Deriving maintenance strategies for cooperative alliances – a Value Chain approach

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Abstract

This paper proposes a decision-helping framework to select an optimal maintenance strategy, consisting of three dimensions: maintenance technique, maintenance organization and maintenance reach. Suggesting that the decision can be made by applying the Analytical Hierarchy Process, this framework builds upon customer value drivers, capabilities and stakeholder expectations to ensure sustainable competitive advantage for cooperative alliances. The results show, that partnering with others to tackle emerging maintenance challenges can be a source of competitive advantage.

Keywords: maintenance strategy, Analytic Hierarchy Process, cooperative alliances.

Introduction

In Germany, maintenance is regulated by industry standards and the professional bodies are engineering organizations. Consequently, maintenance is often regarded as an engineering topic and does not always get the management attention needed to unleash its power to create competitive advantage. This paper aims at linking the engineering-based subject with the contemporary management theory of Value Chain networks.

Garg & Deshmukh (2006) provide an overview of recent literature in maintenance management. Sherwin (2000) introduces different maintenance concepts. A series of three books by Kelly (2006) presents a detailed introduction into selecting, implementing and controlling maintenance strategies.

Decisions concerning technology management are complex and multiple criteria decision-making models need to be applied (Habenicht, 1990, p. 342). The Analytic Hierarchy Process (AHP) introduced by Saaty (1994) provides a clear structure as well as an intuitive and comprehensible way of how weights and ratings are derived. In theory and practice, this method is a highly regarded decision-helping framework that could be used to derive a suitable maintenance strategy. Some authors described the selection of a maintenance strategy by using the AHP. Labib et al. (1998) and Wang et al. (2007) described a model with fuzzy criteria. Bertolini & Bevilacqua (2006) provided a combination of goal programming and AHP. Other works modeled the organizational decisions associated with maintenance using AHP (Bertolini et al. 2004; HajShirmohammadi & Wedley, 2004). None of them, however, considers the implications for cooperative alliances.

The contribution of this paper is to propose a decision-supporting framework of how to decide on a maintenance strategy for firms forming a cooperative alliance. Not only does it take the two traditional dimensions of maintenance technique and maintenance organization into account, it also suggests a third dimension, one that is specific to companies that are part of cooperative alliances: "maintenance reach". It describes why it could be advantageous to develop a maintenance system for the whole Value Chain network, rather than concentrating on a single firm. Thus, the research question is: "How can maintenance strategies be derived that fit the requirements of Value Chain oriented companies"? First, this paper introduces the AHP and then concentrates on the specifics of Value Chain networks. Third, it proposes suitable criteria and alternatives underlying the decision for a maintenance strategy. The framework is then tested in two interviews in the German wind-turbine industry.

Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) aims to propose a best alternative from a given set of options by ranking them. It helps to structure complexity, measurement and synthesis of rankings (Bhushan, 2004, p. 15). As the name suggests, it consists of three components (Bhushan, 2004, p. 19; Harker, 1989, p. 13).

Analytic: It uses logical reasoning, which allows for better understanding the problem and communication of the decision (Harker, 1989, p. 3). *Hierarchy*: The AHP clearly structures the decision problem into levels corresponding to the decision-maker's understanding: goals, criteria, subcriteria and alternatives. It "indicates a relationship between elements of one level with those of the level immediately below" (Bhushan, 2004, p. 16). The root of the hierarchy represents the objective of the problem put under scrutiny. The leaf nodes are the alternatives to be compared. In between, various criteria and subcriteria are mapped. The AHP allows the decision-maker to concentrate on smaller sets of decisions, since only the contribution of the lower level element to the upper level one, are compared (Saaty, 1994, p. 22). This simplification is needed to make a decision at all: humans are only able to compare 5 to 9 items at a time (Yoon, 1995, p. 9). *Process* describes that decisions are not made on the spot. They need to be constantly reconsidered. The AHP aids this, by showing where more information is needed and where major disagreements lie (Harker, 1989, p. 13; Saaty, 1994, pp. 21-22).

