Performance benchmarking of electricity power stations using Data Envelopment Analysis

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Abstract

Performance benchmarking plays a major role in setting and maintaining the objectives of the operational units. Traditional productivity measures are found to be inadequate in assessing the performance and hence advanced techniques like Data Envelopment Analysis (DEA) are recommended. This paper demonstrates the use of DEA for benchmarking the performance of electricity generating and supply stations and illustrates how the results enable to find out the best performers and the poor performers among the selected operational units and provide clues for improvement. DEA has been successfully applied to assess the productivity of different units and further helps to address the gaps between the superior and poor performers. The paper uses the Excel software to perform the computations and thereby providing an easy way to carry out a benchmarking exercise.

Keywords: *Benchmarking, DEA, Gap, Efficiency, Performance, Productivity.*

Introduction

Competition is ubiquitous and organizations are feeling the heat in maintaining their market share or customer base. Obviously, to survive in a competitive world, quality improvement is regarded as a panacea and there is no second opinion. In the recent times there is a significant rise in the number of quality tools and techniques, which are either innovative, new, or modifications of existing methods and practices. The common goal is to improve the quality of products and services. Six Sigma, ISO 9000, and quality awards are regularly discussed among the practitioners and academicians. The reasons for the proliferation of tools and techniques are many and varied as follows:

- Increasing awareness about quality of products and services
- Discernible customers,
- Increasing availability of information,
- Rising competition,
- Standardization
- Global connectivity
- New technologies
- Focus on customer satisfaction

These factors have triggered a fresh insight into the process of quality improvement and people have been experimenting with many new tools and techniques that would give them the desired results. Consequently, the quality tool box is continuously expanding. Because of the huge variety of the tools, different companies may decide to choose select tools that meets their requirements. For example, a company may be using the good old seven quality control tools, where as another company may be using quality function deployment, for their specific application. Though some of the tools are independent of the nature of application and use, some tools are useful only in some select applications.

Among these techniques, benchmarking occupies a prominent place and is viewed as a powerful quality improvement technique. Benchmarking has successfully been implemented for a variety of applications, and many corporate success stories are well documented. Indian companies too have embarked upon the mission of benchmarking and enjoyed success. The different procedures or methods of benchmarking may not be familiar to everyone, but benchmarking as a process is known to manufacturers, service providers, and vendors, as well as customers, as they would be subconsciously applying the benchmarking technique to verify or compare or improve quality. Today, of course, the concept of benchmarking is well known among the industries and almost all the fields have witnessed the applications of benchmarking world over.

Stated simply, benchmarking is nothing but a comparison between any item or product and a corresponding superior performer or product. Benchmarking is a means of identifying the best practices anywhere else and using this knowledge to continuously improve the products, services, processes, and systems to result in total customer satisfaction. Here the comparison is obviously with a better performer and the gap is identified. Once the reasons for this gap are established, appropriate action is taken to plug the gap and improve the performance. This process is not a one-time application but has to be used as an on-going process. Since new benchmarks are regularly created, it is necessary that the spirit of benchmarking is maintained. To be effective, benchmarking should be integrated into operations throughout the organization and should be an ongoing process that analyzes data collected over time. It is a learning process that helps institutions discover how they can best improve the direct or indirect services they offer to their customers.

This paper applies the benchmarking process to a group of companies engaged in the field of electricity distribution, and thus are selected as candidates for performance assessment. While benchmarking provides the necessary baseline judgment to decide the superior and poor performers, it is essential that a quantitative assessment of the overall process is carried out to find out how the different candidates under comparison perform and how to identify the gaps. In this regard, the data envelopment analysis, which has found many applications, is considered as a technique to understand how the individual decision making units (DMU) compare with each other, and how to understand the gaps among the candidates under performance assessment.

