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Strategic management process and SWOT analysis for adoption of maintenance strategies for wind turbine gearbox

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ABSTRACT

SWOT analysis is an important method for formulating strategic management decisions for an organization. An application to strategy formulation for the selection of optimal maintenance strategy is applied for a leading European wind turbine gearbox manufacturer. In this research study, an evaluation of both the organization external and internal analysis is considered, with expert input from the organization and condition monitoring systems manufacturers. The paper concludes with a confrontation matrix which evaluates the best maintenance approach that should be considered given the organizational strengths and weaknesses.

KEYWORDS

Corrective maintenance;
Condition based maintenance;
Condition monitoring systems;
Strengths;
Weaknesses;
Opportunities;
Threats;
Confrontation matrix.

INTRODUCTION

The acronym SWOT stands for “strength, weakness, opportunity, and threats.” The SWOT analysis is one of the key methods considered by an organization while evaluating its strategic positioning (strategic management process) in a competitive business environment. The main steps of the strategic management process are described in section 2.0[1,2,4]. The SWOT analysis is an important step for defining the relevancy of an organization’s current operational strategy. Through identification of weaknesses and strength of its current business strategy, the SWOT analysis can potentially allow the formulation and implementation of new business strategies and thus allow effective competition in the current dynamic business environment.

Studies carried out on wind farms have shown that effective maintenance strategy can lead to significant cost savings on the operation and maintenance cost throughout the life cycle of the wind turbine[1]. Thus the selection of an effective maintenance strategy could provide an important competitive edge for the manufacturer against their competitors. The organization under study pursues corrective maintenance policy. This policy is supported by off-line condition monitoring although it is pursued to a limited extent[5].

In this paper, a SWOT analysis is conducted for a leading European gearbox manufacturer in order to evaluate the company’s internal and external strength and weakness. The first section of this paper discusses the main concepts of the strategic management approach adopted in the research. The approach is divided into six major steps. The scope of this study will however be limited to the first two steps; identifying current mission, goals, strategies, and SWOT analysis. The second section evaluates the mission statement and operational strategy (current maintenance strategy pursued by the service department). The third section examines in-depth, strength, weakness, opportunity and threats. The SWOT analysis is categorized into two main sections; external analysis (opportunities and threats) and internal analysis (strengths and weaknesses). The fourth section describes elements of the confrontation matrix which enables the company to evaluate its strengths and weaknesses relative to external opportunities and threats. The last section concludes on the most important aspects of the strategic management process.

MATERIALS AND METHODS

Research methodology

The methodology adopted in this research is based on the strategic management process. The process consists of six major steps that encompass strategy planning, strategy implementation and evaluation. Figure 1 depicts these phases pursued in the strategic management process. The steps include[1]:

1 Identifying the organization's current mission, goals and strategies
2 Performing an external analysis
3 Performing an internal analysis
4 Formulating strategies
5 Implementing the selected strategies
6 Evaluating the results

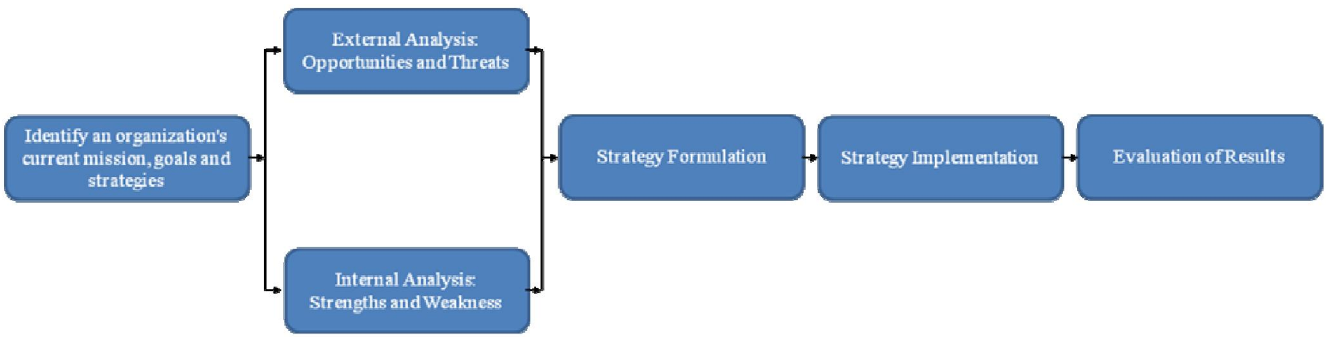

Figure 1 : A schematic representation of the strategic management process[1]