The AHP is based on four axioms (Bhushan, 2004, p. 19; Harker, 1989, pp. 14-15). Firstly, for any two actions a_i and a_j out of the action set A, the decision-maker is able to provide a pairwise comparison a_{ij} under any (sub) criterion from the set of (sub) criteria on a ratio scale which is reciprocal. Secondly, when comparing any two actions, a decision-maker does not rate the one infinitely better than the other. Otherwise, there would not be a decision problem. Typically, the decision-maker will compare the pairs on a scale often to be found between 1 and 9. But it can assume any range, as long as the upper limit is less than infinity (Harker & Vargas, 1987, pp. 1388-1391). Thirdly, the decision problem can be formulated as a hierarchy. Fourthly, this hierarchy represents all criteria and alternatives, which have an impact on the problem.

These axioms clearly show what the tasks of the AHP will be: Firstly, to formulate and solve the decision problem as a hierarchy. Secondly, to obtain judgements in the form of pairwise comparisons. The derived local preference ratios lead to ratings of the alternatives; and importance ratios lead to criteria weights (Vincke, 1992, p. 54). Software can support this process, but determining the ratios that best represent the real world system can be difficult. Saying that one option is between three to five times better is not allowed in the AHP. It demands the decision-maker to decide whether it is exactly three, four or five times better (Wang, Chu, & Wu, 2007, p. 153)

Each criterion results in one matrix, showing the results of relative comparisons between all alternatives (n). The reciprocal assumption of axiom 1 lowers the effort to fill the matrix to n(n-1)/2 comparisons. The diagonal elements of the matrix need to be

1. The element in the *i*-th row is better than the element in the *j*-th column, if the value of cell (i,j) is > 1. The overall rating of an alternative is then derived by normalizing the columns (eigenvector method). The same procedure is also applied to derive the weights of each (sub) criterion. The literature provides evidence that the eigenvector approach (for an introduction see Forman, 1990, pp. 299-301), as chosen by Saaty (Saaty, 1994, pp. 28-29), has been theoretically proven and is suitable in practice for estimating ratings and weights (Harker & Vargas, 1987, p. 1392). In contrast to other methods, AHP allows errors to be made in the preference structure. Thus it allows inconsistencies within the preference matrix and points them out, so that the decision-maker can revise his judgments (Harker & Vargas, 1987, p. 1384). Inconsistency means that the ratio between A and C is not exactly equal to the product of the ratio between A and B, times that between B and C (Vincke, 1992, p. 54). The literature concludes that 0.1 is an acceptable limit for inconsistency (Harker, 1989, p. 16; Saaty, 1994, p. 27). This would mean that with a 10% chance the questions were answered randomly.

The overall ranking of alternative (a) is derived by using the principle of hierarchic composition: It sums the priority (w_a^c) of alternative (a) under criterion (c) times the priority (v_c) of criterion (c):

$$w_a = \sum^{C} v_c w_a^c \qquad (1)$$

This principle is found to be intuitive and straightforward and can be easily applied in practice (Harker, 1989, p. 17). But it is also responsible for the rank-reversal problem, extensively discussed in AHP literature (see Dyer, 1990, p. 252).

The Value Chain Network Approach

To derive the criteria needed to evaluate proposed maintenance strategies, this paper takes the view of an enterprise that is part of a virtual network, subsequently described as a Value Chain network. If two or more financially and legally independent companies decide to partner beyond market transactions, a network organization is founded (Siebert, 2003, p. 8). Typically it is aimed at reaching mutual goals, such as access to new technology, market expansion, joint R&D, profiting from economies of scale, or influence on political decisions (Gerybadze, 1995, p. 471). Cooperation is considered to be strategic if the scope is closely related to the individual company's goals and if it is aimed at being long-term (Schonert, 2008, p. 89).

