beginning, this exercise was done based on a lean framework spreadsheet of questions, checks and observations, but as years went by, it was developed to a standardized process and today the organization has a tool that is used to evaluate and score factories. The factory assessment exercise has become a mandatory prerequisite for any factory to start supplying transformers to Eskom. It must be noted that this does not become a once-off approval, but there are measures put in place to trace the performance of the factory during the contract period to ensure that deviations are detected and addressed on time. In the case of a supplier proving to be a risk, first, a written warning is provided, requesting it to pay attention to the observed gaps. If repeat incidents occur after that warning, a moratorium will be imposed on that factory until all corrective actions have been satisfactorily addressed, and an adjusted factory assessment has been done. The reinstatement may be on a phased approach, starting from small sizes and then going up in rating. Unfortunately, factories that fail to show progress and/or willingness in addressing the gaps are removed from the accredited factory list.

Challenges in doing factory assessments have not been mainly in the exercise itself, but the administration part of it. As an organization, we experienced undocumented rules in terms of how to determine the validity of the accreditation, i.e., when does it lapse? It is not uncommon to find that some factories were accredited and then at the time of the next big tender, they have supplied only a couple of units and/or they have never supplied anything for more than five years. Should their accreditation be valid, despite knowing that a lot can change in five years?

## 3.5 Design reviews

As part of procurement, the parties had to have a formal design review for every design introduced. The organization utilized external consultants to strengthen its resources and skills. The consultants had to first appreciate the challenges and limitations in the purchaser’s operational environment and the failure modes of various units. Unlike in the past where the organization often assessed already built transformers and reactors, with this arrangement it had an opportunity to influence the designs, thereby making sure that the requirements were correctly interpreted as pointed out in [1]. To be cost-effective and reduce the resistance to design changes, factories were contractually instructed not order any materials until a design is finalized and frozen. Any changes from the design review meeting, if they have any financial implications, were referred for approval to the commercial/project responsible, who were often present in the meetings.

The design review meetings dictate any special attention to pay during the production and testing stages. It is therefore influencing the type of the required intervention during the production. These design reviews were done in person at the factory where the transformer was to be produced. The challenges in design review included that in certain cases the recommendations of the consultants, coupled with what the customer required, were not in the comfort of the factory in terms of the technical know-how and general skills. These would be resolved either by providing further assistance to the factory or by agreement reconsider the requirement. In many cases, the engagements assisted the factories to expand their capabilities.

### 3.6 In-production inspections

These activities are intended to ensure that quality is built-in to a product without leaving everything to the acceptance testing time, because many aspects are not tested during the acceptance testing exercise and it is not possible to test quality into a unit. This, however, demanded a pool of skilled personnel and the organization did not have much manpower, especially in factories located outside the country. Satellite offices were established internationally and facilitated the dispatch of foreign, professional, 3rd party inspectors to factories around the globe. This was later terminated as it proved to be costly for the organization and was not meeting the intended outcomes as many of the 3rd parties were just ceremonially attending to these interventions and sometimes with inadequate skills. There were no negative consequences experienced after the withdrawal of the 3rd party inspectors, however, on the other hand, the organization continued with limited inspections, using internal resources, and emphasized that factories reinforced their processes as they were still responsible for providing equipment fit for purpose. This proved effective as many factories pride themselves in quality products. The organization still considers it important to have in-process inspections, however, the inspector’s skills and dedication must be adequate and world-class, respectively.

### 3.7 Shipping and transporting

Shipping was one of the interesting stages during this period. The organization had decided that it would do its own shipping as this was deemed cost-effective at that time. The downside of this arrangement was that the product responsibility would cross hands between factory dispatch and first commissioning. The factories were responsible for handling all the way up to the port of dispatch and then the product was handed over to the organization. At the port of arrival, it got handed back to the contractor before being transported to the site (destination), where was again handed over to the purchaser after completing the installation and commissioning. These handovers required electrical testing, mainly the active part insulation resistance and Sweep Frequency Response Analysis (SFRA), and detailed analysis of impact recorders to ensure that there were no deviations at handover. This too proved to be cumbersome as it hogged the already scarce resources when ships were delayed and while awaiting handover clearances. All these were at a cost to both parties at that time.

In the cases where a shipping incident happened, it was the purchasing organization, through its insurers, that had foot the bill for the equipment to be returned to the factory of origin. Even if the root cause of problems was pointing to the factory activities, the purchaser was still bearing significant costs due to this arrangement. This has since been reviewed and it alleviates the challenges mentioned above as suppliers are now responsible for the equipment all the way, until it is delivered at the site. This cuts out the need for numerous handover points.

This period was a game-changer in the organization, and it yielded many positive outcomes. Although there were teething issues and disappointing incidents on the products procured during this period, the overall of performance of the fleet procured during this time is excellent, it performs very well in service, with only a handful of units that failed or are running with risk. It demonstrated that there is a great gain for the industry when healthy relationships between suppliers and customers are upheld. The way to nurture this relationship includes:

Customers must

- have clear and detailed specifications,
- be open to suggestions by suppliers,
- communicate any operational problems to manufacturers
- have frequent engagements with manufacturers regarding any possible improvements that can be done.

