UNIVERSITY OF AGDER

Developing a Supplier Performance Analysis Model

Case study: Aker MH supplier performance

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This Master's Thesis is carried out as a part of the education at the University of Agder and is therefore approved as a part of this education. However, this does not imply that the University answers for the methods that are used or the conclusions that are drawn.

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Preamble

This thesis is the last part of a Master degree program in International Management & Business Administration at University of Agder (UiA), Kristiansand.

I want to thank everyone who helped during the development process of this thesis. In particular, I thank my supervisor Gøril Hannås, professor from University of Agder and Vidar Bjørkmann, Manager in Component Purchasing, Aker Maritime Hydraulics. Their help and support was very valuable throughout the process.

Abstract

This master thesis focuses on the use Data Envelopment Analysis (DEA) for measuring supplier performance. Goal of the study is to apply a mathematical model for supplier performance measurement which would be able to handle multi-criteria. To test the model in practice, cooperation was established with case study firm (Aker Maritime Hydraulics), which is providing drilling engineering solutions to Oil & Gas industry. Proposing the model for measuring performance of existing suppliers not only demonstrates how DEA can be applied, but also sets the grounds for supplier performance improvement process in a case study firm. At the same time, this thesis makes a small contribution to academic literature on supplier performance measurement by introducing an application in new setting. To reach the goal of the study, the following Research Question is defined: *How can Data Envelopment Analysis be used as tool for measuring supplier performance?*

After the early works related to supplier performance evaluation (Dickson (1966), Lambertson et al (1976)), this field received increasing attention. Mathematical model called Data Envelopment Analysis and developed by Charnes, Cooper and Rhodes (1978) was adopted as one of the tools for measuring supplier performance and resulted in multiple academic articles regarding different application settings and model extensions, e.g. Weber and Desai (1996), Narasimhan et al (2001), Talluri et al (2006), Zeydan et al (2011) etc. Applications of DEA covered various settings - first public, then private organizations. To the best of knowledge, DEA was not applied for supplier performance evaluation in Norwegian Oil & Gas industry related technology firm. In addition, this thesis presents an extended approach of measuring suppliers' relative performance by comparing perceived Ideal supplier and existing suppliers based on performance.

In this thesis, suppliers' performance was measured in terms of efficiency in utilizing inputs (supplier's average price trend over 5 years) to produce outputs (quality, delivery precision, invoice matching to purchase order). Out of 19 suppliers analyzed, DEA identified 2 efficient suppliers. Ideal Supplier, when included in the model, was identified as efficient, together with the same two efficient units that were identified in first application. Findings revealed that three worst performing suppliers accounted for more than half of firm's total spending towards a supplier group, while best five accounted for only 12.4%.

Criteria that both Aker MH used for supplier performance measurement and also this study used for DEA application (price, delivery, quality) is consistent with academic research

results on most important supplier evaluation criteria (Dickson, 1966) and most often used criteria for supplier evaluation in academic research (Weber et al 1991).

Contents

1. Introduction

This master thesis focuses on measuring supplier performance and uses Data Envelopment Analysis (DEA) as a tool. Goal of the study is to apply a mathematical model for supplier performance measurement which would be able to handle multi-criteria. To test the model in practice, cooperation was established with case study firm (Aker Maritime Hydraulics), which is providing drilling engineering solutions to Oil & Gas industry. Study contributes positively for the case study firm by measuring the performance of existing suppliers and setting the grounds for supplier performance improvement process, while at the same time filing the possible gaps in academic literature on supplier performance measurement. The common challenges in supplier performance measurement are such as selecting the applicable criteria for measurement, considering multiple criteria simultaneously and allocating weight for each criterion. The selection of a tool in the thesis is supported by documented abilities of DEA to cope with mentioned challenges.

Researchers' attention on supplier performance measurement increased significantly during past few decades. One of the very first works related to supplier performance evaluation dates back to 1960's, when Dickson (1966) analyzed managers' perception on most important criteria for supplier performance evaluation. His work was later reviewed by Weber et al (1991) re-ranking criteria based on 74 academic articles on supplier performance evaluation. Articles were issued during 1970's – 1980's. Lamberson et al (1976) used weighted linear model while Ellram (1995) proposed a Total Cost of Ownership conceptual approach to perform supplier evaluation. Charnes, Cooper and Rhodes (1976) introduced a mathematical programming tool for efficiency measurement called Data Envelopment Analysis, which was able to handle multiple criteria evaluation simultaneously. Since 1990's this development was adopted by scholars and provided multiple applications in supplier performance measurement (Weber and Desai, 1996; Narasimhan et al 2001; Talluri et al 2006). A classic DEA deterministic model received some extensions and applications for supplier performance evaluation. Wu and Blackhurst (2009) introduced augmented DEA, Zeydan et al (2011) combined DEA and other modeling tools for supplier performance evaluation.

The thesis is valuable in two aspects – scientific and practical. Over the years, DEA had different settings, and this study provides a small extension for DEA model applications on supplier performance measurement. Supplier performance measurement in Norwegian Oil & Gas industry related firm is the setting, which received little or no attention, thus the thesis tries to fill a gap in academic literature. In addition, suppliers are evaluated in relation to company's perception of expected performance. This then raise a discussion on how firm sets and communicate the performance goals to its suppliers. From a practical point of view, company receives proposition on how the performance of its suppliers can be measured on a multiple criteria basis without the need of weight allocation. This should be of importance for a firm seeking constant improvement and representing Southern Norway – a region leading in delivering drilling solutions for Oil & Gas industry worldwide.

In accordance, this thesis answers the following research question:

- *How can Data Envelopment Analysis be used as a tool for measuring supplier performance?*

The thesis contains the literature review of supplier performance measuring tools and measurement criteria. Then the DEA model is presented, explained and adopted for supplier evaluation. Thesis contains a short introduction to a case study company – Aker Maritime Hydraulics – and its suppliers under investigation.

The first step consists of performance analysis of comparable suppliers using Data Envelopment Analysis. The second step is introducing *Ideal Supplier* into the measurement process and analyzing how existing suppliers perform in relation to expected performance. *Ideal Supplier* – is a supplier with a performance level (set of attributes) that is perceived by Aker MH as an expected performance from suppliers. Thesis ends with presentation of findings, conclusions and possible extensions of the study

In this thesis, MS Excel Solver feature is used to conduct DEA, based on preprogrammed DEA model application by Professor Josef Jablonsky (Head of Department of Econometrics, University of Economics, Czech Republic). Software was documented in 2009 (Journal of Management Information Systems).

2. Literature Review

This part provides the review of scholar work within the supplier performance measurement literature. It also contains a discussion on why supplier performance measurement is an important process and what challenges firms meet when conducting the process. This stands as an input into a later discussion on how can Aker MH AS conduct the supplier performance measurement process.

The importance of supply chain management has increased in a second half of the 20^{th} century. Trent and Monczka (1999) described and foresaw executive managers' perceptions, and pointed out that throughout the 1990's there was a trend of increasing understanding of the supplier importance to the firm and that this trend would continue to hold. It is now considered that supply chain management may lead to a sustained competitive advantage. Purchasing process, being part of the whole supply chain management concept, is about providing the firm with essential components, to make it able to run its own value generating activities. This is where supplier's capabilities and willingness to act in accordance with buyer's needs and expectations play a crucial role. Dealing with suppliers and achieving the desired results is a constantly challenging task. The following chapter introduces a framework on achieving high quality supplier performance.

2.1. Getting Better Performance from Suppliers

Trent and Monczka (1999) introduced a framework, which if executed properly, would help firms achieve high quality current and future supplier performance. This framework contains the *"action plan"* – activities that are presented across three dimensions: (1) implementation complexity, that refers to skill, resources and time needed to execute the activity; (2) the rate of performance improvement expected from successful execution of activity; (3) is activity basic, moderate or advanced. See Figure 1. The following are the activities Trent and Monczka (1999) used in their framework.

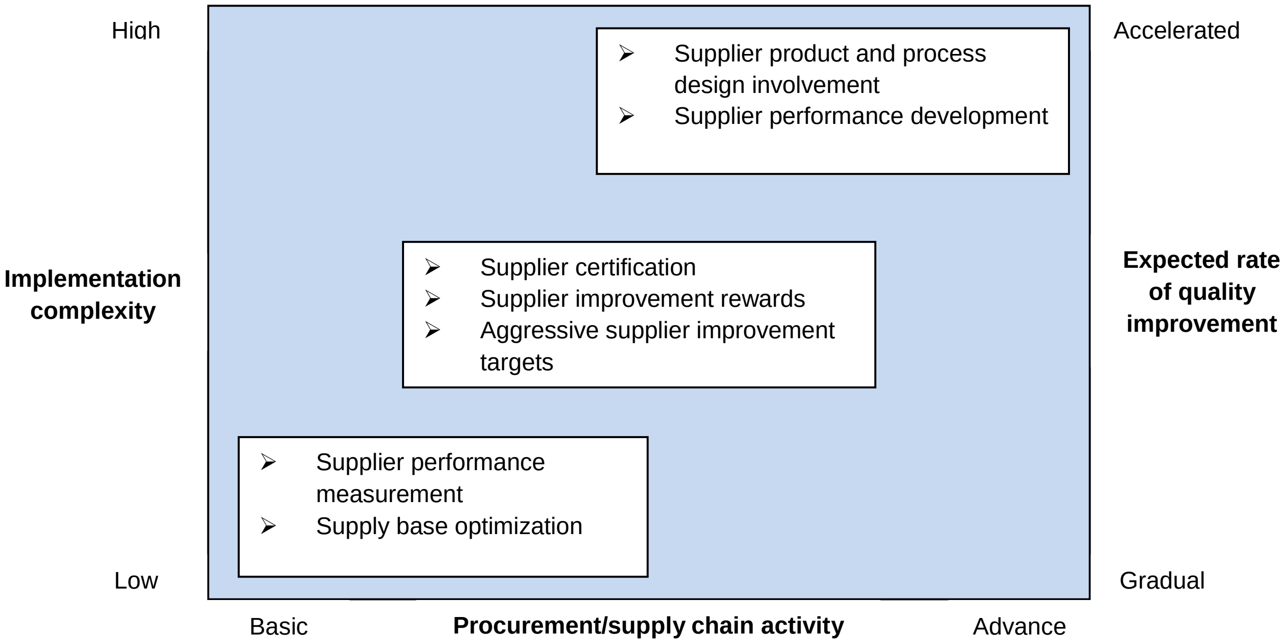


Figure 1. Achieving World Class Supplier Quality
Source: made by author, according Trent and Monczka, 1999

Supplier base optimization. This activity is about maintaining the right mix and number of suppliers to have business with. Simply stated, managing 300 suppliers is easier than managing 2000, and in addition, optimization should lead to a higher average performance of suppliers, assuming that during the optimization process the best set of suppliers is kept. Optimization is only a first basic step to increasing supplier quality, but should be performed by firms, thus laying the foundation for more complex activities.

Measuring supplier performance. Trent and Monczka (1999) argue the importance of supplier performance measuring practices that need to be introduced within the firm. They claim that the use of the data is what makes the evaluation systems valuable, rather than the act of measurement itself. Procurement managers conduct supplier evaluation in order to determine (1) supplier improvement opportunities, (2) performance trends, (3) best suppliers to select, (4) where should the supplier development resources be committed, (5) overall effectiveness of supply chain improvement efforts. Supplier performance measurement process provides opportunities for determining supplier performance and capabilities.

Establishing aggressive supplier improvement targets. Supplier improvement programs may fail to increase supplier performance. Therefore, Trent and Monczka suggests introducing aggressive performance targets, meaning that firm would be expecting the supplier performance to improve faster, than firm's competitors might experience from their suppliers. Once the supplier proves that it can meet the expectations, another set of objectives takes place, thus encouraging constant improvement.

Performance improvement rewards. Purchasers might be reluctant to share the gain that originated from improved supplier performance in the exact same way, as a supplier may be reluctant to reveal its internal improvements and trying to enjoy the gain on its own. There should be a relation between the performance improvement and rewards. Trent and Monczka (1999) suggest some of possible ways to encourage supplier to perform better: longer purchasing contracts, higher total share of purchasing volume, publicly recognize suppliers, provide access to new technology or include suppliers in early stage of new product development. Improvement rewards can accelerate the speed of performance improvement and foster closer buyer – supplier relations.

Supplier certification. Certification means that supplier's processes and operating methods are in control and that incoming material, components, or even system modules do not require further inspection. *"Certification usually applies to a specific part, process or site rather than an entire company or product"* (Trent and Monczka, 1999). A certification process needs a comprehensive measurement system that would identify worsening supplier performance.