Even though a comprehensive theory for cooperation rationale is still absent and the notion of network organizations remains somewhat vague, its potentials in leveraging the shortcomings of the traditional alternatives "market" and "hierarchy" may be important. Networks provide the specialization of a *market organization*, allowing each partner to specialize in those activities it performs best (capabilities) and it also emphasizes the importance of efficiency, forcing partners to leave the network if performance requirements are not met. Knowledge sharing and trust are the two components of a *hierarchy* that networks embrace. The former makes sure that the whole network is learning and sharing all information needed to run processes effectively. The latter means that no partner in the network will engage in opportunistic behavior, such as exploiting other partners (Child, 2005, pp. 50-52).

Looking at an industry as a whole, networks or virtual organizations (McHugh, Merli & Wheeler, 1995, p. 4) are competing with other virtual organizations, rather than single companies with each other (Walters & Rainbird, 2007, pp. 163-164). These virtual organizations are strongly customer value focused. They identify, produce, deliver and service customer needs along the Value Chain.

The Value Chain, introduced by Porter (1985) at a company level, can be extended to describe networks of organizations. Value Chain networks are: “Multi-enterprise organizations integrating supply chain efficiencies with [effective] demand chain management processes that anticipate customer expectations and ensure the availability of products and service in the right place, at the right time, at the required level of service and at the lowest possible supply chain cost” (Walters & Rainbird, 2007, p. 164). Except that the word “chain” does not describe the concept correctly. Instead of a rigid sequential chain the system is a “dynamic, high-performance network of customer/supplier partnerships and information flows” (Bovet & Martha, 2000, p. 2). Within such an arrangement, owning resources or process steps is less important, the access to resources via partnerships is paramount (Boulton & Libert, 2000, p. 34).

The strategic goal of the Value Chain network is to find an optimum between operational efficiency and strategic effectiveness in order to build competitive advantage (Walters & Rainbird, 2007, p. 36). A network can only achieve competitive advantage if it creates value for all stakeholders (Kay, 1995, pp. 23-24). Value in this context is defined as ensuring customer and stakeholder satisfaction (Walters & Rainbird, 2007, p. 24). From a *customer* perspective, the value of a product offer is its benefits received minus its lifecycle costs. *Customer value drivers* are derived from demand chain analysis and include effective management of assets, performance, cost, time, information and risk (Walters & Rainbird, 2007, pp. 104-105). From a *stakeholder's* perspective, creating value incurs cost. Each organization will have to make a decision about the relationship between value generated for its stakeholders (value drivers) and the cost of the value process, namely the costs of creating, producing, communicating, delivering and servicing the value (cost drivers).

Criteria

To assess a given maintenance strategy, a company as a part of a Value Chain network will consider the following criteria that are relevant to achieving sustainable competitive advantage. The first-level criteria chosen are asset management, performance management, cost management and risk management. They are intentionally closely related to customer value drivers, since the Value Chain network acknowledges the central importance of the customer (Walters & Rainbird, 2007, p. 8). Nevertheless, they also reflect the main concerns of stakeholders, such as cost or risk. The customer value drivers of time management and information management are not used as main level criteria, to reduce the number of criteria. They were nonetheless considered, but have been integrated with performance management (e.g. production cycle time) and risk management (e.g. transparency of information), respectively.

Asset management ensures that assets used for equipment maintenance enhance the performance of the customer or B2B partner, meaning for example that relevant spare parts and tools are provided to maintain the equipment. It is also concerned with increasing the overall equipment lifecycle and ensures that a partner engages only in investments that match its capabilities. Simultaneously, this also meets stakeholder expectations, since the overall effectiveness of asset management throughout the Value Chain network is guaranteed, including that of the own company. Figure 1 points out the subcriteria used for this and the following criteria.

Performance management ensures that the product delivered is superior to those of competitors. The customer benefits in that he selects the best available product and a B2B partner is in business with the leading company in its field. A proposition to ensure growth of output and market share, this clearly reflects stakeholder expectations as well. Subcriteria for this value driver are closely related to service levels. A high service level demands that products are delivered in the right place, at the right time, at the required level of service and at the lowest possible cost (Walters & Rainbird, 2007, p. 164). But the service level is not directly used as a subcriterion. The dimension of cost is not incorporated, to avoid duplication with the criterion “cost management”. Maintenance will only have a small impact on the dimension “in the right place”, since this is closely related to distribution logistics and not production. “At the required level of service” is ensured by product quality, being the only determinant maintenance can influence. The main focus of this criterion is to ensure that products get delivered at the right time.