The first 3 steps of the strategic management process entail collection of data and a SWOT analysis. In data collection, the researchers conducted in-depth interviews with a team of experts from a leading European gearbox manufacturer and from Condition Monitoring System manufacturers. Apart from the interview sessions, relevant data and documentation pertaining to adoption of maintenance strategies for gearbox models was also evaluated. The reviews all involved:

- Site visits to the manufacturers premises
- Comparative analysis of documents and reports relating to the SWOT analysis
- Structured interviews with the team of experts from both manufacturers
- Analysis on historical data, including maintenance documentation.

Using the data obtained from the review, the SWOT analysis compared the state of the current maintenance strategy implemented by the gearbox manufacturer, in this case Corrective Maintenance and the best maintenance strategies applied in industry, i.e. Condition Based Maintenance. The SWOT analysis resulted in the identification of strengths, weaknesses, opportunities and threats for the gearbox manufacturer with implementation of CM strategy in comparison to implementing CBM. Results of the SWOT analysis is reported in section 2.1.

SWOT analysis

The SWOT Analysis procedure forms an important step of the strategic management process. The SWOT Analysis is divided into two major steps of performing:

- An external analysis
- An external analysis

The fundamental idea behind SWOT Analysis is the identification of appropriate strategies that ensure a strategic fit between the external environment that a firm competes in (threats and opportunities) and its own internal environment (strength and weaknesses). After identifying the strengths and weaknesses, an organization may proceed on to develop strategies that takes advantage of the strengths while on the other hand minimizing on weaknesses. The company concerned for in context of this study is a leading European gearbox manufacturer. The choice of an appropriate maintenance strategy for the company can be seen as reflecting the idea of an important fit linking the internal environment with the external environment.

A SWOT analysis was therefore conducted for the company and incorporated views and opinions of different experts within the organization. The composition of the team of experts included personnel from different departments that include service, product development, root cause analysis, and product design. Additional opinion was sought from leading European condition monitoring systems (CMS) manufacturers and suppliers[10]. Discussions held with the experts focused on the current operational strategy (corrective maintenance) pursued by the organization and consisted of informal interviews. The team of experts generated interesting ideas on what they consider to be the opportunities, threats, strengths and weaknesses of the current operations strategy, and benefits expected from implementing condition based maintenance (CBM).

Expert opinion was also sought from a team composed of CMS manufacturers. They provided useful information on the CMS cost structure, installation and operations of their systems; and further, information on the effectiveness of their systems in detection failure for wind turbine gearboxes manufactured by the organization and the different monitoring packages they offered for their customers.

All views collected from the interviewees was compiled and categorized into two main divisions; SWOT analysis for corrective maintenance, and SWOT analysis with CBM (proposed new operations strategy). The discussions resulted in a total of 11 opportunities, 9 threats, 9 strengths and 7 weaknesses. The SWOT analysis is discussed in two broad sections. The first section considers the current situation in which the company is implementing the corrective maintenance (CM) strategy. Section 3.3.1 presents an in-depth discussion of the SWOT analysis with CM. The next section considers a SWOT analysis in which the company is implementing CBM. This discussion is presented in section 3.3.2.

RESULTS AND DISCUSSION

SWOT analysis with corrective maintenance

The first part of the SWOT analysis considers the current maintenance scenario (business as usual), in which the company is implementing a corrective maintenance strategy. From the information gathered from the informal interview sessions with the team of experts and from the European CMS suppliers, a list of strengths, weakness, opportunities and threats is compiled and depicted in TABLE 1 and TABLE 2. The SWOT analysis with the current maintenance strategy implemented yielded a total of 5 opportunities, 7 threats, 8 strengths and 8 weaknesses. The SWOT analysis first considers the external analysis (opportunities and threats). This is followed by an analysis of internal strengths and weaknesses. The internal analysis is discussed in the next section.