Performance comparison can be done by several methods (Asandului, Roman, & Fatulescu, 2014) as follows:

1. Ratio analysis,
2. Least-squares regression (LSR),
3. Total factor productivity (TFP),
4. Stochastic frontier analysis (SFA), and
5. Data envelopment analysis (DEA).

Typically the scope of performance assessment is primarily to understand how a candidate under assessment is performing with respect to preset standards and secondly to find out the gaps between the expected performance and the actual performance, so as to enable the planning of the improvement process to be followed.

Among the five methods listed out earlier, in this paper the DEA is used to compare and benchmark the performance among the different DMU's concerned. The main reason is the availability of literature in abundance, and extensive and growing list of applications of DEA in a wide ranging and diverse fields. Further, for productivity measurement and comparison of service organizations, DEA is recommended as an appropriate technique, (Sherman & Zhu, 2006). A large number of applications of DEA has been reported in the literature and it is clearly stated that DEA provides a clear understanding of the performance rating based on the preset criteria and thus provides a clear roadmap to tread the path of improvement. Though many papers have been written on DEA covering various fields and sectors, it seems that there are very few applications of DEA in the field of power generation systems, which is surprising. Because, power sector plays a vital role in the economy of a country and hence the power generating companies should be benchmarked for performance assessment and improvement. In fact, a country's economic prosperity and progress are measured in terms of electricity generated and utilized. When the search was on the power generating companies across the world to identify the benchmarking exercises, the author could identify only a few reports that included the data for DEA application. This perhaps could be a deterrent for proper analysis of the situation. Another observation by the author is, the power generation and distribution companies have carried out the benchmarking exercises regularly using their own methods and assessment procedures which may not be of much help for the industry. However, these studies are limited to identify the better performers and compare all others with them revealing the gaps. In a study conducted by the power companies located in the islands of Pacific Ocean, only comparison is done and no ideas are provided to improve the performance of the poor performers. Hence the author feels that DEA is a good approach. Considering the scope of the paper, the other four methods were not used for the benchmarking purpose as otherwise the paper would become too long and unfocused.

Organization of the paper

This paper is essentially about benchmarking the performance for identifying the gaps between the superior performer and others, and then set the gals for improvement. First, the concepts of benchmarking and the data envelopment analysis are described briefly along with a literature review. Later the DA is illustrated using the case of electricity supplying power stations as candidates for benchmarking. Finally, the results are analyzed and interpreted. For the purpose of computations and analysis, Microsoft Excel has been used in this paper as the author found interesting applications of Excel and also was able to get clear guidance from the management science textbooks. It is to be note that performance benchmarking or competitive benchmarking is used where organizations consider their positions in relation to performance characteristics of key products and services. Benchmarking partners are drawn from the same sector. However, in the commercial world, it is common for companies to undertake this type of benchmarking through trade associations or third parties to protect confidentiality.

Benchmarking and DEA – Literature review

One of the important methods of establishing the operational effectiveness of a production system is to find out the productivity which is a simple way of finding how efficient a system by dividing the output by the input. This ratio is quite often sufficient to understand the ability of a production system in converting the inputs to desirable outputs. Typically the input used to be only one, though it is obvious that many different inputs have been used to obtain the outputs from a production system. For example to obtain a tangible product several inputs like materials, energy, information, capital, and human resources would have been used and the output is measured in terms of, say, units per time period or any other quantifiable resource. To enable operations managers to make better decisions, two types of measures of productivity are commonly used. These are (i) operational measures, and (ii) financial measures. The operational measures enable to express the output per unit of input of different resources either taken one at a time, (single factor productivity), or several resources, (multifactor productivity) or all the resources, (total factor productivity). In the case of using financial resources, the output and the input are expressed in terms of monetary units and productivity as before is calculated taking one or more resources at a time.