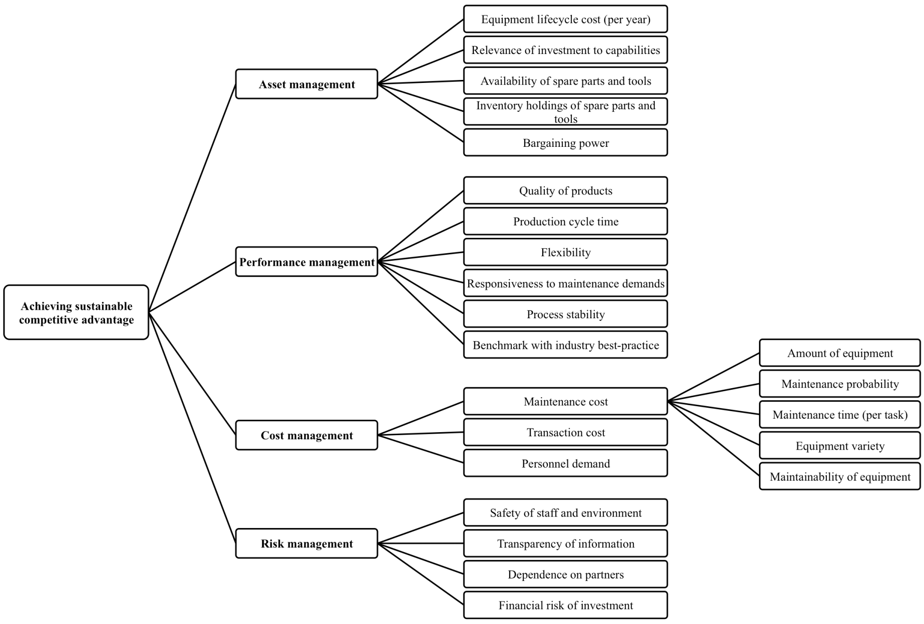

Figure 1: Criteria to evaluate a maintenance strategy

Cost management ensures a low price for the customer, making cost-leadership positioning possible. It also meets stakeholders’ expectations of a high profit margin, if not all cost advantages are given to customers. The subcriterion maintenance cost is broken down into five components: amount of equipment, maintenance probability, maintenance time, equipment variety and maintainability of equipment.

Risk management ensures that the risks for customers and Value Chain network partners are minimized. This is also of major concern for stakeholders. Only if the implied risk of the maintenance strategy is controllable, can the proposed strategy be of advantage (Walters & Rainbird, 2007, pp. 104-105).

In order to be of value and to ensure sustainable competitive advantage, the criteria and subcriteria shown in figure 1 need to address customer value drivers, capabilities and stakeholder expectations. *Customer value drivers* are central to the proposed framework and therefore represent the main criteria. Not only will they ensure that the end-customer but also that the intermediatory-customer, namely Value Chain partners, can maximize their utility. Subcriteria such as “availability of spare parts and tools”, “quality of products”, “flexibility” and “process stability” are to be expected as being the drivers for customer satisfaction. The *capabilities* of each Value Chain partner need to be addressed by a suitable maintenance strategy. Each Value Chain partner only performs those activities it can do better than other partners. Hence, this part needs to make certain that a partner only engages in activities that match with its capabilities. The subcriteria “relevance of investment to capabilities”, “inventory holdings” and “dependence on partners” reflect the capabilities of a company. *Stakeholder expectations* are being met by considering “lifecycle cost”, “bargaining power”, “benchmark with best-practice”, “maintenance cost”, “personnel demand”, “safety of staff and environment”, “transparency of information” and “financial risk”.

Three dimensions of a maintenance strategy

As shown in figure 2, a maintenance strategy can be described along three dimensions: maintenance technique, maintenance organization and maintenance reach.