Contributing resources to supplier development. According to Trent and Monczka, firms pursue supplier development programs for two reasons. The first is to improve an existing supplier performance capabilities, the second is to develop a new performance capability. Developing a new capability can also help the firm revise the supplier base. Firms must consider carefully the resource allocation for supplier development programs. Some supplier may not need that because of excellent results they are currently showing, others on the other hand, may not have it in them to become a high quality performance supplier.

Supplier involvement in early process of product development. Early supplier involvement approach recognizes that qualified suppliers can offer a firm more than just manufacturing according to given specifications. Such supplier can provide early insights on how to produce efficiently and effectively given their capabilities, how to simplify a product's design, thus affecting quality and cost levels.

Flynn and Flynn (2005) analyzed synergies between supply chain management and quality management and agreed with Trent and Monczka (1999), claiming that customers are the actual drivers of supply chain management, and that they are responsible for what they get from suppliers. Marlow and Casaca (2003) referred to Trent and Monczka (1999) framework by emphasizing the importance of setting targets for continuous supplier performance improvement and employing reward system for suppliers. Rodriguez et al (2005) extended Trent and Moncka's (1999) framework by further categorizing supplier development practices based on the level of firm involvement and implementation complexity.

It must be notified, that one of the first steps in applying the framework, is the supplier base revision and supplier performance measurement practices in the firm. Despite being basic low complexity activities, they steer the whole supplier development process, meaning that the actions taken throughout the development process and the end results of process largely depend on how these first steps are implemented. According to Beamon (1999), common challenges in supplier performance measurement are such as, what criteria to use for measurement, how to incorporate multiple individual measures into a system. In addition to that, the existence of statistical noise has to be accounted for. Dealing with multiple challenges affects the extent to which the results of the model can be interpreted and considered to be valid. That puts the pressure on supplier performance measurement model in use. To provide a better grasp of the supplier measurement practices, the following chapter reviews the supplier performance measurement models and criteria suppliers were measured by.

2.2. Previous Research on Supplier Performance Measurement

In the present time, it is very difficult to produce low cost and high quality products without having a satisfactory supplier base. Thus, evaluating the suppliers is one of the critical decisions that purchasing managers have to encounter, and it has a significant practical impact. Such perception dates back to as far as 1940's in purchasing literature. For example, the work of Howard Lewis (1943) was quoted by Weber et al (1991) – *"It is probable that of all the responsibilities which may be said to belong to the purchasing officers, there is none more important than the selection of a proper source. Indeed, it is in some respects the most important single factor in purchasing"*. Purchasing scholars agree that, in general, firm's purchases account for 50 % or even more of the total product costs (Weber et al. 1991; Noordewier et al. 1991).

The following literature review consists of two scopes – first section presents with previous research on which criteria were used in supplier performance measurement process, while second part describes the previous research regarding the methods used for supplier performance measurement.

2.2.1. Supplier Performance Measurement Criteria

To avoid misinterpretation, this section begins with distinguishing terms *supplier performance measurement/evaluation* from *supplier selection.* The scope of this thesis is supplier performance measurement, meaning that suppliers under investigation (those, whose performance is being measured) are already in the contractual relationship towards a certain firm. That is, measuring performance of existing suppliers. A term *supplier selection*, on the other hand, refers to a state of pre-contractual relationship, when suppliers are being evaluated before doing business with them. The need to distinguish between these two terms stems from the review of literature on criteria and methods used for supplier evaluation and performance measurement, where some authors used the mentioned terms interchangeably and made it difficult for the reader to distinguish. It has to be, however, admitted that selection process is difficult without measuring the performance and that measured performance guides the selection process.

Being an extremely important process, supplier performance measurement is a complicated matter in a way that there often are many criteria to be considered when measuring the performance of supplier. For this reason, selecting criteria that are most relevant to any given situation is a very important task. Therefore, some researchers focused on the criteria selection issue. Dickson (1966) conducted a research while trying to identify the most important criteria which are regarded in supplier evaluation. In order to get a comprehensive view, he questioned the purchasing representatives from United States and Canada and summarized their responses in a 23 criteria list for supplier evaluation. Those criteria were divided in 4 groups, ranging from extreme importance to slight importance. Table 1 presents top 6 ranked criteria which, based on Dickson, have the *extreme* or *considerable* impact.

Rank	Factor
1	Quality
2	Delivery
3	Performance History
4	Warranties and claim policies
5	Production facilities and capacity
6	Price

Table 1. Criteria Rankings by Dickson. *Source: made by author, according Dickson, G.W. (1966)*

After a few decades, in 1991, Weber at al. reviewed Dickson's classification by conducting own analysis on supplier (performance) evaluation factors used in scholar literature. They analyzed the literature dating 1968 – 1990 and re-ranked the factors used by Dickson. A total of 74 articles were analyzed, and evaluation and performance measurement criteria extracted, systemized and ranked. Table 2 shows the top 6 ranked factors, according to Weber et al. It is important to mention, that Dickson's work regarded the criteria as used for supplier selection as so did Weber et al (1991). The reason this thesis presents the work of Dickson and Weber et al, is to reflect the purchasing managers' and researchers' organized perception on the important supplier evaluation criteria.

Rank (D)	Rank	Factor
6	1	Net price
2	2	Delivery
1	3	Quality
5	4	Production facilities and capacity
20	5	Geographic location
7	6	Technical capability

Table 2. Criteria Rankings by Weber. *Source: made by author, according Weber et al. (1991)*

It is worth mentioning, that for more than two decades (60's to 80's), *delivery* and *quality* stayed amongst the most important evaluation factors, while *price* became the most often used criteria by researchers. The *geographic location* factor presents the case of greatest shift upwards in perceived importance when measuring supplier attractiveness. It became the 5th most often used criteria in supplier evaluation in Weber's work, while in Dickson's work, *geographic location* did not receive significant attention from purchasing managers.

Considering the supplier evaluation criteria since 1990's, a sustained usage of price, delivery and quality factors is seen. Those same criteria were used by Weber and Current (1993), Naraasimhan et al (2001), Prahinski and Benton (2004), Chang et al. (2007) for supplier performance evaluation. Some authors expand their criteria sight, by adding additional criteria such as cost reduction performance (Naraasimhan, 2001), flexibility or level of service (Chang et al., 2007), while others argue environmental factor importance when evaluating supplier's performance (Lee et al., 2009). As there were many different approaches to which criteria should be used, there were a number of approaches to supplier performance evaluation methods as well. Researchers used various analysis methods to approach the issue during the past several decades. Next chapter presents closer the methods and criteria used for supplier performance measurement since last decade of 20th century.

2.2.2. Supplier Performance Measurement Methods

Narasimhan et al (2001) suggest that strategic evaluation of supplier performance helps firms improve their operations in various aspects. "*Performance measurement is defined as the process of quantifying action, or more specifically the process of quantifying and analyzing effectiveness and efficiency" (Easton et al., 2002)*. It drives the actions of managers and especially helps in supplier process improvement which then enhances firm's performance. It also makes the grounds for optimal resource allocation for supplier development programs and aids managers in restructuring the supplier base. Therefore, the correct metrics are critical for firm's performance.

One of the interesting approaches of supplier performance measurement was presented by Lisa Ellram (1995). She elaborated on philosophy of Total Cost of Ownership (TCO), showing that any link in the supply chain (e.g., supplier) or the whole supply chain can be evaluated and understood better based on the total purchasing costs the firms experience from various purchasing activities related to one supplier. The Total Cost of Ownership approach includes purchasing costs originating from management activities, quality handling activities, delivery handling activities, price determination activities, communication activities, and service related activities. She underlined that this approach can be widely implemented, for example, for measuring supplier performance, for supplier selection or for evaluation of the whole supply chain.

Past few decades provided number of supplier evaluation works based on mathematical or quantitative approaches to supplier evaluation. Narasimhan (2001) claims that supplier performance measurement literature can be divided into three methodological streams: conceptual, empirical and modeling. Lee (2009) proposes that mathematical programming (MP) models can be divided into linear programming, mixed integer programming, and goal/multi-objective goal programming (MOP). Some research on mathematical programming in supplier performance measurement was discussed by Weber and Desai (1996) and Weber, Current and Desai (1998). Multi-objective programming (MOP) is a tool used when there are several criteria under analysis, rather than one single criterion. Weber and Desai (1996) applied Data Envelopment Analysis (DEA) tool to evaluate suppliers providing an individual product and demonstrated the advantages of using DEA. Weber, Current and Desai (1998) combined the two methods – Data Envelopment Analysis and Multi-objective Programming for supplier evaluation and selection to deal with non-cooperative supplier negotiation strategies.

Talluri, Narasimhan and Nair (2006) presented an overview of some of the multi-criteria, mathematical programming and advanced methodologies that were used for supplier evaluation. (Table 3)

Methodology	Authors
Weighted Linear Models	Lamberson et al. (1976), Timmerman (1986), Wind and Robinson (1968)
Linear Programming	Pan (1989), Turner (1988)
Mixed Integer Programming	Weber and Current (1993)
Grouping Methods	Hinkle et al. (1969)
Analytical Hierarchy Process	Barbarosoglu and Yazgac (1997), Hill and Nydick (1992), Narasimhan (1983)
Analytical Network Process	Sarkis and Talluri (2002)
Matrix Method	Gregory (1986)
Multi-objective Programming	Weber and Ellram (1993)
Total Cost of Ownership	Ellram (1995)
Human Judgment Models	Patton (1996)
Principal Component Analysis	Petroni and Braglia (2000)
Data Envelopment Analysis	Narasimhan et al. (2001), Weber and Desai (1996), Weber et al. (1998)
Interpretive Structural Modeling	Mandal and Deshmukh (1994)
Game Models	Talluri (2002), Talluri and Narasimhan (2003)
Statistical Analysis	Mummalaneni et al. (1996)
Discreet Choice Analysis Experiments	Verma and Pullman (1998)
Neural Networks	Siying et al. (1997)

Table 3. Supplier Evaluation Methodologies. *Source: Talluri, Narasimhan and Nair (2006)*

Although multiple methods were applied for supplier evaluation, Talluri, Narasimhan and Nair (2006) argued that incorporation of stochastic considerations received little attention, and therefore proposed a chance-constrained DEA model in order to account for measurement and specification errors. Following chapter reviews DEA model usage in various settings, and in particular for supplier performance measurement in previous academic work.

2.2.3. DEA Model in Previous Research

This chapter first presents DEA model applications in different settings. A few examples of applications within Norway, Oil & Gas sector and Supply Chain Management are then presented in more detailed manner. This is done in relation to the model application setting in the thesis– suppliers' performance measurement in a company within Oil & Gas industry in Norway.

Different settings of DEA applications

Epstein and Henderson (1989) describes DEA method as a linear programming-based technique that converts multiple input and output measures into a single comprehensive measure of productivity efficiency. Narasimhan (2001) refers to DEA as a nonparametric multi-factor productivity analysis model that evaluates the relative efficiencies of a homogenous set of decision making units in the presence of multiple input and output factors. The information provided by DEA may possess a major advantage over benchmarking and other techniques where only one measure can be evaluated at a time, gaining no insight into overall efficiency (Easton et al, 2002). On the other hand, Schmidt (1985) argued that DEA model produces biased estimates in presence of measurement error or other statistical noise. Assumption, that DEA selects the weights for variables so that it would result in maximum efficiency score, means that relatively lower variable value receive lower weight, and that is the source of biases. Banker (1993) showed both that DEA is a maximum likelihood estimator of efficiency and that the estimates are consistent, meaning that biases are tend to decrease when the sample size is increasing. Ruggiero (2004) showed that the biases stem from the fact, that unit under analysis is biased relative to the frontier, and the frontier is biased upward due to measurement error. He also indicated that biases can be evaded if the model is used on averaged data set.

DEA applications are quite widely documented in the academic literature and vary with regard to what the Decision Making Units are. That may be public or private companies, departments within the companies, or even companies across countries. One of the early works in DEA applications was the Charnes, Cooper and Rhodes model developed in 1978 for measuring the efficiency of Decision Making Units within the organizations. Sherman (1986) used DEA in analyzing the medical-surgical areas of seven hospitals and was able to identify inefficient units that were not previously identified by regression or single ratio analysis, and locate the sources of inefficiency. Ahn et al (1989) applied DEA in efficiency analysis for public institutions of higher learning in Texas, while Charnes (1989) compared DEA, ratios and regression systems for efficiency measurement of electric cooperatives in Texas. Kleinsorge et al. (1992) conducted a longitudinal study of the carrier by using DEA, Clarke and Gourdin (1991) used DEA for comparison of vehicle maintenance activities of maintenance shops.

