Selection of Sustainable Supplier for Medical Centers with Data Envelopment Analysis (DEA) & Multi-Attributed Utility Theory (MAUT) Approaches

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Abstract

Background and Objectives: The selection of the sustainable supplier is important for any industry. Medical centers are not an exception in this case, and selecting the best sustainable supplier is a major step towards increasing their productivity. This paper, using the Data Envelopment Analysis and then using Multi-Attributed Utility Theory as a backup approach to fix errors, attempts to introduce the most important criteria and sub criteria for selecting the best sustainable supplier of medical equipment among domestic and foreign suppliers.

Methods: After reviewing the previous papers, the 13 most important sub-criteria are extracted based on the 3 social, environmental and economic criteria. At first a Data Envelopment Analysis (DEA) model is used to find the initial ranking for sustainable suppliers. Then the Multi-Attributed Utility Theory (MAUT) is employed as a secondary and backup approach to find the utility function. The data obtained are first examined in DEA and then by MAUT and the results are presented in the form of figures, tables and analytical results in the relevant section.

Findings: Based on the 13 sub-criteria introduced at the end of the two-stage ranking, supplier C is selected as the best sustainable supplier.

Conclusion: For initial ranking, DEA is a good method, but to find the utility function of the ranking, the use of MAUT is an effective method with a high degree of proximity.

Keywords: Sustainable Supplier selection, Multiple Criteria Decision Making, Data Envelopment Analysis, Multi-Attributed Utility Theory