Maintenance techniques can be divided into three branches (Swanson, 2001, pp. 237-238). *Reactive maintenance* (or fire-fighting tactics) only takes place if the system has stopped working. *Proactive maintenance* tries to foresee upcoming problems in the system to prevent total failure (it includes concepts such as Preventive Maintenance, Predictive Maintenance and Reliability-Centered Maintenance). *Aggressive maintenance* techniques have emerged, since advances in personnel qualification and information systems made them viable. Tactics such as Total Productive Maintenance (TPM) and Effectiveness Centered Maintenance (ECM) propose an all-encompassing strategy to achieve better performance while lowering failure rates.

Maintenance organization deals with the implementation of the selected maintenance technique and provides three options: organizing maintenance in-house, contracted maintenance or outsourced maintenance. Contracted maintenance keeps the planning of maintenance in-house, whereas with outsourced maintenance all strategic and operative tasks are performed by a third party.

The *reach of a maintenance strategy* describes how many parties are involved in setting-up a strategy: a single-plant, a single-company or the Value Chain network. A *single-plant* strategy is a decentralized approach, where every plant of a company chooses the strategy that best fits its needs. When more sophisticated strategies are implemented, *single-company* strategies are more likely to be deployed. They allow sharing the set-up cost of aggressive maintenance or increase the bargaining power via outsourcing providers. On the other hand, it is quite unrealistic that a company-wide strategy will fit all locations, especially if cultural differences or disparities in technology occur. If maintenance is organized *Value Chain wide*, opportunities form pooling spare-parts and staff arise. Moreover, if the operator of a system works closely together with the OEM’s engineer who designs the equipment, maintainability can be increased and thus the TPM goal of maintenance-prevention can be achieved in the long run (Nakajima, 1988, p. 38). If all partners of the Value Chain adopt this policy, gains will occur faster. Spare parts inventories can be reduced throughout the Value Chain network (Bovet, et al., 2000, p. 128), if all partners strive for standardization of equipment. Standardized equipment also reduces complexity, lowers training requirements for staff and increases knowledge transfers. Investing in new technology can be less risky if jointly undertaken with partners. And if the production process along the Value Chain is more reliable due to coordinated maintenance activities, disruptions of the Value Chain are less likely. But the implementation of such a venture may take several years, requires a high level of trust and causes high transaction costs.

When combining the three proposed dimensions of a maintenance strategy, 27 possible combinations arise. But evaluating all alternatives may not be feasible due to time and cost constraints. Moreover, some alternatives may not be easily distinguishable. A company, such as the owner of a wind turbine, may therefore decide to only consider a subset of all possible alternatives for evaluation with the proposed criteria, such as the proposed options A, B and C (see figure 2).

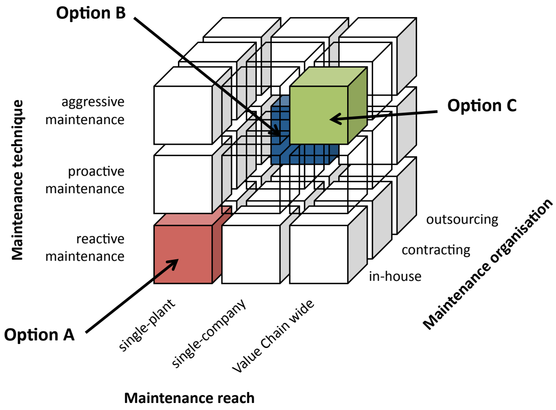

Figure 2 – The alternatives for selecting a maintenance strategy

Option A: "Maintenance as a necessary evil"