TABLE 1 : Summary of external analysis with implementation of corrective maintenance

	Opportunities		Threats
O1	Conduct a criticality assessment to determine the end consequences of failure for a component. Such an assessment allows Strategy 1 (CM) to be maintained on non-critical while Strategy 2 (CBM) may be considered for critical failures.	T1	Gradual shift in the wind energy market from product warranty to service level agreement (SLA). This implies that Strategy 1 is not sustainable on the long term.
O2	Consider optimizing off-line condition monitoring schedule. This may enable technicians to diagnose failure early enough therefore allow for maintenance actions to be taken before catastrophic failure occurs.	T2	Large wind utility companies are more demanding on high product reliability and wind asset availability. Strategy 1 is not best suited to deal with this threat.
O3	Consider outsourcing their maintenance activities altogether and concentrate on the core business of designing and manufacturing wind turbine gearboxes.	T3	Growing competition in the wind turbine gearbox business: Several wind turbine gearbox manufacturers are offering maintenance service contracts based on Strategy 2. This new trend has the potential of eroding the company's market position.

	Opportunities		Threats
O4	Maintenance service provides an income for the company. This is through repair and restoration of gearboxes that have failed after expiry of warranty period.	T4	Reducing profit margins due to strong buyer bargaining position: This implies optimizing maintenance expenditure through measures such spare parts inventory management, resource scheduling.
		T5	Insurance companies require installation of CMS devices on wind turbines as a precondition for offering insurance cover for wind turbine. This is a potential threat for the company with implementation of Strategy 1.
		T6	Difficulty in providing proof against warranty claims: Due to lack of sufficient failure information usually derived from CMS, the company may be forced to compensate customers even for failures that originate from external sources (for instance damage initiated by the wind turbine rotor).

The external analysis: Opportunities and threats

The external analysis aims at evaluating the external business environment and allows the company's managers examine the environment in which they are competing in and to spot changes and trends in this environment. Further, the analysis allows a critical examination of opportunities that can be available to the organization through implementing condition based maintenance (CBM). An analysis of the external environment enables the identification and exploitation of opportunities that can enhance their competitiveness. The external analysis further identified threats in the external (business) environment that could adversely affect their competitiveness.

From the analysis, a criticality assessment for the wind turbine gearboxes is identified as a key opportunity for the company through the current implementation of corrective maintenance strategy. The assessment furthermore enables the identification and prioritization of failures considered as most important in terms of cost and safety. As such critical failures such as low speed shaft breakage should be minimized through application of different maintenance strategy such as predictive or preventive maintenance. Corrective maintenance may still be explored for non critical components such as oil level indicator.

Another key opportunity identified is the strengthening of off-line condition monitoring. By optimizing inspection intervals for off-line condition monitoring, the company's technicians are able to diagnose failure inception at early stages and thus carry out repair actions. The gradual market shift from offering customers with product warranty to contracts based on service level agreements (SLA) is identified as an important threat for the company. A SLA is a part of a service contract where the level of service is formally defined. This could be the number of operation hours or quantity of kilowatt hours generated on a wind turbine system running on a particular gearbox. An important component of SLA is the collection of failure information with a view of tracking failure development.

However, CM does not provide for collection of failure information at early stages of development in the wind turbine gearbox. This information is important in preventing catastrophic failure through initiating repair actions at early phases of the failure development. Thus CM makes it difficult to guarantee gearbox service level availability levels to clients and may lead to loss of business to competitors who base their contacts on SLA.

The internal analysis: Strengths and weaknesses

The internal analysis with implementation of CM reveals important information on resources and capabilities. These resources and capabilities allows for effective handling of threats in the external environment by maximizing on the available opportunities. TABLE 2 presents a summary of results of the company's internal analysis.

A key strength identified is the long experience with CM procedures. As a result the maintenance services department, and personnel training are all oriented towards the CM strategy. Therefore familiarity with the CM strategy may enable minimization of maintenance expenditures through cost saving measures developed within the service department. Additionally by implementing CM, the organization is able to avoid risks associated with adoption of new and unfamiliar maintenance strategies such as CBM. These risks include poor implementation of alternative strategy, need for change in organization structure, re-training personnel and resistance to change by employees.