The manufacturers must

- be diligent in studying and understanding the customer requirements
- pride themselves in quality products
- pay attention to customer problems and provide solutions
- provide open access policy for customers to the factory facilities
- be diligent in root cause analysis on incidents

The authors, therefore, consider that the effective and efficient procurement of power transformers and reactors cannot be put on one of the parties, it requires all the parties involved, including the suppliers, to have a common goal.

## 4. Transformer Procurement at present and in the near future

After the above period, the organization started to enter another era, mainly due to financial constraints that are concluded to be the tail end effects of the 2008/2009 global recession. Year 2014 had national government elections and therefore the political changes, as expected, impacted the country and the organization as well. It was in the same year that the talks to designate (maximizing the local spend on the production of) transformers and reactors intensified. Due to the need for financial savings, technical reviews were done to the equipment specifications. Consultants (internal and external), transformer suppliers, and peer organizations were integrated into this review for best outcome possible. Where gold plating and/or double risk mitigations were identified, adjustments were made to reduce transformer costs. An example of a double mitigation was the enamelling of all conductors while emphasizing that only non-corrosive oils were approved; so, from the review exercise, the enamelling of all conductors was left for the type of a conductor, no longer being a compulsory requirement. This, together with moving away from compulsory brands and then creating an open market in terms of auxiliary components, helped in reducing transformers and reactors' production costs. Since those organizational changes, more emphasis when procuring transformers has been placed on cost more than any other aspect. It is not intended to say this a wrong thing, but it is mentioned to highlight the challenge an engineer will face in trying to advance with technology for transformers and reactors. In all these changes, the technical specifications were kept relevant in achieving the following:

- Acquiring transformers that are fit for purpose and can remain reliable for the expected life span.
- Achieving optimized standardization thereby allowing a wide range of interchangeability.
- Promoting the drive for low maintenance, tending towards maintenance free technologies.
- Supporting the organization's and global drive for reducing the carbon footprint, zero harm to people and to the environment.
- Minimizing the total cost of ownership.

The cost cutting drive mentioned above caused our procurement process to be more laborious and longer, and at the end of the day, it is likely that among the bidders the cheapest winner takes it all. This is advantageous for the successful bidder and for the procuring body, in financial terms, as it means increased revenue and better price negotiation power, respectively. The undoubted downside of it, which our organization has experienced in various levels, is that all the eggs are in one basket and when issues surface, there is no immediate backup, and a large batch of the fleet is compromised. It is not always the case that a delivered transformer is risk-free. The other setback is that lead times quickly grow longer if the capacity and/or capability of the successful bidder reduces due to any of the many factors.

The enactment of the designation instruction in 2016 was a long overdue decision, however, its implementation at that time was too ambitious and rapid because the local market was not capable to meet the country's needs, specifically for the bigger sizes and voltages of 400kV and above. It was a blessing in disguise that since just before the designation started, the demand itself was much lower than in the previous years, however, that phase is also passing, and the demand is slowly picking up. It has then become clearer that designation implementation could have been rolled out better. At the time this paper was written, frequent exemption requests had to be made to the relevant body, either by the procuring organization or by transformer suppliers, and the process for it to be granted is not that simple. The eventuality of this is that it is taking longer than usual to go through the procurement process and realize the product. To be pro-active, projects to source transformers must now start much earlier, which is not always doable or foreseeable.

## 5. Transformer Procurement under COVID-19 pandemic

While dealing with all these changes, the arrival of the Covid-19 pandemic brought further challenges in the procurement process. The pandemic related restrictions meant that many of the activities in the traditional way of doing things were no longer viable, especially physical interactions. This compelled the organization to do things in a new way because transformers and reactors were still required for the sustainability of the network. This was achieved, but not without challenges as detailed in [5]. In [5], it is demonstrated that the collaboration between Eskom and the suppliers made it possible to manage the critical intervention points, although significant gaps exist in factory capability assessments. The conclusion of the authors in this case is that, for the near future, the factory capability assessment will always require a physical visit to assess the culture, production processes, and have access to confidential documents. At the time of writing this paper the organization was finalizing its framework of performing hybrid (desktop activities, online checks, and physical visits) factory assessments.

## 6. Conclusions

This paper, having reflected on the procurement of transformers and reactors by our organization, concludes that:

- The transformer procurement process is a complex activity that requires more than technical expertise and will always be dynamic due to the other integrated factors like politics, environment, legislative, and economic, just to count a few.
- The dynamic nature of the procurement process requires periodical reviews of the technical specification documents in order to ensure that they are always relevant for the intended equipment, irrespective of the prevailing factors.
- A strong collaboration between the customer and the supplier is of utmost importance to achieve world class equipment, which is advantageous for all the parties.
- The present assessment of tenders using the total cost of ownership is a good practice, however, it overlooks certain aspects, and the purchaser is likely to lose at the end

should the product significantly not last up to the expected life span. The authors suggest the inclusion of a factor that will take into consideration the supplier's experience and performance record.

- The wake of the COVID-19 pandemic is enforcing an accelerated paradigm shift in the way of executing most of the intervention points related to the procurement stage and these are continually changing.

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