This option represents the traditional maintenance strategy as it was often found before 1950. It chooses a *reactive maintenance technique*. Hence no planning of maintenance activities takes place; the qualification of personnel can be kept at a minimum. If failures can be repaired quickly, overall maintenance time can be reduced and direct maintenance cost will be low. However, the equipment lifecycle is expected to be relatively short. The quality of output and the performance of the system will be unreliable and fluctuate highly. The safety of staff and the environment may also be in danger. One large centralized maintenance department conducts all maintenance tasks *in-house*. This can be beneficial since low transaction cost occurs. But the responsiveness to peak maintenance demands may be poor, if too few staff are employed. Maintenance is done in-house even if it does not constitute a capability. The reach of this strategy is concentrated on the *single-plant*, allowing every plant to select the policy that best suits its needs. It also implies that the overall company policies can be completely different; knowledge sharing and transparency of information remain low. Overall inventory holdings for spare parts and tools in turn can be expected to be high, since they are duplicated at all locations. This option may be best for small companies with low and predictable maintenance demand (such as for office printers and computers). For maintenance-intensive industries this alternative would not find consideration, since it results in unpredictable maintenance outputs.

Option B: "Maintenance is outsourced"

This option represents the modern approach to maintenance, and can be found in maintenance-intensive industries such as aviation. The chosen *maintenance technique* is proactive. Hence, the company tries to foresee upcoming maintenance requirements to lower total breakdowns. For this option, Predictive Maintenance tactics will be used, because up to date equipment allows real-time monitoring and diagnosing to prevent failure. This allows for extension of the equipment lifecycle, predictability of outputs, process stability, as well as improved production cycle times, due to a higher availability of equipment. The cost, especially for training staff and purchasing the required information systems, may be a disadvantage of this approach. The maintenance tasks themselves are *outsourced*. The chosen form is business process or vertical outsourcing. The third-party guarantees the company the time availability of equipment to a level of, say 98% of a year (performance contract). To be able to control the risk arising in the partnership, it is assumed that performance reviews (based on the derived criteria) are done on a frequent basis. These tactics clearly emphasizes the relevance of the investment to the firm's capabilities: The owner of the equipment recognizes that maintenance is not one of their main tasks and therefore partners with a company, which specializes in the field, has the required level of personnel qualification and the necessary spare parts and tools. Additionally, the responsiveness to changing maintenance demands is higher. Clearly, the dependence on partners and transaction costs are of concern and therefore a possible hindrance for choosing this path. The reach of Option B does not go beyond the *single-company*. If the activities of all plants are outsourced to the same service provider, economies of scales arise and costs can be lowered. That said, the cost of this approach increases if several plants of the company are geographically dispersed. This option is suitable for companies with medium to high maintenance demand and with equipment that allows monitoring of its degradation status. To implement it, finding the right partner will be a challenge.

Option C: "Maintenance as a priority"
This option is visionary. Not only is maintenance a top-management priority, it is also a value driver for stakeholders and customers. ECM is the selected *aggressive maintenance technique*. It is a combination of the all-department encompassing TPM approach, striving for zero breakdowns and zero defects, as well as RCM which focuses on the most critical equipment. Hence, longevity of equipment and high product quality are ensured. TPM is aimed at designing-out maintenance requirements by closely working together with equipment engineers, thus increasing maintainability of equipment. The shortcomings lie on the cost side, since highly qualified personnel are needed, for example. But by focusing on the most important systems, the cost and the time to implement this tactics can be reduced. Autonomous maintenance tasks are performed *in-house*. The underlying assumption of this is that maintenance is a priority for the company and reflects its capabilities. TPM requires this approach, since a close relationship between maintenance personnel and operators is needed. Hence, maintenance is decentralized within the company. A Value Chain wide *reach* is found to be optimal for this alternative. The firm works closely together with its partners along the Value Chain to optimize the maintenance systems of all partners. The advantages of this approach include access to spare parts and tools, lower variety of equipment, a higher bargaining power, transparency of information and a dispersed financial risk. Transaction cost can be lowered since partnerships are assumed to be long-term. Companies already working closely together with Value Chain partners will have an advantage in implementing Option C. The vision of this alternative is especially applicable for companies that operate in maintenance-intensive industries.