Another key strength identified is the company's reputation for high service quality. This has enabled continued revenue earnings through the sale of service maintenance to clients. However, sustaining this reputation may be difficult with continued implementation of CM. In addition, the maintenance service market is fast growing and thereby attracting for many new competitors. These competitors are adopting alternative maintenance strategies such as preventive and predictive maintenance thus presenting a real threat on the company's market position.

Weaknesses identified indicate that CM is considered an inefficient maintenance strategy. By allowing the wind turbine to run to failure, high failure costs are incurred through repairing or replacing the wind turbine gearbox. These costs can especially be significant for off-shore applications and distant on-shore wind farms. Moreover, CM may result to a higher number of failures compared to the number of in-house technicians resulting in the need to sub-contract maintenance services (usually at a higher cost). Additional strengths and weaknesses are depicted in TABLE 2.

TABLE 2 : Summary of internal analysis with corrective maintenance

	Strenghts		Weaknesses
S1	Experience in implementing CM and thereby no additional capital investments in diagnostic equipment, staff training and failure information analysis.	W1	Possible increase in costs associated with repair or replacement of wind turbine gearbox failures. This is especially the case for repairs or replacement that would have been prevented by alternative maintenance strategies.
S2	Highly trained in-house personnel who execute CM tasks for the organization	W2	Implementing CM may lead to an inefficient use of resources. By failing to plan for maintenance, maintenance technicians are deployed based on actual failure occurences in the field. This is an inefficient approach.
S3	Reputation for high service quality among clients. This enables continued revenue streams on maintenance services despite implementing CM.	W3	CM prevents optimization of spare parts inventory. This may lead to long repair lead times especially if the required components need to be ordered from suppliers.
S4	CM requires low capital investment for implementation (cost of purchasing repair tools, diagnostic equipment,..)	W4	Implementing CM may erode reputation for high product quality and thus shrinking their market share. This is due to high incidence of unexpected gearbox failures.
S5	The company does not incur the full costs of gearbox failure within the warranty period. These costs are shared between with customer.	W5	Implementing CM prevents collection of gearbox failure data that would otherwise be useful for improving product reliability. Data on failure mechanisms is especially useful for reliability improvement of new gearbox designs.
S6	Implementing CM provides generates additional revenue through servicing failed gearboxes for clients after expiry of the warranty period	W6	Long down time hours: wind turbine breakdowns may occur at inappropriate times (for instance during high winds or stormy weather). This may lead to long repair lead times resulting in high penalty costs.
S7	Extra costs associated with implementing CBM is not incurred. These costs include failure data analysis, staff training, maintenance scheduling and setting up communication infrastructure (IT networking, ERP systems, spare parts management systems,…).	W7	Safety and environmental compliance: Sudden gearbox failures can potentially cause accidents (broken components could be thrown off as projectiles) or potential environmental damage (for instance leaking gearbox lubricant,..).
S8	Strong pool of maintenance service technicians. This allows the organization to effectively deploy the technicians to respond to failures in different wind sites.		

SWOT analysis with condition based maintenance

This section considers SWOT analysis in a scenario where CBM is implemented. The SWOT analysis is also based on information collected from experts and CMS suppliers. The SWOT analysis with CBM is likewise discussed in two parts; the external analysis and the internal analysis. A summary of results for both the external analysis and internal analysis is presented in TABLE 3 and TABLE 4.

The external analysis: Opportunities and strengths

The external analysis considers the external environment conditions and how they affect operations. Important opportunities identified include the potential for reduction on operation and maintenance costs and the shift in the wind energy market from product warranty to service level agreement. These opportunities are discussed in the following paragraphs.

The reduction in operation and maintenance costs though implementation of CBM is seen as one of the key opportunity for the company. The reason is seen in the potential of CMS devices to diagnose failure at very early stages which enables optimal scheduling of maintenance actions. As such cost savings associated with secondary damage to other gearbox components or catastrophic gearbox failure can be prevented. Furthermore, warranty claims arising due to gearbox failures occurring before the expiry period can be minimized resulting in substantial cost savings. Additional cost savings opportunities are gained through optimizations of spare parts inventory and maintenance equipment hiring logistics (cranes, diagnostic equipments, boats, …).