1. Background and objectives

In this paper, the ranking problem of medical suppliers is considered. The problem of selection and ranking of a supplier of medical center as well as a quality management system for medical devices is an important issue [1]. Selection is one of the basic subjects human always has been faced. According to limited organization resources and the competitive atmosphere of industry in today's world, appropriate decision making can help to achieve to strategic goals. So decision makers try to find ways which can help to make best decisions. Supplier selection can be done with using different supply chain strategies [2]. Research in consumer goods markets has largely confirmed the intuition that information can facilitate search and better decisions for buyers with imperfect information regarding product quality or costs or supplier willingness to accept lower prices [3]. There are many frameworks for the aim of assessing suppliers’ performance [4]. These frameworks have different measures which lead in different scenario [5]. Goh et al. examine the attribute set for healthcare supplier selection such as response time, reliability, stock quantity, in order to realize optimal cube utilization, cost, and customer satisfaction. This operational framework developed can help a logistics service provider in supplier order management based on the selected criteria set, criteria weight calculation, and supplier ranking [6].
Supplier selection measures may be both quantitative and qualitative. This can justify the need of integrating both qualitative and quantitative measures in a unique framework. In addition, companies’ desires are not the same regarding all criteria. They may increase the weight of one measure and decrease the other one. Multi-criteria decision making approaches seem to be a proper tool for the aim of weighting these criteria. Finally, considering all these issues can be a good contribution toward supplier selection [7]. Supplier selection is a multi-faceted strategic decision but there is few researches which consider factors like sustainability. Moreover, when selection criteria are subjective and require decision makers’ judgment, and each candidate supplier dominates a separate selection criterion, so the decision-making process becomes more complex [9]. Bevilacqua et al. (2006) starts the study by identifying the features that the purchased product should have (internal variables “WHAT”) in order to satisfy the company’s needs, then seeks to establish the relevant supplier assessment criteria (external variables “HOW”) in order to come up with a final ranking based on the fuzzy suitability index (FSI) [8]. Supplier selection of globally scattered suppliers represents a strategically crucial (in terms of organizational and supply chain performance) but rather complex decision-making problem [9]. You can’t imagine a medical center without medical equipment, they are important because one flaw can cause unpredictable damages. In Medicine center like hospitals, it’s so important to select best suppliers so it’s important to select appropriate criteria. There are some approaches to make decision like Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), VIKOR, Analytic Network Process (ANP), and DEA, Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), and ELimination and Choice Expressing Reality ( ELECTRE). The MAUT is a second approach to find the utility function. The supplier selection problem is a common issue that numerous companies have faced for many years. Selecting the right supplier can be a real headache and there are many criteria and sub-criteria to consider that assessing them is no easy feat [10]. In MCDM problems, selection appropriate criteria and sub-criteria are important. For example, Sedady and Beheshtinia consider 5 main criteria of technical, economic, social, political and environmental for renewable power plants construction, each including 5 sub-criteria [11]. Supplier selection is a process whereby the companies will have to first identify, then assess, and eventually contract with the suppliers [12]. Such process usually requires massive amount of an organization’s financial resources and it is a critical process [12]. Moreover, the selection process has a significant role in reducing the cost, improves profits and the quality of the products, and firms often misunderstand the supplier selection problem as a single-criterion decision-making problem, considering only cost factors when making decisions [13]. As the sustainable supplier selection (SSS) is a complicated decision. Conflicting sustainability legislation and organizational objectives also add to the complexity of SSS decisions [14]. Some criteria are important to select appropriate sustainable supplier. The SSS problem is widely considered as a multi-criteria decision-making problem. The recent literature reviews of SSS by [14] and [15] indicated that multi-criteria decision methods (MCDM) were amongst the most frequently applied approaches in evaluating and selecting sustainable suppliers. Some papers have used MCDM to solve health care problems. Torkzad and Beheshtinia present that Criteria affecting hospital service quality are identified. Four Iranian public hospitals are evaluated using these criteria. Four hybrid methods, including modified digital logic-technique for order of preference by similarity to an ideal solution, analytical hierarchy process-technique for order of preference by similarity to an ideal solution, analytical hierarchy process–elimination and choice expressing reality and modified digital logic–elimination and choice expressing reality are used to evaluate hospital service quality [16]. William Ho et al. (2010) in his paper reviewed 78 journal articles between 2000 and 2008. It was found that numerous individual and integrated approaches were proposed to solve the supplier selection problem. The most prevalent individual approach is DEA, whereas the most popular integrated approach is AHP–GP. Second, it was observed that price or cost is not the most widely adopted criterion. Instead, the most popular criterion used for evaluating the performance of suppliers is quality, followed by delivery, price or cost, and so on [17]. The first approach to be reviewed is AHP. AHP is the most popular and widely used method for assigning weights to criteria with consistency check of experts. Some papers have used AHP for health care system problems. Lupo submits an Analytic Hierarchy Process (AHP) method to elicit reliable estimations of hospital service quality expectations [18]. Singh and Prasher use Fuzzy Analytical Hierarchy Process to find out the priority of each of the dimensions and sub-dimensions of healthcare service quality (SQ) attributes and add Hospital management needs to recognize and make a match with patients’ perception of what SQ is and deliver better healthcare services [19]. Samani and Hosseini-motlagh present an enhanced perspective incorporating a two-phase preemptive policy by which the disruption risk is diminished through a hybrid technique using the fuzzy analytic hierarchy process and grey rational analysis for determining supplementary blood facilities, to cooperate in production process and decrease interruptions [20]. Asadi et al. submit an AHP based model for Prioritization of hospital services for outsourcing and presents that Prioritizing the services to be outsourced is a crucial challenge toward efficient