Continuous quality improvement of products and/or service offered by a company is essential for survival in the market and meeting the competitions of the customers. Hence the organizations are continuously searching for new techniques and tools to enable them to improve quality. Benchmarking is one such quality improvement technique that helps quality improvement by comparing the performance or any other measurable attribute with those who are doing it better. In essence benchmarking involves comparison with the superior performer, identify the gaps, and take proper action to overcome those gaps, thereby improving the quality. This process is not a one-time application but has to be used as an on-going process. Since new benchmarks are regularly created, it is necessary that the spirit of benchmarking is maintained, (Elmuti & Kathawala, 2013). This means the benchmarking efforts need to be continued to improve the performance and not to be done just one and stopped.

Benchmarking is an ongoing, systematic process for measuring and comparing the work processes of one organization to those of others that exhibit functional "best practices". These best practices are often thought to be the change agents to improve the performance. However, what constitutes best practices, and whether such practices are applicable at different places or situations is still being debated. Several authors have covered the best practices, (Codling, 1992), (Bogan, 1994), (Keehley, 1997), & (Coers & Raybourn, 2001), but there is no clear evidence to claim that the practices that worked best at one place replicated the success at another place. This may be due to organizational mismatch, differences in culture, people, processes, and even the time of implementation. The goal of benchmarking is to provide an external standard for measuring the quality and cost of internal processes, and to help identify where there may be opportunities for improvement. To be effective, benchmarking should be integrated into operations throughout the organization and should be an ongoing process that analyzes data collected over time. It is a learning process that helps institutions discover how they can best improve the direct or indirect services they offer to their customers. For a complete list of literature on the process of benchmarking literature review papers on benchmarking can be consulted, (Zairi & Youssef, 1995), (Dacko, 2000) (Kozak & Nield, 2001), (Scott, 2011) and (Dattakumar & Jagadeesh, 2013). All these authors have provided a detailed classification of literature and also the list of applications that include success stories which would inspire the readers to go for similar exercises. From these papers it is quite obvious that benchmarking has gained a wide popularity as well as industry recognition as a prominent quality improvement technique.

Benchmarking process has a procedure, which, though not standardized, needs to be established for any project, (Camp, 1989). The procedure, being different among many organizations has certain common steps. One popular procedure is as follows:

- Determine what to benchmark
- Identify customers
- Identify critical success factors
- Convert them into measures where possible
- Form a benchmarking team (4-6 people)
- Identify type of benchmarking team to organize
- Allocate sufficient resources (time, funding, process support)
- Identify benchmark partners
- Collect and analyze benchmarking information

- Check benchmarking information for patterns, misinformation, omissions, etc.
- Produce summary report of benchmarking investigation
- Continue to improve the benchmarking process along with improvements in product/process

These steps when followed meticulously would lead to desired results and thus would reinforce the confidence on the benchmarking process. Hence it can be observed that the process of benchmarking is useful to everyone in the organization and irrespective of the nature of the industry, number of employees, type of industry, products or processes, the technique can be applied and hence will be useful to anyone who is interested in quality improvement. In fact it is interesting to note that benchmarking has been applied in all types of fields for various applications whether it is manufacturing, warehouse management, product design, transportation, product quality, and others.

When it comes to comparison of performance among various manufacturing or service organizations, a single measure like productivity or efficiency would give only a partial picture. Because in any organization, multiple inputs are involved and multiple outputs emerge from the systems. However, it has been observed that the individual contribution by each of the different inputs is not revealed by the productivity measures and hence such measures have a limitation. In this context, DEA plays a stellar role as it enables quantification of the individual efforts towards the output and thus allows benchmarking when similar operational units are compared.