DEA applications in Norway

There were some settings in Norway, where scholars used Data Envelopment Analysis to address certain cases. Torgersen et al (1996) employed DEA model to measure the efficiency of Employment offices across the country. Data for the study were taken from a registration of 40 offices' activities done during one work week in 1990. The survey was conducted by Directorate of Labor in Norway. The total of 108 offices existed, but 40 offices were randomly drawn, representing 4 offices per each county. Number of hours worked were set as an input variable, while 7 variables were set on the output side (e.g. number of contacts providing information, number of cases from jobseekers, number of cases from employers etc.). The analysis concluded that if the number of total variables is relatively high compared to number of units under investigations, relatively many efficient units are being identified. Odeck and Alkadi (2001) applied DEA to measurement of efficiency of bus transport companies subsidized by Norwegian government. They proposed that the model can be used for identifying efficient units, and regarded when subsidies are to be assigned based on firm's efficiency.

In the work of Kashani (2005), DEA was used to measure the extent to which the Norwegian state intervention caused inefficiencies in the Norwegian Continental Shelf activities. The efficiency of oilfields was measured across time (in the period of 1972 – 2000) and relative to other oilfields (a total of 37 fields were covered). Model assumed that input data of construction cost and variable cost were utilized to produce output of the oilfield. With regard to Norwegian regulations introduced during the period, Kashani (2005) concluded that when the regulatory regime strictly required the application of domestic goods and services and the monitoring instruments were strong, the inefficiencies were higher than during other periods. The inefficiency of each year of activity was highly correlated with the share of domestic goods and services in the total procurement of the shelf oilfields.

DEA applications related to Oil & Gas industry

Thompson et al (1996) conducted a study of major U.S. oil companies. DEA was applied to 12 years of data for 14 major oil companies. Both their efficiency and profit potential were measured in exploration and production. Findings showed that unique resource waste (primal slack) and modeled price (dual multiplier) pairs were identified for all but one of the inefficient firms - that is 98% of the inefficient units. Unique primal slacks mean that the projections of the respective inefficient DMUs onto the DEA-efficient frontier are unique.

Hawdon (2003) explored some of the policy developments, which affect efficiency of resource use in the gas industry, and used data envelopment analysis to measure relative performance at the individual country level. He used gas sales and number of customers as output variables. Labor force involved in gas production activities and capital services of the pipeline system were used as the input variables. A total of 33 countries were considered. The efficient units were identified as well as conclusions were drawn that governmental reforms towards gas industry contributed positively towards the efficiency level of companies operating in those countries.

Eller et al (2011) conducted a study of efficiencies of National Oil Companies across the different countries. The findings they made conclude that higher degree of government ownership may reduce efficiency in producing revenues from employees and reserves and suggest that the reduced efficiency level was the result of governments exercising control over the distribution of rents. Number of employees, oil reserves and gas reserves were considered as inputs, while generated revenue were considered as the output variable.

DEA applications for supplier evaluation

There were DEA studies within supply chain management as well. Weber and Desai (1996) compared 6 suppliers of one of the Fortune 500 companies. They were able to identify inefficient suppliers for the purpose of negotiation leverage. In addition, they presented how parallel coordinates can be used to determine which aspects of the supplier's performance need improvement to increase the overall efficiency. Narasimhan (2001) proposed a framework for supplier performance evaluation and rationalization, combining supplier performance and efficiency scores, thus helping the studied firm to revise the supplier base or encouraging introducing supplier improvement programs. Talluri, Narasimhan and Nair (2006) applied a case study in a division of Fortune 500 pharmaceutical company. They compared the CCDEA (chance-constrained) results to deterministic DEA results and highlighted its usefulness in the decision-making process. Wu and Blackhurst (2009) introduced an augmented DEA model. Their proposed methodology incorporated standards that enhanced the ability for companies to evaluate and rank suppliers. By doing that, augmented DEA had enhanced discriminatory power over basic DEA models to rank suppliers. In addition, weight constraints were introduced to reduce the possibility of inappropriate input and output factor weights.

Kang et al (2010) introduced a supplier performance evaluation model based on combined methodology. Analytical Hierarchy Process (AHP) and DEA were combined together to conduct quantitative and qualitative analysis. During a case study of microchip packaging suppliers, a quantitative analysis was performed through DEA, while qualitative analysis was performed through AHP. The DEA part used *defect rate, price* and *response-to-change-time* as input variables. *On-time delivery rate, process capability* and *capacity* were the output variables. Then the matrix of measures acquired from both models was generated. Finally, the suppliers were ranked according to scores received by multiplying relative qualitative performance (obtained from AHP) and relative quantitative performance (obtained from DEA) with relative weight vectors of qualitative and quantitative factors (obtained from experts' pair wise comparison and the Delphi method).

Wu (2010) model is a methodological extension to Data Envelopment Analysis and applicable to efficiency analysis for entities from different systems with imbedded uncertainty. Suppliers from different countries were grouped in three groups that represented business situation for each country relative to other countries. Efficiency analysis proceeded as follows: they evaluated the efficiency of vendors in Country A (severe business situation) only in relation to other vendors of Country A. Vendors in Country B (normal business situation) were evaluated in relation to both countries A and B. Vendors in Country C (advantageous business situation) were assessed in relation to all three countries. Thus, the vendors were evaluated under operating handicaps by taking into account their particular environments. Overall evaluation criteria categories were *quality, price, performance* and *facilities/capabilities.*

In Zeydan et al (2011) study, a methodology was introduced and proposed for increasing the supplier selection and evaluation quality. The approach considered both qualitative and quantitative variables in evaluating performance of suppliers based on efficiency and effectiveness in one of the biggest car manufacturing factory in Turkey. This methodology was realized in two steps. Firstly, qualitative performance evaluation was performed by using fuzzy AHP (Analytical Hierarchical Process) in finding criteria weights and then fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was utilized for finding the ranking of suppliers. In this way, qualitative variables were transformed into a quantitative variable for using in DEA methodology as an output, named *quality management system audit*. Secondly, DEA was performed with four output variables - quality management system audit, warranty cost ratio, defect ratio, quality management. The only input variable was selected to be a dummy variable, and all suppliers were assigned an equal value of 1 of input, thus ignoring the supplier differences from the input point of view.

Azadi and Saen (2012) proposed a chance-constrained DEA model in the presence of uncontrollable outputs. They then demonstrated the model application in supplier evaluation, by conducting the case study at the health informatics company. Company under investigation had 20 specialized application developers, whose performance was addressed. The number of personnel and average time for serving the customers were used as the input variables, while profit margin and supplier variety were considered as the output variables. Supplier variety was considered to be non-discretionary output (non-controllable) as this factor could not be increased at least in short term.

Some new DEA derivations occurred during past several years, such as chance constrained or augmented DEA. However, this thesis builds on the classic DEA model developed by Cooper, Charnes and Rhodes (1978) because the model is very well established and regarded as guidance in many other scholar works. It also successfully deals with multiple criteria (with no need of identifying weights) considerations providing a comprehensive evaluation of supplier, and is aimed for evaluation of homogenous group of DMU’s. Vendors supplying same type of products are just that – a comparable, homogenous set of units. To deal with possible statistical noise problem, data normalization is conducted prior to DEA model is run. A deeper presentation of methodology is found in chapters 3.2 and 3.3. The following chapterart 3.1 presents the case study company.

3. Research Method

The following chapter introduces to case study firm and explains the choice of it as a case study firm. This part also introduces and explains relative performance concept as well as the Data Envelopment Analysis model, which is used to conduct the performance analysis of the hydraulic component suppliers for Aker MH. In addition, the data sources are described.

3.1 About Aker Solutions

The firm under analysis is a part of a large scale global entity that operates within energy industry engineering field. The following section of the thesis shortly presents the Aker Solutions group and its historic development as well as Aker Maritime Hydraulics affiliate.

3.1.1 The Historic Background

The historic background dates back to 1853, when Kvaerner Brug was founded in Oslo. Kvaerner Brug began cooperating with Myrens Verksted in 1922, when the two companies divided the hydropower and the pulping product areas between them. Kvaerner Brug concentrated on hydropower, while Myrens Verksted became the Norwegian partner in Kamyr - a Norwegian/Swedish/Finnish joint venture that was the predecessor of the present day pulp and paper activities of the Group.

Kvaerner and Myren jointly acquired the majority shareholding in Thunes Mekaniske Verksted in 1943. In 1960, Kvaerner Brug's President, Kjell Langballe, was appointed President of all companies within the 'Kvaerner Group' and a joint holding company Kvaerner Industries AS was established in December 1967 and since that year it was listed on the Oslo Stock Exchange.

The Moss yard in Norway became the first Kvaerner shipyard, where in 1965 the first Kvaerner-developed gas carrier was built. In addition, Kvarner owned shipyards in Stavanger, Glasgow in Scotland, Masa-yards in Finland, Warnow Werft in Germany.

The Group entered the offshore oil and gas market from its base in Oslo through Kvaerner Engineering, which was established as an engineering and contracting company in the late 1960's. Offshore construction work started at Kvaerner Egersund in 1978 and during this period the shipyard in Stavanger was converted into an offshore fabrication facility. In 1996, Kvaerner sought to strengthen its engineering base internationally through the acquisition of the UK-based conglomerate, Trafalgar House. In July 2000, Aker Maritime ASA, a Norway-based offshore products, technology and services provider, bought 26 % of the shares in Kvaerner ASA. In 2002 the Group adopted the Aker Kvaerner name, but in 2008 it announced its new name: Aker Solutions.

3.1.2 Aker Solutions ASA

Aker Solutions ASA, through its subsidiaries and affiliates, is a leading global oil services company that provides engineering services, technologies, product solutions and field-life solutions for the oil and gas industry. The range of offerings include deepwater drilling technologies, subsea oil and gas production systems, well services, mooring and offloading systems, well stream processing technologies, as well as life-of-field solutions through its maintenance, modification and operations business. Aker Solutions is also a dedicated Engineering Procurement and Construction contractor for onshore and offshore oil and gas facilities. The Aker Solutions Group is organized in a number of separate legal entities. Aker Solutions is used as the common brand/trademark for most of these entities. The Aker Solutions Group employs around 18 000 people in 26 countries and generates around NOK 50 billion of yearly revenues. Aker Solutions has the following four business areas: energy development and services, subsea, products and technologies, process and constructions and each of them are shortly presented below.

Aker Solutions' Energy Development & Services business area (ED&S) develops new oil and gas production facilities, both offshore and onshore, and delivers operational services for the entire lifecycle of such facilities. Company delivers the full value chain from studies, front-end design and detailed engineering, through procurement, project management, fabrication and hook-up, to installation, maintenance and modifications. (Aker Solutions Annual Report, 2010)

Aker Solutions' Subsea business area (Subsea) is an established provider of subsea production systems and technologies. It is stated that company combines these offerings with reservoir evaluation services, installation of subsea equipment, maintenance services on subsea products, as well as intervention services and decommissioning. Aker Solutions ability as a complete life of field subsea partner is unrivalled in the marketplace. (Aker Solutions Annual Report, 2010)

Aker Solutions' Products & Technologies business area (P&T) provides innovative drilling and topside solutions to the upstream oil and gas industry, based on proprietary technology and knowhow. Company's key deliverables include advanced drilling equipment, systems and risers, upstream processing technologies and mooring systems also loading and offloading technologies. (Aker Solutions Annual Report, 2010)

Aker Solutions' Process & Construction business area (P&C) is a global provider of onshore engineering and construction services to the natural resources and energy markets. Company states (2010), that supply niche process expertise with high technology and know-how content for projects across chemicals, polymers, gas processing and refining; mining and metals; onshore liquefied natural gas (LNG) receiving terminals and storage tanks; power generation; bio fuels; carbon capture and storage; acid plants; nuclear; and water treatment. (Aker Solutions Annual Report, 2010)

3.1.3. Aker MH (Maritime Hydraulics) Business Scope

Aker MH is a part of Aker Solutions ASA and is located in Kristiansand, Norway. It delivers world-class deep water drilling technologies, systems and lifecycle services. Aker MH offers support through the entire process, including engineering, manufacturing, and installation and commissioning. Aker MH provides drilling lifecycle services, including spare parts, technical support, overhaul/modifications and professional rig training. Aker MH offers support through the entire process, including engineering, manufacturing, and installation and commissioning. In addition, it provides drilling lifecycle services, including spare parts, technical support, overhaul/modifications and professional rig training.

Speaking of drilling equipment and systems, there are two main rig types Aker MH produces - Conventional Rig and RamRig™ .