outsourcing of health services. In spite of fruitful efforts in improving the outsourcing process, there still remains room and need for developing more systematic approaches [21]. Also Asadi et al. presents a hybrid model of balanced scorecard and analysis of hierarchical process for evaluation of the outsourced services suppliers in supply chain of teaching hospital outsourcing has been considered by hospital managers as a model to reduce the financial burden and modify the financial system. The external suppliers must be qualified for the services they ought to provide to the hospitals. The use of the balance scorecard and the analysis of hierarchical process can help assessing suppliers’ capability to solve existing problems in the field [22]. Bhattacharya et al. (2010) combined AHP with Quality Function Deployment (QFD) with Cost Factor Measures (CFM) to rank suppliers. This method uses the QFD to identify customer’s needs and cost factors [23]. Another paper about this approach which can be mentioned is that focal companies are assigned responsibility from civil society to enforce at least minimum sustainability-related production standards, often throughout their entire supply chains. However, current managerial decision-making tools for supplier selection do not take sustainability risks from the wider supply chain into account. Contributing to filling this blank, Gold and Awasthi propose a two-step fuzzy AHP approach for sustainable global supplier selection that also considers sustainability risks from sub-suppliers [24]. Ahmad Dargi et al. work on Supplier Selection with A Fuzzy-ANP Approach and develop a framework to support the supplier selection process in an Iranian automotive industry [7]. The TOPSIS method is amongst the well-known MCDM methods that considers both positive-ideal and negative-ideal solutions in decision-making. TOPSIS is an effective approach to find the most efficient alternative, which has the shortest geometric distance from the positive ideal solution. There are many papers which present TOPSIS approach or its combination with other approaches. Some of them are mentioned in following: Behesthini and Nemati-Abozor propose a novel hybrid approach to rank suppliers in advertising industry and considers two new criteria to evaluate the suppliers in the industry. The proposed approach combines Modified Digital Logic (MDL) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) using fuzzy theory [25]. Behesthini and Ahangareian present a new method to obtain a suitable technology transfer strategy for roller concrete road pavement using Modified Digital Logic (MDL) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [26]. According to Zimmer et al. [15] who reviewed models supporting SSS, TOPSIS is the dominant method among MCDM methods for SSS problem. One potential reason for this popularity is the fact that the TOPSIS method appears easier to understand and simpler to implement compared to outranking methods such as PROMETHEE and ELECTRE that seem to be substantially more complicated as well as less transparent to DMs when compared with the TOPSIS method. Other method to supplier selection using MCDM is proposed by Sanaye et al. (2010). They propose a MCDM model based on VIKOR method and define 4 sets consist of decision makers, possible suppliers, criteria and performance. The method is implemented in 9 steps on an auto parts manufacturing company [27]. A case study of the hospital service evaluation in Taiwan is presented to describe the fuzzy VIKOR method in [28]. Hamid et al. propose a novel multi-objective model for the operating room scheduling problem and use the PROMETHEE-II method to select the best solution among the obtained Pareto solutions [29]. M. Gul et al. presents an integrated fuzzy method consisting of simulation, interval type-2 fuzzy analytic hierarchy process (IT2FAHP) and ELECTRE approaches to evaluate the emergency department (ED) performance in a university hospital in eastern region of Turkey and select the best scenario that contributes most to the performance improvement of the ED [30]. Beheshtinia and Omidi use fuzzy TOPSIS, AHP, fuzzy VIKOR, modified digital logic (MDL) and combinations of these approaches for performance evaluation in the banking industry [31]. The next approach is DEA. DEA is a linear non-parametric programming methodology, which calculates the efficiency of each decision making unit (DMU) according to various inputs and outputs [32]. Braglia and Petroni used DEA to help purchasing managers choose the best supplier based on their overall performance. DEA has been investigated deeply in recent years. The main challenges in realizing appropriate supplier selection are threefold, namely meeting environmental requirement, dealing with fuzzy data and considering multiple objectives [33]. There are some papers which used DEA for a health care case study. Shafaghat et al. presents that Managers will be able to allocate resources optimally using performance evaluation data, specifically, efficiency evaluation of organizations. An efficiency evaluation of hospitals can be provided by determining the optimal scales for each hospital, to which optimal allocation of resources will be possible [34] and Al-Refai et al. (2014) propose and utilize a cellular service system for developing ten nurse assignment scenarios using data envelopment analysis (DEA) [35]. NTseng et al. proposed an integrated model which used AHP, fuzzy multi-criteria and DEA to determine the business performance [36]. Puri and Yadav (2014) proposed a fuzzy DEA model with fuzzy input and output data to overcome the limitations in the existing DEA model [37]. Fallahpour et al. mentioned that a DEA model that consists of n DMUs, for finding the efficiency score of a sample should be calculated in n times. This process is time-consuming for decision-makers in cases where the number of DMUs is large and increases the computational complexities of solving the linear programming [38]. DEA can be combined with other approaches. DEA could not involve
qualitative attributes in its analysis. On the other hand, Analytic Hierarchy Process (AHP) can be used to assign values (which are known as weights) to qualitative attributes [39]. Multi-Attribute Utility Theory (MAUT) can help in these situations by creating a decision model through the elicitation process of expert practitioner. Multi-attribute utility theory attempts to identify relevant objectives for any given decision. Where a decision is typified by multiple objectives it can be difficult to quantitatively compare these objectives one against another. In order to provide insight into this problem a utility function is assessed for each of the relevant objectives. This allows for an appropriate multiple-objective utility function that is then used to identify trade-offs and compare the various objectives in a consistent manner [40].