DEA is today considered as a prominent tool to compare and benchmark the performance across similar operations systems or organizations which are termed as “Decision Making Units (DMU). Ever since the publication of the seminal article on DEA (Charnes, Cooper, & Rhodes, 1978), the history and development of DEA have been very well documented by several authors, (Charnes, Clark, Cooper, & Golany, 1984), (Cooper, Seiford, & Tone, 2007), (Cook & Seiford, 2009), (Cooper, Seiford, & Zhu, 2011), (Ji, Lee, & others, 2010), and recently in a handbook, (Hwang, Lee, & Zhu, 2016). As the literature is pretty rich and many well narrated papers have already been published about DEA, this paper will not attempt a detailed review and instead focuses on the applications. An extensive analysis of applications of DEA reveals that more than 4000 articles have been written by approximately 2500 authors covering many diverse applications of DEA, (Emrouznejad, Parker, & Tavares, 2008). This means at the time of this paper it is quite likely that the number of articles would have more than doubled and many more applications have been illustrated by different authors.

DEA applications span both manufacturing and service sectors and a wide ranging applications can be spotted in the literature. An interesting application of performance comparison of schools is described to illustrate the application of DEA in a non-manufacturing situation, (Bessent & Bessent, 1980). Another non-manufacturing application of DEA is about the efficiency analysis of maintenance units in the United Sates Air Forces, (Charnes et al., 1984), which was a project funded by the government. How the different branches of a commercial bank perform is explored by applying DEA by different authors, (Sherman & Gold, 1985), (Vassiloglou & Giokas, 1990), (Yue, 1992), (Luo, 2003), which is another good example of a commercial business application of DEA. Potential effects of variable set expansion and data variations upon the efficiency scores generated using the Data Envelopment Analysis (DEA) model is examined with respect to the performance assessment of non-profit organizations, (Nunamaker, 1985). Selecting technology for a specific industry or an organization is challenging task and DEA has been effectively applied for technology selection, (Khouja, 1995), (Baker & Talluri, 1997). Crime management is a big challenge for police forces in any country and a successful application of DEA (Thanassoulis, 1995) reports how the analysis helped in improving the performance of police forces. Concepts of cost and outcome efficiency are required in order to gain further insights into the universities' operations and a specific application of DEA to assess the performance of 45 universities in UK is reported to indicate the usefulness of DEA in an academic context, (Athanassopoulos & Shale, 1997). A similar assessment of universities in Australia demonstrates the use of DEA using various measures of output and inputs, (Abbott & Doucouliagos, 2003). Typically studies focus on financial measures when it comes to the assessment of performance of airports and ports. However, in a special application DEA, (Roll & Hayuth, 1993), (Gillen & Lall, 1997), (Martínez-Budría, Díaz-Armas, Navarro-Ibañez, & Ravelo-Mesa, 1999) the technique has been used to assess the performance of airports and seaports. Data collected from retail stores belonging to a restaurant chain, has been used in assessing retail productivity, (Donthu & Yoo, 1998). Selection of suppliers is a crucial decision and is considered to be a multi-criteria decision making problem. Observing this DEA has been applied to evaluate suppliers for an individual product, with the help of a case study, (Liu, Ding, & Lall, 2000). Hotels are worried about the quality aspects to attract more customers, and thus have a potential to conduct performance assessment studies, (Hwang & Chang, 2003). A literature survey on the application of data envelopment analysis to energy and environment studies followed by a classification of 100 publications in this field is good summary of specific applications of DEA, (Zhou, Ang, & Poh, 2008). DEA is used to construct performance indices on the basis of the multiple outputs which airports produce and the multiple inputs which they utilize. Performance evaluation of 25 property and casualty insurance companies with the goal of determining the efficiency of each company compared to the peer competitors within property and casualty insurance industry, has been reported by (Wang, 2010). The analysis reported here follows very much the practice of using the efficient frontier analysis. To identify the superior performers and the gaps between the top and poor performers. Examining the efficiency of public healthcare systems in Europe using statistical data for 30 European states for 2010, demonstrates the use of Data Envelopment Analysis in another service application namely health care system, (Asandului et al., 2014). An interesting and useful application for academics is using DEA in the field of higher education to compare several institutes, considering inputs like faculty, living costs, enrollment, and loan raised by the students, to evaluate the most important output namely the graduation rate, (Liu and Tsai, 2014). From this study it is reported that about 38% institutes were found to be efficient in private domain while only 11% institutes were found efficient in the public domain. These results are quite useful to the administrative authorities in the Government and also the public. The handbook of DEA (Hwang, Lee, & Zhu, 2016) gives a wonderful explanation about the techniques involved in DEA along with several applications. It can be observed that the DEA has now been extended with other techniques for example, fuzzy logic, and genetic algorithms. Researchers (Zervopoulos, Brisimi, Emrouznejad, & Cheng, 2016) have used a DEA–based performance measurement methodology that is consistent with performance assessment frameworks such as the Balanced Scorecard, to compare banks in Mozambique, which should be a good application in the area of finance.