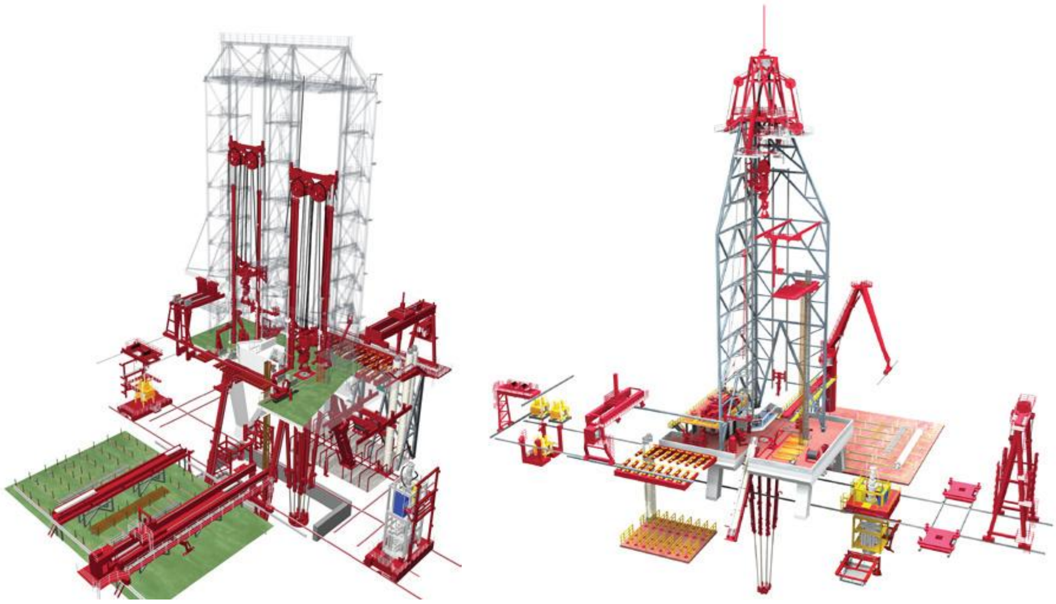


Figure 2. Dual RamRig ™ (left) and Conventional Rig (right)
Source: Aker MH General Drilling Equipment Catalogue (2008)

Complete Conventional Rigs can be provided on an EPC (Engineering Procurement Construction) basis. Aker MH provides the following services as part of the complete drilling facilities delivery:

- Project management
- Conceptual design/front-end engineering design (FEED)
- Detail engineering and procurement
- Supply of complete drilling equipment/mud treatment packages
- Fabrication, supervision and follow-up
- Commissioning, supervision and assistance
- Life cycle/operational support

RamRig ™ was developed later than the Conventional Rig, in 1998, and has proven to provide the same dual rig functionality for lower operational costs. RamRig ™ is especially suitable when drilling in deep waters, because it has lower centre of gravity. Since the rigs are mounted on floating platforms (semi-submersibles) or drilling-ships, lower centre of gravity means better stability and possibility to operate when rough weather conditions appear. In addition, it is lighter, safer and has lower space requirements.

3.1.4. Aker MH Suppliers

The company's objectives in procurement and supply management are improving the quality of purchased products and services, improving on-schedule delivery rate, developing long-term relationships with key suppliers. In order to achieve these objectives, Aker MH has emphasized supplier reliability improvement, stressing on-schedule deliveries and least possible inspection of purchased components. Other important activities are continuous evaluation and feedback on suppliers' performance in order to improve quality, and revising the supplier base by employing those vendors whose performance do meet the high standards Aker MH has.

Aker Maritime Hydraulics Purchasing Department is located in Kristiansand, Dvergsnes, and consists of several sub departments responsible for certain purchasing activities. There are Fabrication, Spare Parts, and Component sub departments of the purchasing department. Each of the sub departments works with a certain group of suppliers, which delivers products relevant for that subdivision.

Fabrication suppliers deliver items that are fabricated according to the drawings of the Aker MH, meaning that items are usually not standardized. In this case, the items produced by different suppliers can differ to a high degree amongst each other, e.g. while one supplier produces metal frames needed for transportation of equipment and other produces parts of equipment itself. And again, equipment or machinery parts can differ dramatically in terms of size and technology needed to craft certain products. Fabrication suppliers are also widely scattered around the globe, located from as close as Norway and Eastern or Central Europe to as far as the distant East Asia countries. Mentioned suppliers' differences as well as certain internal challenges that Aker MH faces, with regard to Fabrication suppliers' performance measurement, make DEA model implementation questionable.

The components are elements of various systems, and are either standardized or customized to match the system specifications. Even if customization applies, it is conducted to a rather low extent. In case of high customization or non-standard specifications, there are Manufacturing/Fabrication suppliers that deliver the required products. Under the name *Component purchasing* there are four categories of purchased components. Component purchasing is further categorized into Electro Components, Hydraulic Components, Mechanical Components, and Consumable Components. Out of the four, the hydraulic components contribute to the highest expenditure within component purchasing – more than half of total component expenditure. Since DEA model allows differences among DMU's to a certain extent, the model should be implemented for performance measurement of homogenous units (Easton (2002). This suggests that performance measurement should be conducted within the Electro, Hydraulic, Mechanical and Consumables supplier groups separately. This thesis is further concerned about hydraulic component suppliers' performance measurement, claiming it to be the most important category in terms of total spending across the component purchasing. Figure 3 shows the total component expenditure allocation between the Component categories.

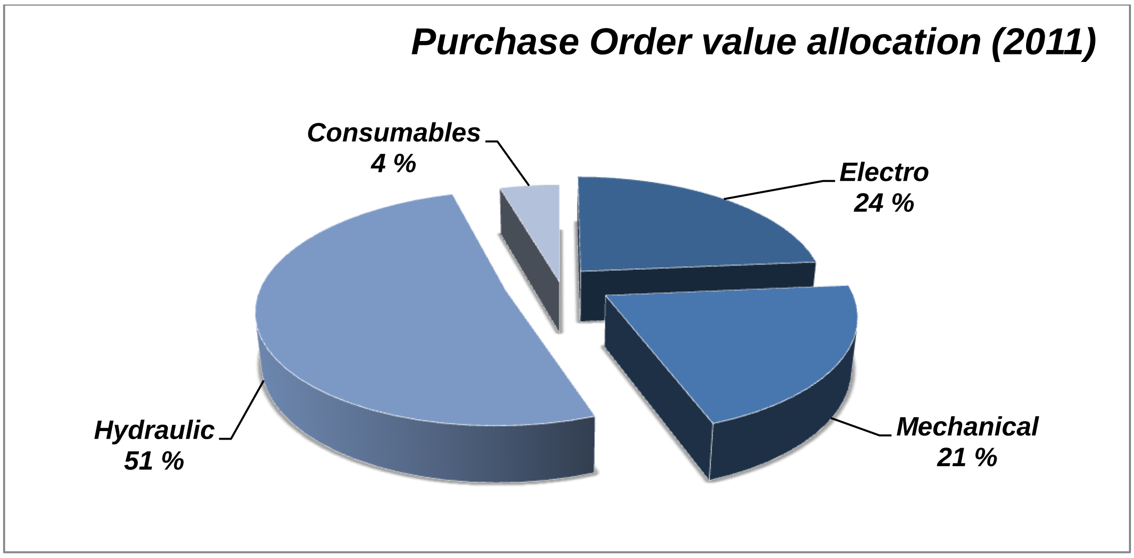


Figure 3. Aggregated PO Value Shares Accross Component Purchasing
Source: made by author

There were approximately 50 suppliers registered in the Aker MH purchasing database that delivered hydraulic components in 2011. A large deviation can be seen in the business intensity between Aker MH and each of suppliers on the list. This thesis regards business intensity between Aker MH and the suppliers in two ways: by number of purchase orders that were placed for each supplier, and the total spending towards each supplier. Number of purchase orders (PO's) per supplier varied from 1 to 721. The total amount of purchase orders per supplier varied from a few thousand NOK to millions of NOK in 2011. Due to information being sensitive, no names of suppliers or total purchasing expenditures towards suppliers will be revealed. Instead, each of the suppliers under analysis will be called Supplier A, Supplier B and etc. To reach a certain degree of representativeness, the suppliers with relatively low number of purchase orders and/or total sales in 2011 towards Aker MH were excluded from the further analysis. A minimum target of 25 purchase orders and 300 000 NOK of sales towards Aker MH were set, to filter the units that would not have representative data samples. The suppliers that had both, more than 25 purchase orders and more than 300 000 NOK were further considered in the analysis.

3.2. Research Design

As Figure 3 showed, the hydraulic components accounts for the highest expenditure level towards a supplier group within component purchasing, and accounts for more than a half of total spending towards component purchasing. This makes hydraulic components suppliers of a very high importance, since they have relatively strong impact on successful deliveries of Aker MH very own projects. The fact that Aker Maritime Hydraulics has the highest spending towards hydraulic components is no surprise, since even the name of the company itself prompts the business scope. As mentioned, hydraulic component suppliers constitute a homogenous group with similar products, manufacturing processes and goals, which make this group compatible with Data Envelopment Analysis usage for performance evaluation. Supplier performance is measured in terms of efficiency, by analyzing how input resources are utilized to produce output resources by each and every supplier under investigation. Aker MH is a suitable case study firm for DEA application. It provides a classification of suppliers, which identifies homogenous groups with a relatively higher number of units. Some DEA applications compared just 6 suppliers (Weber and Desai (1996), Narasimhan et al (2005)). In addition, as an employee of this firm, I had access to more detailed and relevant information.

Out of all the hydraulic suppliers that Aker MH had business with in 2011, suppliers with aggregate purchase order value of NOK 300 000 and more, and 25 purchase orders and more were considered. This was done in order to increase statistical reliability of the evaluation. A total of 50 hydraulic suppliers delivered components to Aker MH in 2011. However, 27 suppliers had less than 25 purchase orders and/or a total purchase order value of less than NOK 300 000 – pre-defined minimum values for business scope evaluation. In fact, there were 24 suppliers that had less than 10 purchase orders from Aker MH, but two of them had more than required NOK 300 000. Of all the 27 suppliers that had less than 25 purchase orders, five had aggregated order value higher than required minimum. Further selection procedure was conducted, during which suppliers that did not possess all needed data for evaluation were removed from the sample. Four such cases were found among the 23 suppliers that were left after the first filter was applied. Two of the suppliers were missing Automatch measure, one supplier was missing delivery measure, and one supplier – quality measure. Afterwards, it was made sure that data for every criterion does not contain *odd values* across suppliers, otherwise it would have identified that data sample contained possible statistical or man-made errors while building up the data base. No such cases were found. A thorough search was performed in order to prevent *false efficiency* to appear in analysis results (as noted by Johnes and Johnes, 1993). Finally, a total of 19 suppliers were selected for final step. Supplier names were changed to avoid revealing sensitive information.

In addition to all the selected suppliers, an IDEAL supplier was included in the evaluation. The IDEAL supplier possessed the preferred attributes across all the criteria suppliers were evaluated on. During the attribute definition meeting with a manager within component purchasing, the actual attribute values of existing suppliers were not presented.. This was done to avoid influence this presentation could have had on manager's perception and in order to obtain as clear as possible picture, which purchasing management has, on how an IDEAL supplier should perform. However, this does not imply that the respondent was not aware of performance level generated by existing suppliers. Preferred values for quality, delivery, invoice automatch and Cost Reduction Performance were set during the meeting. Actual preferred values are presented in chapter 4.3.

DEA model requires both input and output variables, therefore the criteria mentioned above needed to be considered either as input or output. Cost Reduction Performance was set as an input variable and considered to be a result of supplier's cost management practices, both internal (e.g., development of internal manufacturing, management or administrative processes) and external (e.g., managing own suppliers, distribution channels, etc.). Quality, delivery and invoice automatch were selected as output variables. The logic behind this distribution is such that DEA model analyzes how the results of suppliers' cost management practices (input variable) impact the overall service level (output variables) that suppliers are able to provide. In other words, the model analyses how an increase or decrease of the price over the period of time is supported by corresponding shifts in overall service level. The general rule within this model is that supplier is more efficient when it delivers higher output by utilization of same or lower input. Therefore, the input variable is being calculated in a way, that a lower value is preferred to higher, while output variables are calculated in an opposite way - higher value is preferred to lower value.

What is very important to underline, is that even though Data Envelopment Analysis in its essence is used for measuring efficiency of any DMU, the input utilization to produce outputs that is described in this thesis is not necessarily the exact measure of actual supplier efficiency. This stems from an assumption, that a change in price level that is asked from Aker MH by each of the suppliers, consists, as a general rule, of the costs supplier actually experiences, plus the profit margin supplier is willing to earn. While the efficiency would drive the internal supplier costs down, the acquired extra savings can be replaced by an extra profit. Those extra savings can as well be shared between the supplier and Aker MH, or the whole savings margin can be enjoyed by Aker MH. Therefore it is more precise to say that, from a definition point of view, the DEA model in this thesis shows proximity of efficiency of suppliers.