The shift in the wind energy market from offering product warranty to service level agreement is also identified as a key opportunity. This shift is attributed to the fact that large utility firms are acquiring large wind assets and thereby reducing the number of players in the sector. It is thus projected that this market consolidation by the wind energy utility companies will create few wind energy customers with huge bargaining power. The team of experts is of the opinion that this will eventually cause a market shift towards service level agreement. This opinion is supported by a market survey on the wind energy market carried out by[14,15].

In external analysis, several threats were identified. A key threat identified is the potential loss of revenue by the maintenance service department. The main revenue sources include servicing broken down wind turbine gearboxes, replacement of damaged components, lubrications and cleaning. Much of this revenue is generated from wind turbines whose warranty has expired. By implementing CMS, the customer is better informed on the condition of their wind turbines through access to failure analysis reports. This information allows the customer to make better maintenance decisions (for instance when to change lubricant, or replacing a worn out component) and choice of maintenance services (the customer may decide to source for services from a different maintenance contractor). For these cases, loss of substantial revenues through implementing CBM may be possible.

TABLE 3 : External analysis summary with CBM

	Opportunities		Threats
O1	Pursue CBM through partnerships with CMS suppliers and wind turbine manufacturers. This could provide an opportunity for extend product warranty or offering contracts based on SLA.	T1	Potential revenue loss through customers initiating independent maintenance decisions: With installation of CMS devices, customers are better informed on the gearbox condition and may choose to allocate maintenance tasks to an alternative service provider.
O2	Implementing CBM may enable the company reduce on claims resulting from gearbox failures within the warranty period	T2	Loss of revenue due to shift of gearbox service . Clients may decide to use failure reports from CMS to initiate their own maintenance actions (freedom to choose when and who to maintain their wind turbine gearboxes).
O3	Implementing CBM may allow for improve on the reliability of the wind turbine gearbox through utilizing failure information from CMS devices.	T3	Several wind turbine gearbox manufacturers are implementing CBM. This results in the saturation of predictive maintenance services and thereby creating strong competition among the manufacturers.
O4	Implementing CBM amy provide an opportunity to increase market share through enhanced customer confidence.	T4	Decisions regarding selection and installation of CMS devices are made by the wind turbine manufacturer and not component suppliers. Under such an arrangement, it is difficult to decide on which CMS systems to install on gearboxes.

	Opportunities		Threats
O5	Implementing CBM may result in reduced operation and maintenance expenses (these include cost of hiring cranes, equipment downtime losses, and gearbox replacement)	T5	Design of CMS devices is fast evolving. This implies that the company should negotiate favorable contractual terms (CMS upgrades, retro-fits,..) to avoid situations where the organization installs CMS devices that soon become obsolete
O6	Implementing CBM may allow for better scheduling of maintenance activities and thereby optimize deployment of resources required to carry out repair actions (deployment of technicians, cranes, vessels,..)	T6	Wrong life predictions for wearing parts in the wind turbine gearbox: Current CMS systems periodically give out false alarms. These alarms may reduce availability (by unnecessarily shutting down the wind turbine). Furthermore, resources may be expended in responding to the alarms.
O7	Implementing CBM, may allow for optimization of spare part inventory which may result in significant maintenance cost savings	T7	Risk of losing intellectual knowledge to competitors through failure reports sent to customers. This information may be used by competitors on competing gearbox designs.

The internal analysis: Strengths and weaknesses

The internal analysis with CBM provides important information on their resources and capabilities. These consist of both tangible and intangible resources. On the one hand, tangible resources include financial (cash in bank), and physical (machinery, manufacturing facilities,…). On the other hand, intangible assets include its gearbox design knowledge, reputation for quality and highly skilled designers and technicians. TABLE 4 depicts a summary of the internal analysis.

Results of the internal analysis assist managers in identifying the organizational strengths and weaknesses. The organizational strengths include activities the company does very well, while organizational weaknesses are those activities that they don't perform well. TABLE 4 summarizes results for internal analysis.