In a succinct manner, the way DEA has risen in rank and preference as a powerful technique and the research thrust it has enjoyed is illustrated in a paper (Cook & Seiford, 2009), which also highlights the technical aspects of the DEA analysis. An excellent coverage of DEA and the way the research has progressed is captured in a handbook, (Cooper et al., 2011), which illustrates a wide ranging applications of DEA across the globe. Considering the use of spreadsheets in DEA, the technique has been illustrated to enable easier applications by researchers, in several books, (Ramanathan, 2003a), (Laguna & Marklund, 2005), (Zhu, 2014) & (Winston & Albright, 2015). In fact, the spreadsheet application of DEA has greatly enhanced the utility of the technique as the Excel sheet provides a number of results and interpretations, which should be very useful to the decision makers. Particularly those who have practiced the liner programming problems using Excel, would find the DEA quite easy and would explore further in to the analysis. It is clear that DEA applications have increased over a period of time, and continue to attract the attention of researchers today as benchmarking the performance of organizations is a commonly undertaken exercise to remain competitive in the chosen field.

The extensive literature review made here shows ample proof of the power of DEA in making comparisons across a chain of candidates from various fields. In particular it is noted that the contribution of the inputs in achieving the desired outputs is clearly established by the DEA method. Thus in a group of candidates selected for comparison how many of them are efficient will be clearly established. This focuses the attention on the poor performers and prompts for further action to be taken to improve the performance. What really matters after the DEA process is to find out how the inputs and outputs need to be configured to reach maximum efficiency. This is well described in Winston & Albright (2015), who suggest running the Excel based DEA model to benchmark with the best performer and improving the efficiency.

Benchmarking in power sector – An application

Power sector is considered as the backbone of industry, trade, and commerce, in any country and has a direct influence on the growth of an economy. Given this background, power sector usually is seen as a vital pillar for a country's growth and prosperity. The typical functions handled by the power sector are: generation, distribution, and maintaining of power sources. In addition it has the major role of setting the tariff for the consumers of power, and also setting the tax and other applicable charges. This indicates that the power sector is also helping in policy making and goal setting which would enable the people in the sector to standardize and improve their operations. Benchmarking greatly helps in all these cases. Both the technological and the financial aspects can be benchmarked against the best practices and substantial improvements can be seen.

In the case considered in this paper, data related to certain inputs, and outputs are given and thus lends for DEA application. The case chosen in this paper pertains to Utility Performance Benchmarking Analysis, of Nova Scotia Power Company, Canada. As stated in https://en.wikipedia.org/wiki/Nova_Scotia_Power, it is a vertically integrated electric utility in Nova Scotia, Canada, and privately owned by Emera and regulated by the provincial government via the Nova Scotia Utility and Review Board (NSUARB). Nova Scotia Power Inc provides electricity to 500,000 residential, commercial and industrial customers in the region of Nova Scotia. There are six units as listed in Table 1, called as Decision Making Units (DMU's), as per the jargon of DEA.