Since none of the variables used for supplier performance measurement were uncontrollable or undesirable inputs/outputs, no adjustment to the DEA model was necessary. To overcome a pitfall of statistical noise, a normalization of the data set is conducted prior to application of DEA. Moreover, a correlation analysis is conducted on the data sample, to identify the extent of existing relationship across the variables used in model. The actual values of input and output variables are presented in section 4.1.

3.3. The Data Envelopment Analysis and Relative Performance

The concept of relative supplier performance is used as described by Weber and Desai (1996). They underlined that conceptual basis of relative supplier efficiency was the theory of consumer demand developed by Lancaster (1971). He modified the analysis of consumer demand for a product by proposing that this demand was better understood in terms of product attributes. Weber and Desai extended the approach to evaluating the vendor with regard to vendor's ability to produce efficiently. Supplier's ability to produce efficiently is reflected in the amount of resources (e.g., quality, on-time delivery rate, auto-match rate, etc.) supplier produces with a given amount of input. Then the term relative performance was introduced, by considering the supplier efficient if there exist no other supplier or combination of suppliers that would deliver same quantity of products by using less of some of resource while not increasing the usage of other resources. Oppositely, the supplier is showing lower performance if there exists another supplier that manages the identical task with less input of some resources without the increased usage of other resources – meaning, a more efficient supplier exists.

This master thesis applies Data Envelopment Analysis model for evaluating supplier performance. The DEA is a linear programming-based model that converts multiple input and output variables to one comprehensive ratio that reflects the performance of each of the units under investigation (Easton, 2002). DEA provides a measure that helps to compare the relative performance of homogenous units; in this thesis the units are hydraulic components suppliers. *When measuring the relative efficiencies of the organizations, DEA measurement can be defined as the ratio of the total weighted output to total weighted input*. *With DEA* *each organization can utilize different weights for the set of the performance measures. Weights are selected in such a way that would maximize the composite score for each unit under investigation. That allows each unit to take advantage of their own unique areas of specialization (Sexton, 1986).*

Easton (2002) argues that this variable weighting allows the evaluation while considering differences of a certain degree; in case of major strategic differences between the parties under investigation, the study should not be conducted by using the DEA. The range of all weights is controlled by requiring all weights to be positive, and specifying that sum of the weights should not exceed unity. The model is run *n* times, where *n* represents the number of suppliers, in determining the efficiency scores of all the suppliers. Each unit is allowed to select optimal weights that would maximize its efficiency. Model (1) contains the objective function (with normalizing constraints) of output to input ratio maximization (Cooper et al, 2011).

<u>Output to input ratio (1):</u>

$$\max h_0(u,v) = \frac{\sum_k u_k y_{ko}}{\sum_i v_i x_{io}}$$

$$subject\ to\ \frac{\sum_k u_k y_{kj}}{\sum_i v_i x_{ij}} \leq 1\ for\ j = 1, \dots, n,$$

$$u_k, v_i \geq 0 \text{ for all } i \text{ and } k.$$

Where:

μ_k, v_i *- weights given to output k and input i respectively;*

x_{io} *– amount of input i consumed by DMU o ;*

y_{ko} *– amount of output k produced by DMU o* ;

o – marks DMU being evaluated.

Cooper et al (2011) explains that this ratio form generalizes engineering science definition of efficiency from a single output to single input and does so without the use of pre-set weights. Ratio of weighted output to weighted input prompts that the model is input oriented. At the same time the efficiencies of all the units in the set when evaluated with these weights are prevented from exceeding a value of 1. It is also needed to be notified that model

(1) has an infinite number of solutions; if (u*,v*) is optimal, then (αu*, αv*) is also optimal for all α > 0. To obtain a model that would select a single solution a transformation had to be made. The transformation that was developed by Charnes and Cooper (1962) for linear fractional programming selects a solution (i.e., solution (u, v) for which$\sum_{i=1}^{m} v_i x_{io} = 1$) and yields the equivalent linear programming problem in which the shift from variables (u, v) to (μ, v) is a result of the "Charnes – Cooper" transformation (Cooper et al, 2011). This transformation is the multiplier model (2).

<u>Multiplier model (2):</u>

$$\max z = \sum_{k=1}^{r} \mu_k y_{kq}$$

$$subject\ to\ \sum_{k=1}^{r} \mu_k y_{kj} - \sum_{i=1}^{m} v_i\, x_{ij} \ \leq 0$$

$$\sum_{i=1}^{m} v_i x_{ij} = 1$$

$$\mu_k, v_i \geq \varepsilon > 0$$

Where:

q – the DMU being evaluated;

j = 1,2, …, n number of DMU's ;

x_{ij} *– amount of input i consumed by DMU j ;*

y_{kj} *– amount of output k produced by DMU j ;*

m – number of inputs;

r – number of outputs;

μ_k, v_i *– weights given to output k and input i respectively;*

z – output to input ratio, which is to be maximized.

First line in the Multiplier model (2) explains that the output to input ratio is to be maximized. The following part then introduces the boundaries transformed ratio is subject not to exceed. The described model (2) has the following linear problem, see model (3).

Linear programming dual problem (3):

$$\theta^* = \min \theta$$

$$subject\ to\ \sum_{j=1}^{n} x_{ij}\lambda_j \leq \theta x_{iq}, \qquad i = 1, 2, \dots, m;$$

$$\sum_{j=1}^{n} y_{kj}\lambda_j \geq y_{kq}, \qquad k = 1, 2, \dots, s;$$

$$\lambda_j \geq 0 \qquad j = 1, 2, \dots, n.$$

Where:

x_{ij} *- amount of input i consumed by DMU j ;*

y_{kj} *- amount of output k produced by DMU j ;*

j – number of DMU's ;

λ_j*- weights assigned for each DMU.*

As Cooper et al (2011) claim, *"In the economics part of DEA literature, this model is said to conform the assumption of 'strong disposal', but the efficiency evaluation it provides ignores the presence of non-zero slacks. In the operational research part of the DEA literature, this is referred to as 'weak efficiency'* ". Therefore, Charnes, Cooper and Rhodes (1978) introduced slack variables to convert inequalities of model (3) to equivalent equations and notified, that solving model (4) is equivalent to solving model (3).

Envelopment model (4):

$$\min \theta - \varepsilon \left(\sum_{i=1}^{m} s_i^- + \sum_{k=1}^{r} s_k^+ \right),$$

$$subject\ to \quad \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{iq},$$

$$\sum_{j=1}^{n} \lambda_j y_{kj} - s_k^+ = y_{kq} ,$$

$$\lambda_j \geq 0, \qquad s_i^- \geq 0, \qquad s_k^+ \geq 0$$

Where:

j = 1,2, …, *n number of DMU's ;*

m – number of inputs ;

r – number of outputs ;

q – the supplier being evaluated ;

s_i^- *- slack variables for particular inputs ;*

s_k^+ *- surplus variables of particular ouputs ;*

θ *- variable expressing level of efficiency ;*

λ_j *- weights assigned for each DMU ;*

ε *- non-Archimedian element defined to be smaller than any positive real number, which does not need to be specified.*

Multiplier model (2) and Envelopment model (4) constitutes an input-oriented Data Envelopment Analysis model introduced by Charnes, Cooper and Rhodes (1978), and used by Josef Jablonsky in preprogramming the Excel Solver algorithm (Jablonsky, 2009). The model assumes that performance of a DMU (in this thesis - supplier) is fully efficient (100%) if and only if both $\theta^* = 1$ and all slacks $s_i^- = s_k^+ = 0$. The performance of a DMU is of 'weak efficiency' if and only if both $\theta^* = 1$ and $s_i^- \neq 0$ and/or $s_k^+ \neq 0$ for some inputs or outputs.

Johnes and Johnes (1993) notified a couple of DEA features that need attentive considerations. First, the DEA assumes that at least one unit is technically efficient so that the efficiency frontier could be defined. As already mentioned before, this implies evaluation of the relative performance and does not rule out the possibility of achieving even greater performance. Secondly, in some circumstances a unit under investigation could achieve high efficiency score just by being different in its input or output mix from other units. This is sometimes experienced because each unit under investigation chooses its own criteria by which it is willing to be judged (weights are allocated in such a way that a highest possible score would be acquired by that unit). Where the number of units under investigation is rather small, some of the units might appear as efficient just because they are unusual. Therefore, a thorough check is conducted to avoid this potential problem, as well as normalization for data is applied in the model of this thesis where a total of 19 existing suppliers and an Ideal supplier are under investigation.

3.4. Data Sources

Information and data collection process during the thesis development period took place at Aker Maritime Hydraulics in Kristiansand, Dvergsnes. A handful of meetings and extensive communication were held with Aker MH employees in order to get a grasp of the purchasing environment within the company. The communication started with Purchasing Department manager and was continued down the organizational hierarchy. Purchasing managers responsible for sub departments and purchasers were addressed in order to get acquainted with everyday purchasing processes. These addressees were also asked to identify attributes of the *Ideal Supplier*.

It is no surprise that Aker MH conducts its own supplier evaluation. There is a senior consultant that has developed and helped implementing the current evaluation model used by Aker MH. Therefore, a separate meeting was held in order to familiarize author of the thesis with the existing evaluation methods, practices and data used for evaluation. In Aker MH, the idea of existing supplier evaluation is to determine best and worst suppliers performance-wise, and to award the best suppliers with additional contracts. The worst performing suppliers may get involved in a close dialog regarding the observed performance issues, receive fewer contracts or can even be removed from the Aker MH supplier base.

All the necessary data on supplier performance that is used in this thesis was acquired from Procurement Department SPS (Share Point Site) in company's Intranet (access rights were needed to enter this part of Intranet. Primary data was processed by Aker MH responsible employees, and the summarized data was used for this study. Thus, this research is based on secondary data. The time frame of this research did not allow double-checking the data, which was of an extensive amount.

4. Research Data and Analysis

This chapter will present the data acquired during the meetings with supply chain managers and purchasers, and the data acquired from Aker MH intranet. List of suppliers and values of criteria will be presented, as well as IDEAL supplier attributes will be introduced and explained. Also, the analysis of the data acquired during the process is presented.

4.1. Supplier Evaluation Criteria

The initial step in data acquisition and criteria selection process was to review the supplier performance measurement model used by procurement department at the time being. The model specifications will not be revealed in the thesis since that is information of a sensitive type. As stated earlier, data revision process was not conducted due to limited time frame. Step two was to identify the input and output criteria that will be used in Data Envelopment Analysis model.

As referred in the literature analysis, there is seen a frequent usage of price, delivery and quality as criteria for measuring supplier performance, e.g. Weber and Current (1993), Naraasimhan et al (2001), Prahinski and Benton (2004). In addition, level of service is used by some authors as well (Chang et al., 2007). Naraasimhan et al (2001) and Talluri et al (2005) use delivery precision, quality level and price criteria for supplier performance measurement by using DEA. In addition to that, Naraasimhan (2001) uses a Cost Reduction Performance as one of criteria. For this research, suppliers' performance will be measured with regard to their ability to deliver on-schedule; ability to deliver components of the required quality; invoicing performance; and ability to reach and maintain efficient production which would contribute to cost reduction for Aker MH.

- **Delivery precision.** *Acceptable deliveries (number of PO's)/Total deliveries (number of PO's)*

  The delivery performance is measured by a ratio of acceptable deliveries to total deliveries. One acceptable delivery is considered to be a delivery of one purchase order on agreed time, delivering agreed contents of acceptable quality, and delivering in acceptable packaging. Based on the ratio described, delivery measure would vary from 0 to 1, where 1 would be an ideal case and would mean 100 % acceptable deliveries.
- **Quality.** *(Total PO's - Non-conformance score) / Total PO's, where:*

  Non-conformance score = **(***NCO + NCR x 3).*

Quality of supplier is monitored and measured in terms of non-conformance observations and non-conformance reports. The following definition was provided by Aker MH representatives: *"Non-conformity is regarded as inadequate performance of a specified requirement, including delays and cost overruns on supplies – an opportunity for improvement".* Non-conformance of delivered items or equipment means that it is defected, damaged, missing parts or documentation or that any other quality issue exists that makes the equipment not suitable for further use. In a usual and not critical case of non-conformity, a non-conformance observation (NCO) is issued. Such cases might be, for example, missing documentation, damaged delivered equipment or packaging issues. Non conformance report (NCR) is usually derived when a more serious quality related issue appears, for example if the delivered item contains a quality issue that originated in the manufacturing process or the lighter case of non-conformance is observed repeatedly (3 observations). It is internally agreed that 1 NCR is considered to have negative impact towards supplier performance and is equal to 3 NCO's. Therefore, non-conformance score is calculated by multiplying the number of non-conformance reports by 3 and adding it to non-conformance observations. Then, the total non-conformance score is divided by number of purchase orders in 2011.