A strong research and development team was identified as a key strength for implementing CBM. The implementation of CBM is viewed as a long term strategy and requires a dedicated team with the right technical capabilities. This implementation phase is usually associated with several technical difficulties (selecting the right device, interpretation of failure information and optimal maintenance scheduling). If the CBM implementation is poorly managed, the entire strategy may fail. Thus with a good team possessing the right

TABLE 4 : Internal analysis summary with CBM

	Strenghts		Weaknesses
S1	Overcapacity in manufacturing facilities: This enables quick respond to market demand that may arise from implementation of CBM.	W1	Lack of an own an in-house CMS device. Therefore to implement CBM, the company has to rely on partnerships with CMS suppliers.
S2	Strong research and development team: This reduces the learning curve during early implementation phases for CBM.	W2	Limited in-house knowledge on CMS devices: This knowledge is especially critical during selection of appropriate CMS devices.
S3	Reputation for high quality wind turbine gearboxes: Installing CMS involves high upfront investment. Thus the company may use its strong market reputation to encourage uptake of CMS by their clients.	W3	CMS devices available in the market are not capable of diagnosing all possible failures that may occur on the gearbox. This limitation prevents the company from fully benefiting from implementing CBM.
S4	Strong business relationship with wind turbine manufacturers: This relationship may enable the company influence the choice of CMS to be installed in their gearboxes.	W4	Implementing CBM requires high upfront cost. These include CMS installation costs, setting up condition monitoring infrastructure and hiring skilled personnel to analyze failure data.
S5	Strong business relationship with CMS manufacturers: This enables a substantial gain in cost savings (bulk purchasing of CMS devices) during implementation of CBM.	W5	Optimum selection of CMS systems requires reliable data on actual field operating parameters (wind speed, dynamic forces on rotor,..). However the company lacks reliable failure data on which to base the CMS selection.
S6	Strong integrated service department that supports growing service activities. This enables the effective schedule maintenance and deploy repair personnel to carry out repair actions in different wind turbine sites.	W6	Technical staff lack the necessary skills and knowledge (for instance analyzing failure information) on CBM. This impacts negatively on the implementation of CBM.

technical skills and knowledge, these difficulties can therefore be managed.

A strong business relationship with CMS suppliers and good product reputations were also identified as key strengths for the successful implementation of CBM. Implementation of CBM is usually capital intensive and requires substantial financial resources. These costs include selection (trial runs and experiments), purchase of CMS devices and setting up monitoring infrastructure. Depending on the contractual agreement (for instance the CMS supplier may provide monitoring services) between a gearbox manufacturer and CMS suppliers, additional costs may include establishing monitoring infrastructure, hiring skilled personnel on CMS, and training of in-house staff. Therefore, a good working relationship with CMS suppliers may enable the organization benefit on CMS technological know-how. Additional benefits may include financial savings through bulk purchasing and CMS device upgrades (hardware and software).

An additional important weakness identified is the difficulty in selecting optimum CMS devices for wind turbines operating in varying wind regimes. Currently, the company relies on an in-house test bench for conducting trial runs on different CMS devices. However, the test bench only simulates ideal environmental conditions and does not account for dynamic loads on the gearbox (resulting from varying wind regimes). Therefore failures diagnosed by the CMS device on the test bench may not necessarily represent actual failures that will occur during actual operation of the wind turbine gearbox. This may result in the selection of inappropriate CMS devices for the gearboxes.

Confrontation matrix

The confrontation matrix is created through combining the strengths, weaknesses, opportunities and threats of a product or strategy (the strategy under consideration is implementing the CBM policy for wind turbine gearboxes)[33]. The confrontation matrix is used to answer the following questions[12]:

1 How can the company use a specific strength to take advantage of an opportunity?
2 To what extent can the company use a specific strength to anticipate a threat?
3 How can the company use a weakness be improved to participate in an opportunity?
4 How can the company improve a weakness to defend itself from a threat in the external environment?