World over benchmarking exercises have some common assessment as observed in typical benchmarking of power generating companies, (Flores, 2012). As stated in the report, overall approach of this performance benchmarking analysis was to apply the specific benchmarking metrics that include:

a) Operating expense as a percent of revenue

b) Operating expense per customer

c) Operating expense per megawatt hour (MWh)

However, in the present analysis, these metrics are not used as the data related to these parameters could not be obtained from public sources. Hence the data used for the analysis in this paper consists of assets, generation capacity, the total number of customers served, length of the transmission line, and the distribution line, pertaining to each of the power station. Data is based solely on public information sources as provided in ttps://www.nspower.ca/ site/media/Parent /20110718.pdf. The data is illustrated in Table 1. In this table, there are five data variables pertaining to each of the power production and distribution companies. Each company has the specific objective of producing the power and then distributing the same across its customer base. As the data available is limited to these variables only, it is necessary to carefully categorize the variables as input and out values. Thus the two categories considered for DEA application are as follows:

Input variable

Assets expressed in Dollar value. This represents the entire infrastructure developed for the purpose intended including all the physical and other tangible assets. As this is the only data available with respect to the investment made, it is considered as the input variable. As expressed in the Table 1, it is in Billion Dollars.

The output variables are as follows:

1) Customers: This represents the total number of customers served by the company and includes all categories of customers like domestic, commercial and industrial users.

2) Generation capacity: This is the output capacity expressed in megawatts. This is considered to be the actual capacity that is the best possible output considering the usual operating conditions.

3) Transmission line: This is a vital element that enables the power to be transmitted from the generating point to the main distribution centers and expressed in kilometers.

4) Distribution line: This is the last part of the network that enables the customers to get the electricity power at their places. This is obviously much longer than the transmission line, as it connects the supply company to the end users. It is also expressed in kilometers.

Thus it is observed that the DEA case here involves one input variable and four output variables. The values of all these variables are presented in the Table 1. The different DMU's are shown in the first column of Table 1.

Table 1 : Benchmarking candidate companies and their performance related variables

	Assets, Bn $	Customers	Generation capacity (MW)	Transmission line, km	Distribution line, km
ATCO	12	1411000	4885	10000	63000
EPCOR	1	338100	180	203	5548
NB Power	5	383896	3194	6841	20595
New found land Power	1	243426	140	11000	11000
NSPI	3	491158	2368	5000	29000
Sask Power	5	481985	3840	12404	145169

DEA Methodology

The DEA methodology followed in this paper essentially follows the approach as given in the standard management science text books. The reason for selecting these sources, is all of them describe the method using Excel as the supporting software. As the author did not have access to any commercial software as suggested in some sources, for example, (Ramanathan, 2003b), it was decided to use the Excel software which is available on a much bigger scale. The management science books typically describe the use of Excel to solve the problems related to the subject and hence the author found it easier to adopt for this research work. The management science books referred (Winston & Albright, 2015), (Bernard W. Taylor, 2014), (Powell & Barker, 2008) suggested a common approach which included calculating the weights for the inputs and weights for the outputs and establishing the efficiency of each of the DMU's by using Excel Solver. However, (Anderson, Anderson, & Parker, 2013) suggested using a composite DMU approach to establish the efficiency and then comparing it with the efficiency of the DMU's to decide the better and poor performers. In this paper, the methodology followed involves finding the weights and the efficiency as described by several authors. Further, in iterative approach has been followed using Excel Solver to determine the weights of the inputs and outputs while establishing the efficiency of the DMU's. The methodology is briefly illustrated and for more details the earlier cited text books can be referred.

The procedure involves determining the efficiency of a DMU as follows:

$$\textbf{Efficiency} = \frac{\textbf{Value of DMU's outputs}}{\textbf{Value of DMU's inputs}}$$

As no DMU can be more than 100% efficient, the efficiency of each DMU is constrained to be less than or equal to 1. To make this a linear constraint, the condition is expressed as:

Value of DMU's outputs <= Value of DMU's inputs

Thus any DMU reporting an efficiency of 1 is considered efficient and any DMU showing less than 1 is considered as inefficient.