- **Automatch**. *Number of automatched invoices/ Number of total invoices.*

  The term a*utomatch* refers to Aker MH invoice handling system, which automatically accepts and approves the invoice if it is issued within the agreed terms for each purchase order. An automatched invoice means the payment document is built on pre agreed terms in purchase order and contains no mistakes. Flaws such as mismatching invoice dates (invoice issued prior to full delivery), invoiced amounts, actual delivery dates of orders, payment beneficiaries and etc. cause that invoice are not automatically matched to the purchase order they were actually built on. In this case, there is manual labor needed in order to locate and eliminate the problem, and that is a time requiring procedure that keeps the purchasing department staff away from their direct and value generating activities. Wider discussion about automatch is presented in the ideal supplier attribute definition chapter.

- **Cost reduction performance (CRP).** *1+Average price trend during 5-year period*.

  The cost reduction performance concept used in this thesis is about the supplier's willingness to help reduce the costs of Aker MH. It is assumed that every supplier has control over the prices they charge for their production, thus have control over their cost reduction performance towards the customer. However, in reality this might not be the case, there might exist inputs or outputs that are not under management's power. The cost reduction performance of the supplier is expressed by the use of longitudinal price trend. Price trend during a 5-year period reflects the supplier's ability to reach and maintain efficient production and willingness to share the benefits - offer better terms to Aker MH. A reduction in supplier price for the delivered products means cost savings for Aker MH. The lower price trend (can also be of negative value), the better terms that are offered to Aker MH by a given supplier. A formula for measuring of cost reduction performance is derived to match the Data Envelopment Analysis model specifications, where lower input values are preferred to higher. It is also worth notifying that yearly price changes were not inflation adjusted. Further discussion on this matter is found in ideal supplier attribute definition chapter.

It is important to notify, that delivery precision measure also includes (some) instances of rejected deliveries due to quality issues. That would imply that one case of quality issue would drive down the delivery precision and quality level ratios simultaneously. Therefore, a correlation analysis was conducted to identify the relation between all variables(correlation results are presented in chapter 5). Table 4 presents the input and output variable values as used in DEA.

Suppliers	**Outputs**			**Inputs**
	Quality	Delivery	Automatch	CRP
A	0.899	0.632	0.563	1.068
B	0.990	0.444	0.742	1.004
C	0.950	0.786	0.796	1.030
D	0.962	0.576	0.887	1.002
E	0.987	0.596	0.691	1.068
F	0.961	0.886	0.940	1.038
G	0.962	0.657	0.844	1.100
H	0.943	0.361	0.746	1.014
I	0.971	0.554	0.632	0.992
J	0.979	0.448	0.888	1.040
K	0.938	0.512	0.812	0.982
L	0.934	0.666	0.767	1.022
M	0.821	0.500	0.578	1.020
N	0.858	0.152	0.793	1.038
O	0.923	0.692	0.548	1.028
P	0.962	0.917	1.000	1.018
Q	0.966	0.634	0.792	0.968
R	0.927	0.808	0.704	1.028
S	0.967	0.686	0.800	1.078

Table 4. Input and output variables. *Source: made by author, based on Aker MH data*

4.2. Data Analysis

A set of 19 suppliers is being evaluated. To keep the sensitive information discreet, each supplier was given a name that is used in the research presentation and analysis. The following table presents the supplier attributes and identifies number of purchase orders per supplier, as well as ranking by total hydraulic component sales towards Aker MH.

Supplier (ranked by aggregated sales towards Aker MH)	PO's	Quality	Delivery	Automatch	CRP
A (1)	398	0.899	0.632	0.563	1.068
B (16)	101	0.990	0.444	0.742	1.004
C (4)	721	0.950	0.786	0.796	1.030
D (6)	211	0.962	0.576	0.887	1.002
E (9)	313	0.987	0.596	0.691	1.068
F (18)	51	0.961	0.886	0.940	1.038
G (19)	79	0.962	0.657	0.844	1.100
H (14)	53	0.943	0.361	0.746	1.014
I (5)	343	0.971	0.554	0.632	0.992
J (7)	286	0.979	0.448	0.888	1.040
K (12)	144	0.938	0.512	0.812	0.982
L (10)	242	0.934	0.666	0.767	1.022
M (8)	56	0.821	0.500	0.578	1.020
N (3)	386	0.858	0.152	0.793	1.038
O (13)	26	0.923	0.692	0.548	1.028
P (17)	26	0.962	0.917	1.000	1.018
Q (11)	116	0.966	0.634	0.792	0.968
R (2)	441	0.927	0.808	0.704	1.028
S (15)	30	0.967	0.686	0.800	1.078

Table 5. Attributes of Analyzed Suppliers. *Source: made by author, based on Aker MH data*

As the Table 5 indicates, suppliers were evaluated based on quality, delivery, automatch and Cost Reduction Performance. Attributes corresponding to each of supplier is the data set that reflects each of suppliers performance during 2011.

The first column in the Table 5 contains an assigned name and the ranking in purchase order aggregated value of each supplier in 2011. The column PO's indicates the number of purchase orders that were placed (internal term within Aker MH) for each of the suppliers, or in other words how many orders each supplier had to fulfill in 2011. Supplier O and Supplier P had the fewest – 26 purchase orders, while Supplier C, Supplier R and Supplier A had the highest number of purchase orders - 721, 441 and 398 respectively in 2011. Average number of purchase orders per supplier is 211.7. It is worth notifying that purchase order number does not reflect the aggregated income each supplier received from Aker MH in 2011. For example, Supplier C had most purchase orders, but was only 4th in aggregated purchased value; while Supplier A had 398 purchase orders and ranked 1st in aggregated purchase order value.

Quality level per supplier was measured by the use of following formula:

- *(Total PO's - Non-conformance score) / Total PO's.*

The actual measured attributes varied in the range of 0.821 to 0.990. Figure 3 illustrates the quality level evaluation.

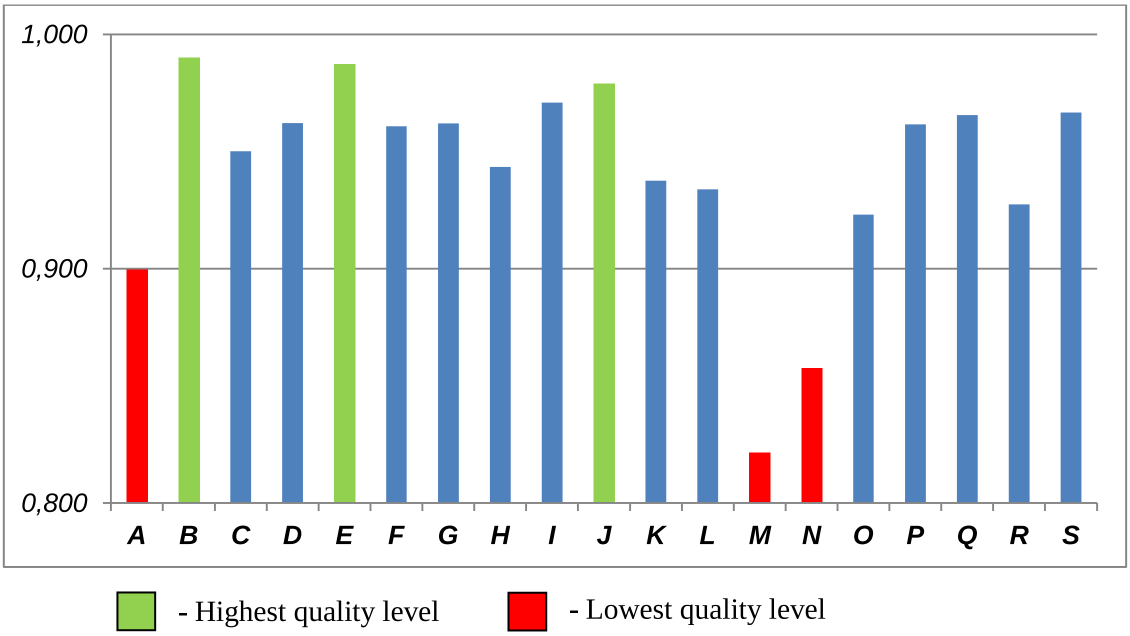


Figure 4. Quality Level Values, Calculated Per Supplier
Source: made by author, based on Aker MH data

Figure 4 shows the 3 suppliers in green highlighting with the highest quality level, Supplier B, Supplier E and Supplier J. On the other hand, Supplier M, Supplier N and Supplier A, highlighted in red, were the three that demonstrated the worst quality level. It is important to notify that all three worst performers quality wise, were amongst the biggest hydraulic component suppliers: Supplier M ranked 8th, Supplier N ranked 3rd and Supplier A ranked 1st respectively. The average quality level of all the analyzed suppliers was 0.942.

Delivery precision of suppliers was measured by the use of following formula:

- *Acceptable deliveries (PO)/Total deliveries (PO).*

Variation in delivery precision amongst suppliers was higher than variation in quality levels. The lowest delivery performance was shown by Supplier N (see Figure 5), with rate of only 0.152 of acceptable deliveries. Supplier B, Supplier H and Supplier M were the "low-performers" and delivered less than 50 % of own deliveries within the agreed terms. Again, suppliers M and N were amongst the biggest hydraulic component suppliers and at the same time showed poor delivery precision. On the other hand, suppliers C, F, P and R were the ones that delivered the orders with highest precision. The case is similar, Supplier F and Supplier P had a small business scope and showed good numbers in terms of delivery precision.

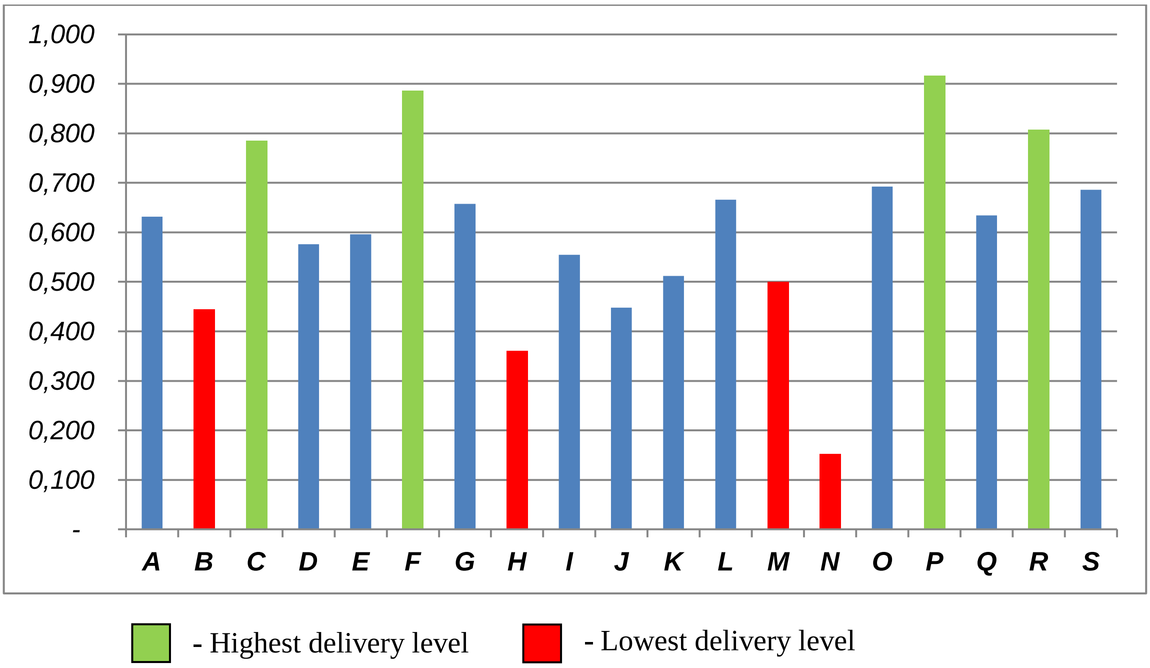


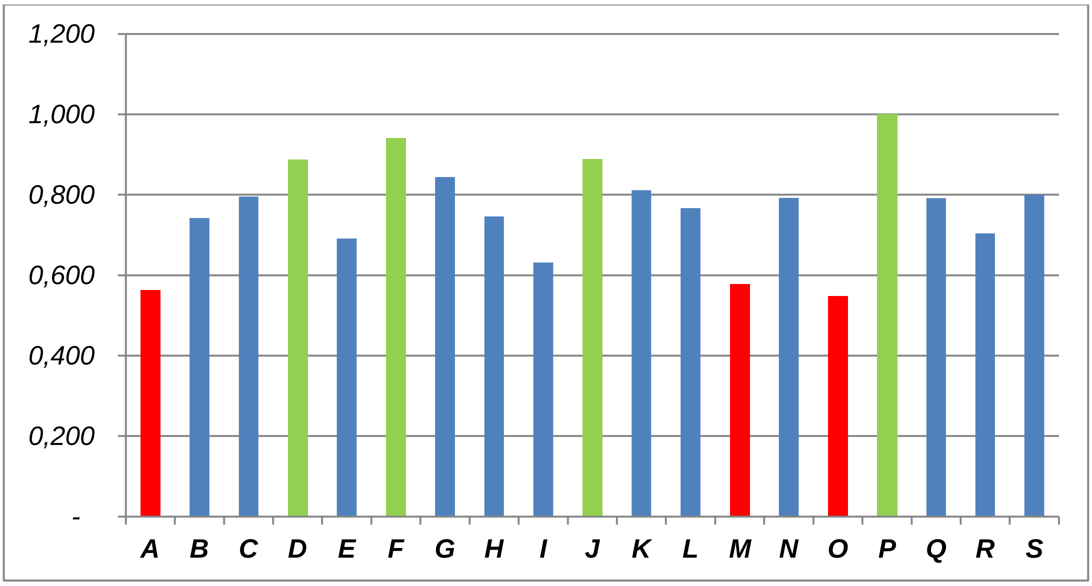
Figure 5. Delivery Precision Showed for Each Supplier
Source: made by author, based on Aker MH data