Some previous papers had studied on Decision Making problem using different selection approaches or combination of them. An overview of these papers and their approaches is given in Table 1.

Table 1: Pervious articles for sustainable/green supplier selection.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Publish Year</th>
<th>Industry Type</th>
<th>Criteria Type</th>
<th>Approach</th>
<th>Uncertain Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>SSS Green AHP ANP VIKOR TOPSIS DEA MAUT MAUT</td>
<td></td>
<td>Gray Fuzzy</td>
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<tr>
<td>(1) 2014</td>
<td>Health care</td>
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<tr>
<td>(6) 2018</td>
<td>Health care</td>
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<tr>
<td>(7) 2014</td>
<td>Automotive</td>
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<tr>
<td>(8) 2006</td>
<td>Manufacturing</td>
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<td>(14) 2015</td>
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<tr>
<td>(20) 2018</td>
<td>Health care</td>
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<td>(21) 2017</td>
<td>Health care</td>
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<td>(22) 2017</td>
<td>Health care</td>
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<td>(24) 2015</td>
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<td>(27) 2010</td>
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<td>(28) 2014</td>
<td>Health care</td>
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<td>(30) 2016</td>
<td>Health care</td>
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<td>(31) 2017</td>
<td>Health care</td>
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<td>(34) 2017</td>
<td>Health care</td>
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<tr>
<td>(35) 2014</td>
<td>Health care</td>
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</tr>
<tr>
<td>(37) 2014</td>
<td>Bank</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>(38) 2016</td>
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</tr>
<tr>
<td>(39) 2008</td>
<td>Manufacturing</td>
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<tr>
<td>(40) 2010</td>
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The required data in the literature of DEA is mostly provided by questionnaires, and so it may have errors. No pervious paper has covered its result errors with second decision making approach and no pervious paper has attempted to find its efficiency utility function. In this paper MAUT is used as a second decision making approach to cover our errors. In other aspect, no pervious paper has studied on the both the data envelopment analysis and sustainable criteria for supplier selection contemporaneously.

This paper has 5 sections. The methodology is described in Section 2. Important results, the analysis and interprets the results summarize in the form of text, tables and figures, and there are sensitivity analysis and some managerial insights to examine our potential to support the study hypothesis is mentioned in section 3. A compact summarization of the general outcome and advices for future works are provided In Section 4. Lastly, the paper ends with references in Section 5.

2- Method

2-1- The method framework

The developed framework for our study is shown in Figure 1. There are 5 main steps in our study process. Step 1 our ultimate purpose is the selection of best sustainable supplier so it is crucial to find
suitable candidate supplier to be evaluated from beginning. In this step a list of potential sustainable suppliers should be prepared. Step 2 for a useful supplier evaluation, appropriate criteria and sub-criteria are needed in 3 economic, environment and social areas. It is important to choose criteria in an unbiased process. Pervious papers and expert opinions can help choosing best criteria. Step 3 each selected sub-criteria must be identified that is input or put. The input sub-criteria must be decreased and output sub-criteria must be increased. Step 4 in this step, candidate suppliers should be evaluated by Super-Efficiency Ranking Techniques DEA approach. At first selected sub-criteria is weighted, each supplier efficiency is identified and our candidate suppliers ranking is obtained. Step 5 in this step the result obtained from DEA, is evaluated by using MAUT approach. The similarity between 2 approaches and their correlation is identified.

2-2- Criteria Identification

Now it is important to answer, what are right criteria and sub-criteria for the supplier selection? appropriate criteria and sub-criteria are selected according to expert opinion from the officials most extensively involved in quality improvement, including the chief executive officer, hospital manager and human resource director of the hospital, the deputy for education and research, and heads of department [21]. The first step is to identify the necessary criteria for which the examination of applicability is vital in the supplier selection process for making an objective and unbiased decision. In this case, the researcher first conducts a desk research, and then by reviewing the articles and the researchers conducted regarding this issue, the criteria will be refined. Those criteria that appear most often in these documents will be selected. Next, the researcher investigates instructions and procedures, previous suppliers’ records, to find criteria which are important to consider, in order to selecting suppliers [41].

Figure 1: The proposed sustainable supplier selection framework
Increasing outsourcing trends, environmental policies and social concerns are now forcing companies to integrate sustainability Triple Bottom Line (TBL) attributes (economic, environment and social) into their supply chain activities [42].