In the next step, the input and output weights or costs of inputs and prices of outputs are determined by formulating the liner programming problem, and also establishing the efficiency of the chosen DMU. It is interesting to note that by appropriate formulation both the set of weights and the efficiency of the DMU are determined at a time for a chosen DMU. Hence it is necessary to repeat the process as many times as there are DMU's and then consolidate the results. This is comfortably done using the Excel Solver and the results are shown in Table 2.

Table 2 : Overall weights of inputs and outputs an efficiencies of DMU's

DMU	**Efficiency**	**Assets, Billion $**	**Customers**	**Generation capacity (MW)**	**Transmission line, km**	**Distribution line, km**
ATCO	0.6008	0	0	0	0	0
EPCOR	1	0	0	0	0	0
NB Power	0.8099	0	0	0.00024009	0	0
Newfound land Power	1	0	0	0	0	0
NSPI	1	0	0	0.00020206	0	0
Sask Power	1	0	0	0	0	0

Results and discussion

The results displayed in Table 2 indicate that out of the six DMU's, two units namely, ATCO and NB Power are showing efficiency less than 1 and hence are considered inefficient, compared to the remaining four units who have all have the efficiency equal to 1. This is based on the axiom that no entity can have efficiency greater than 1.00. The concept of declaring the DMU's as "efficient" or "inefficient" is relatively not straight because all the DMU's have been provided with the same input and have produced the same output, though the quantum of input and outputs differ. As explained in the management science book, (Winston & Albright, 2015), a DMU is efficient if it can price the inputs and outputs in such a way that the DMU gets all the value for all the inputs invested. However, in the present case except for generation capacity, rest of the outputs and the lone input have received zero weight. Again out of the two DMU's who have charged a positive weight for the generation capacity, NSPI is shown as efficient and NB Power is shown as inefficient. Hence to understand this kind of a conflicting behavior among the DMU's, more detailed analysis needs to done using data related to various other variables that might be influencing the operational characteristics of the DMU's. If by DEA a DMU is declared as inefficient, then there is no pricing scheme where the DMU can recover its entire input cost in output values. Hence it is to be understood that an inefficient DMU should pick up good practices from those DMU which are declared efficient by DEA and improve by benchmarking their efforts to attain similar results as efficient DMU's.

The objective of this paper is to benchmark the companies that are in the same sector so as to identify the top performers and the poor performers. Besides the poor performers need to identify the areas for improvement so as to catch up with the better performers.

Alternatively a simple thumb rule can be used to compare the DMU's based on their relative rank under each criteria. Using a simple guideline of "lower the input higher the rank, and higher the output higher the rank, the relative ranking of all the DMU's under each of the input and output factors is done. The results are shown in Table 3.

Table 3. Relative ranking of DMU's

	Assets, Bn $	Rank	Customers	Rank	Generation capacity (MW)	Rank	Trans. line, km	Rank	Dist. line, km	Rank
ATCO	12	6	1411000	1	4885	1	10000	3	63000	2
EPCOR	1	1	338100	5	180	5	203	6	5548	6
NB Power	5	4	383896	4	3194	3	6841	4	20595	4
Newfound land Power	1	1	243426	6	140	6	11000	2	11000	5
NSPI	3	3	491158	2	2368	4	5000	5	29000	3
Sask Power	5	4	481985	3	3840	2	12404	1	145169	1

The different ranks for each of the DMU's are combined to form a composite rank and reordered from high performer (ranked 1; minimum input, maximum output) to low performed (ranked 6; maximum input, minimum output). The results are shown in Table 4. In addition, the DEA based efficiency for all the DMU's are also indicated in a separate column.