Suppliers C (4) and R (2) were amongst the biggest suppliers in the analyzed range and had a relatively high delivery precision evaluation of 92 %. It is worth notifying, that both of these suppliers were the entities of the same business group. The average delivery precision rate for the whole sample was 0.606.

Automatch level is being calculated by the use of following formula:

➢ *Number of automatched invoices/ Number of total invoices.*

The automatch level measured across the suppliers varied in the range of 0.548 to 1 (see Figure 6).The worst results were shown by suppliers A, M and O. they all had the automatch level in the range of 0.548 to 0.578. Supplier A was the one having the highest business scope with Aker MH, Supplier M ranked 8th in the same list. The best performers in terms of automatch were Supplier P, Supplier F and Supplier D, whose evaluations were 0.888 and more. It is worth mentioning that Supplier P was able to reach highest score of 1, by issuing all the invoices in acceptable manner. However, Supplier P had only 26 purchase orders, meaning it had the least amount of invoices to take care of. The average automatch level was 0.764. 11 suppliers had automatch performance higher than the average performance.



- Highest automatch level - Lowest automatch level

Figure 6. Automatch Level Showed for Each Supplier
Source: made by author, based on Aker MH data

The Cost Reduction Performance of the suppliers was measured by the following formula:

➢ *1+Average price trend during 5-year period.*

The cost reduction performance level across suppliers varied from as low as 0.968 to as high as 1.100. An average value of the measure was 1.028. Opposite to previous illustration, lowest values are highlighted in green, since these values are now preferred, while highest values are highlighted in red (see Figure 7). Supplier A (1.068), supplier E (1.068), supplier G (1.100) and supplier S (1.078) had the highest CRP values, meaning that their prices increased the most during the past five years. Supplier I (0.992), supplier K (0.982) and supplier Q (0.968) had the lowest values of CRP. A value that is less than 1 indicates that on average basis supplier's sales price level decreased throughout a period of 5 years. It is to be notified, that neither the yearly price changes nor the average 5-year price change were inflation adjusted.

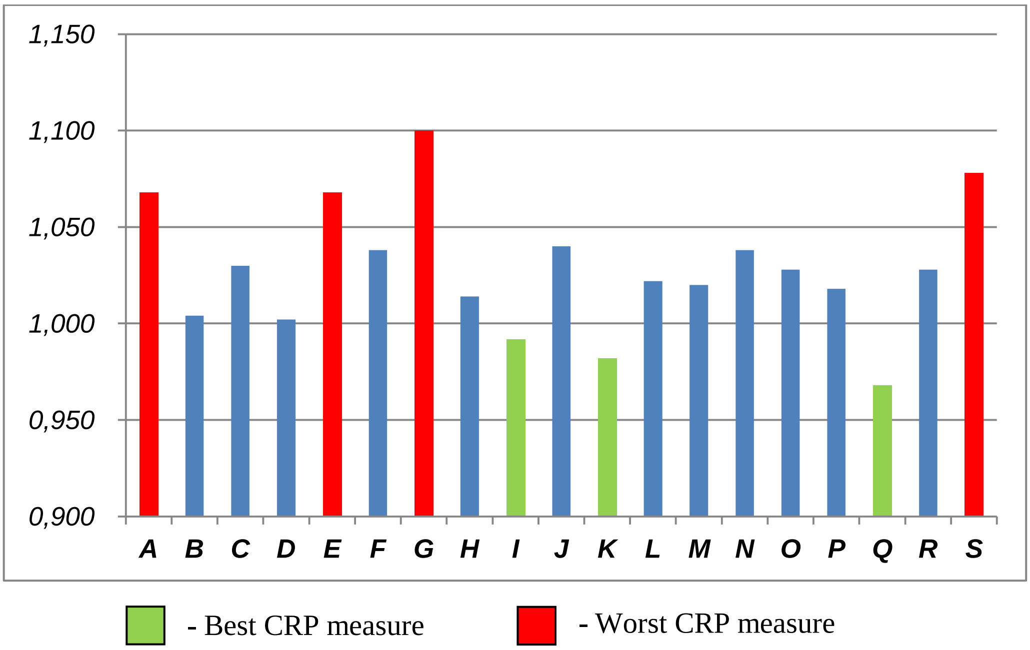


Figure 7. CRP Level Showed for Each Supplier
Source: made by author, based on Aker MH data

The data sample for Quality, Delivery precision, Automatch and CRP was run through a correlation analysis to identify the relation between the variables. The need for this step in data analysis stems from the specifications of measurement variables that Aker MH uses for supplier evaluation. As it was found out during the extensive communication process with Aker MH purchasing staff, delivery precision also incorporates some instances of quality related issues. Therefore, supplier is *penalized* in terms of decreased evaluation score more than once if quality issues appear – both rates of quality and delivery level become affected. Automatch attribute, which shows invoicing performance level also becomes negatively affected since failed delivery and quality issues have an impact on invoice parameters. The results of correlation and significance test with a required *significance level* of 0.05 between 19 data observations are presented in Table 5.

	Quality	**Delivery**	**Automatch**
	Correlation/Significance	Correlation /Significance	Correlation /Significance
Delivery	0.3171 / 0.1859	-	-
Automatch	0.4504 / 0.0530	0.2302 / 0.3431	-
CRP	-0.0207 / 0.9330	0.1362 / 0.5783	-0.0297 / 0.9039

Table 6. Results of Correlation Analysis among Variables. *Source: made by author*

As the Table 5 shows, a relation of some extent is found between *Quality* and *Delivery*, with a correlation rate of 0.3171. Correlation rate can vary in the range of [-1;1], where a value closer to each of the extremes identifies stronger relation between the analyzed variables. Correlation analysis of *Quality* and *Automatch* yielded a rate of 0.4504 which indicates some stronger relation between the two variables. Correlation between *Delivery* and *Automatch* and *CRP* shows rates of 0.2302 and 0.1362 respectively, which would suggest a very vague relation between those variables. Analysis showed no correlation between *CRP* and *Quality*, and *CRP* and *Automatch*. However, significance test results showed that none of the measured significance levels between variables were lower than the required, thus the analyzed relations are not statistically significant.

4.3. Attributes of an Ideal Supplier

This thesis aims to measure the relative performance of existing suppliers. The DEA model ranks the suppliers based on the efficiency of each supplier. After the ranking is completed for the 19 existing suppliers, an Ideal Supplier is introduced in the data sample and the model is rerun. An Ideal Supplier possesses preferred attributes, which indicate the performance level Aker MH is expecting from its suppliers. This is done in order to find out how Aker MH perceives a role model and how the latter would be evaluated in the light of DEA. Table 7 presents the attributes of the Ideal Supplier.

	Quality	***Delivery***	***Automatch***	***CRP***
Ideal Supplier	1	0.8	0.8	1.020

Table 7. Ideal Supplier attributes. *Source: made by author, based on Aker MH preferences*

Aker MH seeks to deliver drilling equipment that would help maximize the uptime of the drilling rigs. That means that equipment has to be of highest quality and reliability, meaning that Aker MH wants to use components delivered by suppliers also of the highest quality. Therefore, an Ideal hydraulic component supplier should deliver components of 100% quality, meaning that preferred value of Quality is 1. As the sample data analysis showed, there were some suppliers that had a very high quality level – Supplier B had a rate of 0.990 and Supplier E had a rate of 0.987. However, all suppliers demonstrated lower quality level than Aker MH would expect.

Acceptable delivery level of 80% was set as sufficient. This gives a respective rate of 0.8 to match the expression used in this study. An average delivery precision level of 0.606 compares lower than expected value, and indicate that Aker MH requires an increase in this attribute on the average basis. Just 3 of 19 suppliers had higher delivery performance than required and 10 suppliers performed better than the average level.

Automatch level per supplier is expected at 80%. In accordance with numeral expressions used in this study, that is a level of 0.8. The average Automatch level in 2011 was 0.764, which is just under the required performance. 7 suppliers were showing higher results than the perceived performance of the Ideal Supplier while 12 suppliers performed worse. What is interesting in the case of automatch, is that not always higher percentage of automatched invoices means less manual work for purchasing staff. In some cases when a large order is issued and some components have long delivery times, agreements on partial deliveries are made, both initiated by Aker MH or suppliers. In a case of partial deliveries of large orders or long-lead items, the initial purchase order will not be matched by multiple partial invoices Aker MH would receive. To make the invoices suitable for handling by automated system, the purchase orders would have to be redefined and that would cause more manual labor than just handling the multiple invoices of one purchase order manually. For the latter reason the internally agreed required level of automatch for suppliers is 0.8.

The CRP measure consists of the average price change rate over the 5-year period. There were 17 suppliers that had an average yearly price increase, while 2 suppliers decreased the price over the period. An average yearly price shift for all suppliers was 2.8% for the period of 2007-2011. Aker MH acknowledges the supplier's price adjustment every year that is in accordance with existing inflation rate. The average price inflation in Norway over the period of 2007-2011 was 1.98% (Eurostat, 2012). Therefore, the accepted price increase of Ideal Supplier components would also be 1.98% a year for the given period. The price shifts for the existing suppliers were not inflation adjusted; therefore an average inflation rate is added to a value of 1.That makes a CRP level of 1.020. Average price shift of 2.8% over the last 5 years indicates that, on average, suppliers increased the price not only due to overall inflation. Other reasons may apply, such as increased profit margins or increased costs, which may indicate inefficiencies within the internal operations.

Next part of the thesis presents the findings of the study, which are followed by discussion.

5. Discussion and Findings

This part presents with the final findings of the supplier performance study in Oil & Gas related company. Results of DEA applications are analyzed based on two sample sets, and presented in separate sections.

Performance evaluation of existing suppliers

Data Envelopment Analysis input-oriented model was run by using MS Excel Solver. The first analysis was conducted on the existing 19 suppliers. Results for this analysis are presented in Table 8. DEA identified two relatively efficient suppliers, Supplier P and Supplier Q. The latter two suppliers were fully efficient, with efficiency score of 1, and slack and surplus variables were equal to zero. Rest of the suppliers was found relatively inefficient, where efficiency variation was from 0.807 regarding Supplier M to 0.989 regarding Supplier B. It is worth mentioning that Supplier B and Supplier D were the closest to relative efficiency and were evaluated at the score of 0.989 and 0.988 respectively. Supplier A (0.852), Supplier N (0.850) and Supplier M (0.807) were ranked at the bottom in terms of supplier performance.