The confrontation matrix is used to develop strategic actions and plans. In the confrontation matrix, strong and weak points are confronted with external threats and opportunities. The confrontation matrix determines which strong points, weak points, opportunities and threats should be targeted with a new strategy. The cells in the matrix (which indicate combinations of opportunities and threats with strengths and weaknesses) are used for listing risks of different strategic actions or options. The strategic options are defined through pair-wise combination of strength-opportunity, strength-threats, weakness-opportunity and weakness-threats. These pair-wise combinations are illustrated in TABLE 5[13].

TABLE 5 : Confrontation matrix using SWOT analysis results as strategy options framework[13]

	OPPORTUNITY	THREATS
STRENGTH	How to use a strong point to take advantage of an opportunity **Offensive approach**	How to use a strong point to battle a threat **Adjusting approach**
WEAKNESS	How to improve a weak point so that an opportunity can be seized **Defensive approach**	How to improve a weak point so that a threat can be faced **Surviving approach**

TABLE 6 shows the results of the confrontation matrix for the company. The matrix depicts the different strategies which can react to in any of the four approaches (offensive, adjusting, defensive and survival).

The current approach for the company can be described as the adjusting approach. Based on the adjusting approach, the company is aware of threats facing its competitive position in the wind turbine gearbox manufacturing market. Some of these threats include the market shift from product warranty to service level agreements and the consolidation of large wind utility companies (this consolidation creates few buyers with huge bargaining potential and thus driving down wind turbine prices). To effectively react to these threats, implementing CBM should be considered. This enables the organization optimize on their maintenance costs. Implementing CBM creates additional benefits through reduced failures and better component failure prediction (CMS allows early failure prediction of the remaining useful life of gearbox components). As part of its CBM implementation action plan, the company is quantifying the expected gains through implementing CBM. These studies include determination of total life cycle cost (LCC) comparing corrective maintenance and condition based maintenance. Furthermore, in-house experiments on condition monitoring devices from different CMS suppliers are being considered. The studies are aimed at determining the feasibility of implementing CBM. Additional adjustment approaches currently being undertaken include new product innovation.

TABLE 6 : Confrontation matrix

	OPPORTUNITY	THREATS
STRENGTH	**Offensive approach:**	**Adjusting approach:**
	SO1: Harness the idle manufacturing capacity and strong R&D to quickly respond to increased market demand resulting from implementation of CBM	**ST1:** Leveraging reputation for high maintenance service quality and thereby minimising threat of potential shift of their customers to other maintenance service providers.
	SO2: Explore the possibility of retraining its in-house technicians and designers on CBM.	**ST2:** Technological leadership in geartrain technology can be combined with CBM to develop high reliability gearbox designs. This will enable the company to fend off competion from manufacturers of direct drive wind turbine.
	SO3: Leverage the strong customer base to pursue partnerships with wind turbine manufacturers aimed at standardising CMS for their gearbox designs	**ST3:** Position the company so as to take advantage of market consolidation by wind energy utility firms. Implementing CBM may provide a strong competitive edge.
	SO4: Explore possibilities for technological partnerships with CMS suppliers.	**ST4:** Consider utilising failure data from CMS devices to improve on product reliability. This may enable the company counter the growing threat from direct drive wind turbine manufacturers.
	SO5: Consider extending warranty periods on gearboxes or consider offering SLA to large wind utility firms.	**ST5:** Consider using CBM stratergy to reduce operational costs. This may enable the company remain profitable despite reducing gearbox prices.
	SO6: Cost savings gained by optimizing maintenance costs may be invested in strengthening product reliability. Further, CBM may allow pursuit maitenance service excellence (world class maintenance excellence).	**ST6:** Pursue technological partnerships with CMS suppliers. This may allow for a better understanding of CMS devices and thus make better selection choices.
WEAKNESS	**Defensive approach:**	**Surviving approach:**
	WO1: Consider partnering with CMS suppliers as part of implementing CBM, instead of developing their own condition monitoring device	**WT1:** The gradual trend towards service level agreement (SLA) is shaping the wind business environement. Implementing CBM may enable the company take advantage of this trend.
	WO2: Technological partnerships with wind turbine manufacturers may enable standardisation of CMS devices on all gearboxes manufactured irrespective of the wind turbine design	**WT2:** With growing competition from maitenance service providers, the company may consider using CBM to further mprove their maintenance service quality.
	WO3: Weak financial position and high investment cost for CBM are limiting factors to aggresively take advantage of high growth in the wind business	**WT3:** Market consolidation by large wind utility firms imply the need to to create strong supplier partnerships with wind turbine manufacturers. This may be through better maintenance service quality resulting from implementation of CBM.
	WO4: Explore on improving on knowledge of their maintenance staff through providing learning opportunities. This is possible through partnerships established with CMS suppliers.	**WT4:** Consider outsourcing specific CBM activities for instance on-line monitoring of wind turbine gearbox and analysing failure information. This would reduce the cost incurred through sustaining these activities (in terms of personell cost and maintaining monitoring infrastructure).
	WO5: Consider hiring in-house experts on CMS. These experts would be instrumental on the implementation of CBM.	**WT5:** Utilising the CBM stratergy to achieve product innovation (with improved reliability) and maintenance service excellence.