Findings in the German Wind Turbine Industry

To test the framework, two AHP-based expert interviews were conducted in the German wind turbine industry, one with a service company and one from the perspective of a turbine owner. Over the 20 year-lifespan of a turbine, maintenance costs are expected to be up to 54 per cent of the initial investment, representing 26% of annual operating costs (Bundesverband WindEnergie, 2010). Consequently, the wind turbine industry can be described as a maintenance-intensive industry and thus maintenance strategy could be an important source of competitive advantage. The interviews were based on the hypothetical situation of selecting a maintenance strategy for a wind park with some 50 MW of installed capacity. Table 1 reports the aggregated results for each of the three alternatives, while distinguishing between the two interviews. It also states the relative weights in respect to the overall goal (achieving sustainable competitive advantage). The overall inconsistency was found to be irrelevant in both interviews (.02 and .03 respectively). Both interviewees selected Option C as best suiting their needs. This is interesting since industry common-practice is a proactive, outsourced, single-company approach (Option B).

Table 1: AHP based results form the two conducted interviews.

	Wind turbine service company				Wind turbine owner			
	Critera weight	**Option A**	**Option B**	**Option C**	***Critera weight***	**Option A**	**Option B**	**Option C**
Achieving sustainable competitive advantage		24.0%	27.3%	48.7 %		12.0%	43.0%	45.0%
Asset Management	*30.0%*	9.8%	35.8%	54.3%	*4.2%*	15.7%	61.7%	22.6%
Performance Management	*30.0%*	9.9%	30.3%	59.7%	*13.5%*	7.8%	49.4%	42.7%
Cost Management	*30.0%*	55.7%	12.3%	32.0%	*45.4%*	15.5%	36.5%	47.9%
Risk Management	*10.0%*	13.5%	37.3%	49.2%	*36.9%*	8.7%	46.5%	44.7%
Maintenance Cost		13.2%	19.0%	67.8%		6.2%	36.7%	57.1%

The results show a clear effectiveness orientation for the outsourcer and an efficiency orientation for the equipment owner. For the *service company* Option A has clear advantages in cost management. Certainly, maintenance cost can be lowered, if no preventive maintenance is conducted. However, considering the whole lifecycle these advantages may be more than compensated. Option B scores well in three categories: asset management, performance management and risk management; but is still dominated by Option C. Option B scores the lowest in cost management, due to the fact that it has to deal with a high variety of equipment and high transaction costs. Option C is found to be the best alternative in all criteria but cost management. It shows clear advantages in increasing and ensuring the performance of a wind turbine, while lowering maintenance costs. For a *wind turbine owner*, alternative A is not considered an option at all. It scores the lowest in all categories and is therefore discarded. Option B is found to score the highest in managing the assets, in performance management and risk management. But the relative importance of cost management is high, resulting in the selection of Option C. Since options B and C lie closely together, a sensitivity analysis was conducted. For most subcriteria the difference between the relative weight and the sensitivity threshold are found to be large, indicating stable results.

The relative weights of subcriteria for performance and risk do not vary considerably between the interviews. This is different for asset management and cost management, however. *Asset management*: For the outsourcer, the most important subcriterion was bargaining power, with a relative weight of almost 50%. The least important are total lifecycle cost and inventory holdings. Lowering total lifecycle cost was the most important to the owner, followed by availability of spares. *Cost management*: When it comes to maintenance cost, the owner does not agree that the variety and maintainability of the equipment play a major role. However, the outsourcer ranks the variety the highest. Clearly, if maintenance is outsourced, the variety becomes the "problem" of the outsourcer. The major cost driver for the outsourcer is personnel cost. With almost 82%, maintenance cost are the main concern for the owner, showing the cost pressure he will try to pass on to the outsourcer.

Conclusion

The proposed framework derived criteria, subcriteria and alternatives for selecting a maintenance strategy for a company in a value chain network. The shown results imply that Option C could be a feasible and viable alternative to Option B, which is the standard for maintenance in the wind turbine industry. Surely the two interviews just illustrate how a decision can be made. They are far from being representative for the whole industry. Nevertheless, the idea behind Option C could be worthwhile examining.

Offshore wind parks will require well-planned maintenance. Teaming up with others and switching to Option C could be the answer to arising challenges and to gain competitive advantage in the long-term.

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