DEA Ranking	Supplier (ranked by aggregated sales towards Aker MH)	Efficiency Score
1	**P (17)**	**1.000**
2	**Q (11)**	**1.000**
3	B (16)	0.989
4	D (6)	0.988
5	I (5)	0.981
6	F (18)	0.975
7	K (12)	0.968
8	J (7)	0.965
9	C (4)	0.955
10	R (2)	0.941
11	H (14)	0.933
12	E (9)	0.927
13	L (10)	0.926
14	O (13)	0.916
15	S (15)	0.908
16	G (19)	0.890
17	A (1)	0.852
18	N (3)	0.850
19	M (8)	0.807

Table 8. DEA Results for Existing Suppliers. *Source: made by author*

A very important finding is that the largest hydraulic component supplier was ranked 3rd to the last, the 3rd largest supplier was ranked 2nd to the last, and that 8th largest supplier of the hydraulic components was ranked as the least efficient supplier. A combined spending towards these three suppliers accounts for more than 50% of the total spending on hydraulic components. Based on the DEA model results, more than half of total purchase value for hydraulic components is entrusted to the worst performing suppliers. This finding suggests that the source for improving the overall quality of hydraulic components supply chain activities lies within managing the latter three suppliers. Referring to Trent and Monczka (1999) framework for supplier performance improvement, a non-complex process of supplier base optimization, would suggest consider removing the low-performers from the supplier base or initiate a process of performance improvements. Since the three worst performing suppliers are amongst the largest suppliers, removing them instantly from supplier base would hurt Aker MH. Therefore, a recommended step would be initiating the dialogue with low-performers, which would be critical regarding the success of the improvement process.

On the other hand, Supplier P, Supplier Q, Supplier B, Supplier D and Supplier I ranked at the top five in terms of relative efficiency. A total purchase order value towards these five suppliers accounted for only 12.4% of the total spending for hydraulic components. These findings suggest that purchase order distribution for suppliers requires closer attention. In order to enhance the overall supply chain performance, reallocation of shares of total hydraulic components spending per supplier, in such a way that best-performers receive more orders, must be considered. Best performers are expected to deliver better overall service level, which would be of great benefit for Aker MH to utilize. The latter findings reveal great potential for improvement of hydraulic components supply chain.

IDEAL supplier in relative efficiency model

This study contains an attempt to present Aker MH perception on preferred supplier in terms of performance, and analyze how this supplier would perform in relation to the existing group of suppliers. Therefore, an IDEAL supplier with attributes described in Chapter 5.2 was incorporated in DEA modeling. That resulted in a total of 20 DMUs analyzed simultaneously. Results of this multi-criteria evaluation are presented in Table 9.

Rank	Supplier (ranked by aggregated sales towards Aker MH)	Efficiency Score
1	**P (17)**	**1.000**
2	**Q (11)**	**1.000**
3	**IDEAL**	**1.000**
4	B (16)	0.989
5	D (6)	0.988
6	I (5)	0.981
7	F (18)	0.973
8	K (12)	0.968
9	J (7)	0.965
10	C (4)	0.947
11	R (2)	0.936
12	H (14)	0.933
13	E (9)	0.927
14	L (10)	0.923
15	O (13)	0.910
16	S (15)	0.906
17	G (19)	0.890
18	N (3)	0.850
19	A (1)	0.849
20	M (8)	0.807

Table 9. DEA Results on Ideal Supplier Relative Performance. *Source: made by author*

IDEAL supplier was assigned the attributes that Aker MH purchasing department would expect. Even though some of the existing suppliers had higher values across some of the variables, IDEAL supplier ranked as relatively efficient, with efficiency score equal to 1, and slack variables equal to zero. DEA model showed that Aker MH expects IDEAL supplier to be of the best performance efficiency-wise, however it was not the only relatively efficient supplier identified by second DEA application, see Figure 8.

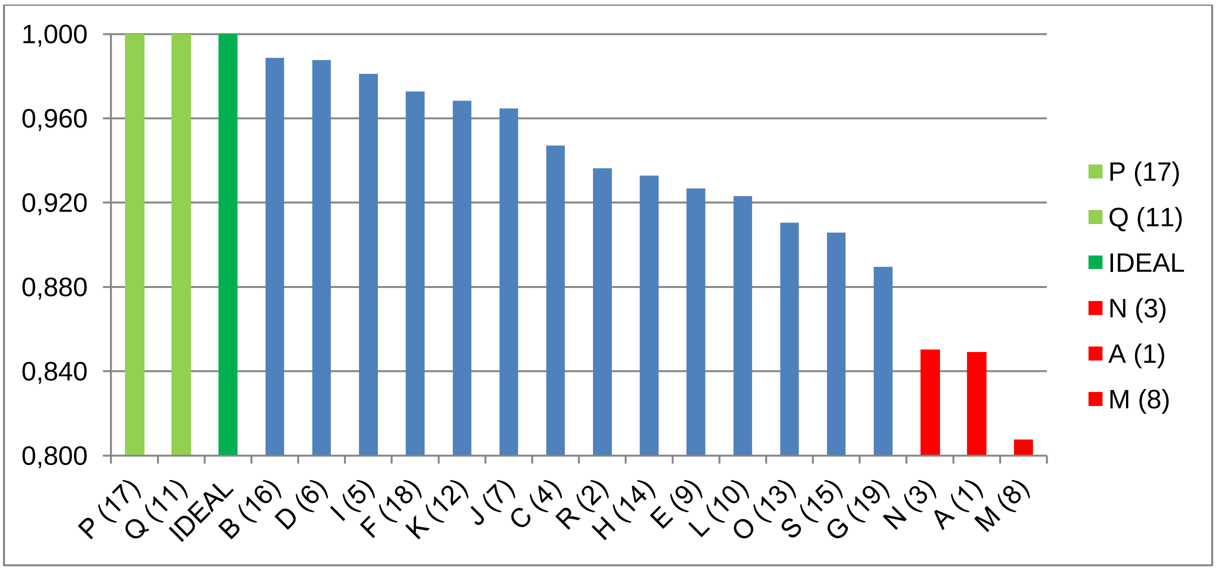


Figure 8. DEA results with Ideal Supplier. *Source: made by author, based on Aker MH data*

Supplier P and Supplier Q, as in the first model application, were identified as relatively efficient units. Based on DEA relative efficiency model, IDEAL supplier is relatively efficient, thus showing best performance in relation to existing suppliers. Supplier P and Supplier Q are relatively efficient in relation to other existing suppliers and also shows equal efficiency level as a pre-define role model. Such results would suggest that Aker MH expects performance of the suppliers that is feasible, but that also raises a question if the expected standards are high enough. Trent and Monczka (1999) suggest that setting an aggressive performance improvement target is a very important element in supplier performance improvement process and that it should be considered thoroughly. While reaching a certain expected level may be a great improvement for some of the suppliers, others might already be at that level and become not encouraged to seek further improvement. Therefore, more aggressive improvement goals need to be introduced that would ensure that all suppliers are expected to improve their performance. This observation should be of interest for Aker MH purchasing executives.

On the other hand, Ideal supplier expected performance level is higher than the most of the suppliers currently show. Some of the largest suppliers are behind by a great margin, which also raises questions if the communication methods are effective enough to reflect the actual expectations of the Aker MH, and if suppliers are motivated enough to deliver better results? Establishing supplier rewarding system is in accordance with Trent and Monczka (1999) supplier performance improvement framework.

As DEA measures relative performance of suppliers in terms of relative efficiency, the relative efficiency score of each supplier depends on other suppliers that are included in the analysis. When IDEAL supplier attributes were incorporated in the data sample, they had an impact on the efficiency score of the other suppliers, in comparison to results without IDEAL supplier involved. For example, Supplier's F relative efficiency score decreased from 0.975 to 0.973, Supplier's C from 0.955 to 0.947 or Supplier's R from 0.941 to 0.936 and etc. Due to introduced additional unit, Supplier A received a lower score and, therefore, ranked lower in relation to Supplier N, which had relatively lower score in the first DEA application. This shift demonstrates that relative efficiency scores depend not only on the attributes of the unit under investigation, but also on the attributes of other units that are used for comparison. These findings are in accordance with other scholars (e.g. Johnes and Johnes, 1993), which said that DEA identifies the efficient units but do not assume that it is the best possible performance. Therefore, if Aker MH would revise the supplier base in a way that low performers are excluded, then the newly run DEA results for rest of suppliers would show that relative efficiencies of remaining suppliers have changed, because their performance would no longer be measured in relation to considerably worse units. To sum it up, DEA does not provide absolute performance measures, but shows the relatively best among the existing units.

Study implications for theory and Aker MH management

Criteria that both Aker MH used for supplier performance measurement and also this study used for DEA application (price, delivery, quality) is consistent with research on most important supplier evaluation criteria (Dickson, 1966) and most often used criteria for supplier evaluation in academic research (Weber et al 1991). Same criteria were also used for vendor performance evaluation by Narasimhan et al (2005) and others. This study demonstrates the application of DEA model for measuring supplier performance. A case study company was used to illustrate the application process. The DEA was run by using some of the variables (price, quality and delivery) used in previous studies and also included a variable that was specific to a case study firm (automatch). Therefore, this study shows how can multiple and even firm-specific criteria be handled to measure supplier performance, as well as versatility of DEA in terms of applicable variables.

There were some DEA applications within Oil & Gas industry, e.g. Thompson et al (1996), Hawdon (2003), Eller et al (2011). Also multiple applications are found in supplier performance measurement, e.g. Weber and Desai (1996), Narasimhan et al (2001, 2006). There have been some applications of DEA in Norway, such as performance evaluation of employment offices (Torgersen et al, 1996) or measurement of efficiency in bus transport companies subsidized by Norwegian government (Odeck and Alkadi, 2001). A setting of Oil & Gas sector in Norway was presented by Kashani (2005). However, using Aker MH as case study company for measuring supplier performance, happened to provide a small extension to DEA settings map, since there exists little or no research regarding supplier performance evaluation of Oil & Gas related companies in Norway.

Supplier performance measurement sets grounds for successful supplier performance development process and supplier base revision. Moreover, supplier performance measurement should be a support for reallocation of business scope with suppliers in such way that best suppliers are involved to a highest possible extent. The study also analyses Aker MH perception on Ideal supplier by comparing it to the existing supplier base. The rankings and efficiency scores that DEA provides, identifies how suppliers perform relatively to each other’s performance. Since Ideal supplier was also included in second DEA application, the efficiency results show how existing suppliers perform in relation to what Aker MH actually expects from its suppliers. It provides a base for internal discussions if expectations are adequate or why do majority of existing supplier underperform, especially the largest suppliers, or how to make suppliers perform better. It is also possible to perform longitudinal study of the supplier performance by using DEA, see Kleinsorge et al (1992), which would help identify when certain shifts in supplier performance happened (if any), and what were the possible reason that triggered them. This research therefore should be meaningful for Aker MH as a representative of Southern Norway Oil & Gas cluster, a cluster which leads the world in delivering drilling solutions.

Conclusions and Limitations

This thesis introduced a study of supplier performance measurement with illustrational setting in Oil & Gas industry related Norwegian firm. An application of Data Envelopment Analysis was demonstrated to measure the supplier performance in terms of efficiency in utilizing inputs to produce outputs. Criteria selected for supplier performance measurement were regarded in academic literature as amongst the most important criteria for such cases. Average price trend over 5 years was selected as input variable, while quality, delivery and invoicing performance were set as output criteria. Two applications of DEA followed, one for measuring performance of existing suppliers, and other for measuring performance of existing suppliers in relation to Ideal Supplier. Ideal Supplier represented performance level Aker MH expects from its hydraulic component suppliers.

Deterministic input-oriented DEA model (as developed by Charnes, Cooper and Rhodes, 1978) identified two efficient suppliers in first application. In second application, IDEAL Supplier was identified as efficient in addition to best performers identified by first application. Analysis also showed that more than 50% of total hydraulic component supply to Aker MH was handled by 3 least efficient suppliers, while only 12,4% was handled by five best performing suppliers. The performance level Aker MH expects from its suppliers was reached by two suppliers.

This study suggests a few continuation directions. It is possible to perform longitudinal study of the supplier performance by using DEA, see Kleinsorge et al (1992), which could then be analyzed trying to identify when certain shifts in supplier performance happened (if any), and what were the possible reason that triggered them. DEA can also be employed as a tool for supplier performance monitoring. From empirical perspective, continuation of this study may address managerial issues on how supplier performance improvement or communication plans should be developed and implemented.

The empirical part of this study bases on the secondary data, which was not reviewed by the author, since that would have required a vast amount of time and would have exceeded the scope and aim of the master thesis. The extent, to which the findings and results of this thesis may be treated as valid, largely depends on the quality of the data provided by Aker MH. This regards the initial process of data acquisition and systemization. Internal Aker MH recommendations and guidance on when and how to perform certain reporting activities are aimed to help purchasing personnel, but the extent these recommendations are regarded contribute largely to representativeness of data and thus, final supplier performance measurement results, both of this study and the performance measurement method currently employed at Aker MH. Aker MH managers should interpret the results of the study carefully since DEA model possesses biases of certain extent.

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