The offensive approach builds on the existing strengths. The offensive approach is considered the most appropriate since it enables the organization to fully take advantage of the available opportunities in the external environment. A possible offensive approach that may be considered is offering extended warranty periods to clients. Additional offensive approach may include offering service level agreements to large wind utility companies. This may be possible through harnessing the advantages resulting from implementation of CBM (being able to predict remaining useful life of gearbox components). Such an offensive approach would allow for an increase in market share and thereby sustain market leadership in manufacture of wind turbine gearboxes. An additional offensive approach is through using CBM to raise their maintenance service to world class standards. Raising their service excellence may enable effective utilization of maintenance service as a strategic tool for leadership in the gearbox manufacture market. Failure data from the CMS devices is important in enabling product improvement through redesign. This presents an opportunity to further improve product reliability and sustain their market position.

The defensive approach builds on existing strengths in order to fight off threats. The main focus of the defensive approach is to enable the company defend its market position. Defensive approaches that may be considered include providing training to their technical staff on CBM. This allows for development of important knowledge required to effectively sustain the CBM strategy. This may be achieved through in-house training sessions, inviting consultants on CBM, or training by CMS suppliers. However, CBM should be viewed as a long term strategy whose benefits can be realized on the long term. Therefore CBM implementation programs should also be developed for the long term. Additional defensive approaches may include hiring their own in-house experts.

The surviving approach is aimed at minimizing existing weaknesses in order to be in a good position to fend off threats. One of the main threats is the growing market consolidation of large wind utility companies. These utility companies are more demanding on product reliability and quality of maintenance services. CBM may be used as a tool for improving the maintenance service levels. This would enable effective positioning of the organization to take advantage of the market consolidation. Despite having far-reaching effects, part of the maintenance service may be outsourced to specialist maintenance service providers with thorough understanding of CBM. This avoids the need of having to commit resources towards implementing and sustaining CBM. An additional survival approach is through pursuing product innovation and service excellence. These goals may be achieved through implementation and effective application of CBM.

CONCLUSIONS

The wind energy business environment is fast evolving. This requires that an evaluation of current operation strategy(s) and their applicability in the current business environment. The strategic management process has been applied for a leading European gearbox manufacturer to evaluate its current operation strategy (corrective maintenance) and strategic options are available for adoption. A SWOT analysis is carried out to determine the company's positioning with respect to its internal strengths and weakness and how capable the organization is to face opportunities and threats in the business environment. Two scenarios are considered which include the corrective maintenance and condition based maintenance. Further in order to understand the requirements for future strategic actions, the confrontation matrix analysis is applied.

The findings from the SWOT analysis and confrontation matrix show that the company is currently adopting an adjustment approach. This means that the company is well aware of its internal strengths and external threats facing the organization. By implementing condition based maintenance (CBM) strategy, the company is better placed to respond to major threats such as a market shift towards SLA. The organization is however not in a good position to strongly respond to challenges in the business environment. The main reasons for its weak position include manufacturing overcapacity and weak financial position. Despite these positions, pursuit of partnerships with wind turbine manufacturers and CMS suppliers is a viable option. These partnerships may enable leverage of weak financial position and through implementing CBM.

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