Table 4 : Simple ordered ranking of the DMU's

DMU	**Overall rank**	**DEA based efficiency**
Sask Power	1	1
ATCO	2	0.6008
NSPI	3	1
NB Power	4	0.8099
Newfoundland Power	5	1
EPCOR	6	1

From the results displayed in Table 4, it is seen that the two inefficient DMU's, ATCO and NB Power, are relatively ranked high compared to other units having ranked 2^{nd} and 4^{th} respectively among the six units. This happens because the input and the outputs have all been weighed equal and only relative magnitude is considered. On the other hand, DEA has given different weights for input and outputs under each of the DMU's and thus looks at their relative contribution.

This is where the power of DEA is to be appreciated. This point is to be carefully noticed when benchmarking is done using only relative ranking of the units. Thus it is clear though ATCO and NB Power are considered as better when compared with respect to individual parameters, they are not efficient because they are not using their input properly and hence producing lesser outputs compared to other units. It is important to notice that in the absence of complete data, the assessment made using DEA or composite ranking may not be realistic nor can be completely relied upon for analysis or further managerial decision making. This perhaps may diminish the value of the work reported in this paper but nevertheless demonstrates the application of DEA to a hitherto not tried engineering sector. DEA in this case has exposed the relative efficiency of the DMU's particularly with respect to converting the inputs into the outputs. This means it is the transformation processes that consume inputs and produce outputs that should be thoroughly investigated. Once the transformation processes of the poor performers, in this case ATCO and NB Power companies, are compared with the other remaining companies, the roadmap towards improvement can be drawn and all the DMU's can be ensured to exhibit high efficiency. Overall from the analysis it is clear there is no one company that demonstrates high performance in all the parameters considered, and hence this could be a challenging task to accomplish involving analysis of complete data. Because of the limited data available in the case, a more detailed analysis is not possible.

It is interesting to observe that the report on benchmarking of power generating companies, (Flores, 2012) considers the specific benchmarking metrics which include the following:

a) Operating expense as a percent of revenue

b) Operating expense per customer

c) Operating expense per megawatt hour (MWh)

Based on this comparison NSPI company was found to be most efficient on all the three metrics. The DEA carried out in this paper has also recognized NSPI as the efficient DMU.

Conclusion

Benchmarking has been very well accepted as a powerful technique for quality improvement as seen by the growing number of applications. While benchmarking is seen as imitating or duplicating a success model, it goes beyond the usual meaning. Just by duplicating the quality will not improve. It is only when benchmarking is applied through proper spirit the benefits will accrue. Further, benchmarking is not to be done using only relative ranks or positions in a list. Particularly when it comes to performance benchmarking, the individual factors responsible for a given performance have to be carefully examined and then only the better and poor performers to be identified. In this context DEA plays a vital role and helps to find out how well the contributing factors compare among different DMU's. This paper once again ascertains the utility of DEA by applying the technique in a very important sector of power generation and distribution which plays a crucial role in a nation's economy. The power of DEA is to be identified in appreciating the fact that the efficient units illustrate how well the inputs have been converted into outputs. The less efficient units need to be monitored for the transformation processes and thus improved towards better efficiency. As the entire data is not available, having taken the data from the public sources, the analysis is limited to only identify the poor performers but would not be able to pinpoint the curse of action to be taken to improve the efficiency. Hence suggestions to derive the full benefit of DEA results is to supplement the analysis with value stream mapping technique, which enables observing the process parameters during the transformation stage in a close manner thereby providing an opportunity to make appropriate changes. Secondly DEA has not taken into account the time factor, that is, the time taken by the individual DMU's in reaching the outputs nor there is any data related other resources for example, human resources, utilized in achieving these outputs. This diminishes the comparison results because time plays a crucial role in accomplishing the results. However, by proper activity tracking it should be possible to capture the time data and thus more realistic comparison is possible. The DEA can be repeated using time also as an input variable. This definitely extends the benefit of DEA and benchmarking would be more meaningful and convinces the decision makers.

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