- Economic criteria: Quality, Warranty, Cost, Lead Time, Logistics Costs.
- Environmental criteria: Eco-design, Recycling, Energy Consumption, Production of Hazardous Radiation.
- Social criteria: Health and Safety, Responsiveness, Unsatisfied Customers.

This section provides an answer to this question that how the suppliers with sustainability can be found and prepares background of criteria and sub-criteria with regards to the environmental sustainability along with social sustainability criteria extracted from earlier studies in the SSS field relevant to the scope of selecting sustainable supplier for a medical center.

Figure 2 shows the relations between output and input criteria and sub-criteria in a medical.

2.2-1 Sustainable supplier selection criteria

After studies in scope of sustainable Supplier selection for a medical center, it is obtainable that appropriate criteria can be quantitative or qualitative attributes. The selection of suitable criteria also depends on the medical center situation too.

2.3 Data Envelopment Analysis (DEA)

After finding appropriate criteria, the DEA method is used for selecting best sustainable supplier. Super-efficiency ranking techniques DEA method is defining as follows:

Andersen and Petersen [43] developed a new process for ranking efficient units. The methodology enables an extreme efficient unit $k$ to achieve an efficiency score greater than one by removing the $k$th constraint in the primal formulation, as shown in model (1).

$$ h_k = \max \sum_{r=1}^{s} u_r y_{rk} $$

Subject to

$$ \sum_{i=1}^{m} v_{ij} x_{ij} - \sum_{r=1}^{s} u_r y_{rj} \geq 0 \quad \text{for} \quad j=1,\ldots,n, \ j \neq k, $$

$$ \sum_{i=1}^{m} v_{ij} x_{ij} = 1, \quad u_r \geq \varepsilon \quad \text{for} \quad r=1,\ldots,s, $$

$$ v_{ij} \geq \varepsilon \quad \text{for} \quad i=1,\ldots,m. $$

The dual formulation of the super-efficient model, as seen in model (2), computes the distance between the Pareto frontier, evaluated without unit $k$, and the unit itself i.e. for $J = \{ j=1,\ldots, n, j \neq k \}$

$$ \min f_k $$

Subject to

$$ \sum_{j \in J} L_{kj} x_{ij} \leq f_k x_{ik} \quad \text{for} \quad i=1,\ldots,m, $$

$$ \sum_{j \in J} L_{kj} y_{rj} \leq y_{rk} \quad \text{for} \quad r=1,\ldots,s, $$

$$ L_{ij} \geq 0 \quad \text{for} \quad j=1,\ldots, n. $$
Table 2: Description of each Criteria and Sub-Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
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<tbody>
<tr>
<td>Quality</td>
<td>The ability of the supplier to meet quality specifications consistently which include quality features (material, dimensions, design, durability), variety, production quality (production lines, manufacturing techniques machinery), quality system, and continuous improvement.</td>
</tr>
<tr>
<td>Warranty</td>
<td>Warranty is a type of guarantee that a manufacturer or similar party makes regarding the condition of its product.</td>
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<tr>
<td>Training</td>
<td>The ability of supplier to train users to use equipment appropriately.</td>
</tr>
<tr>
<td>Cost</td>
<td>The cost is a monetary valuation of effort, material, resources, time and utilities consumed, risks incurred, and opportunity forgone in production and delivery of a good or service.</td>
</tr>
<tr>
<td>Logistics Costs</td>
<td>This contains the lengthy distribution channel cost, transport expenses, inventory cost, handling and packaging cost, damages in the way and insurance costs, these are usually high when suppliers are international.</td>
</tr>
<tr>
<td>Lead Time</td>
<td>The total time from the placement of an order until the delivery is completed.</td>
</tr>
<tr>
<td>Health and Safety</td>
<td>Supplier’s potential with regards to offering productive programs to protect its personnel.</td>
</tr>
<tr>
<td>Responsiveness</td>
<td>The supplier’s responsibility to use natural resources carefully, minimize damage, and ensure these resources will be available for future generations.</td>
</tr>
<tr>
<td>Unsatisfied Costumers</td>
<td>The performance history of supplier and its costumer’s satisfaction.</td>
</tr>
<tr>
<td>Recycling</td>
<td>The ability of supplier to convert waste products into new materials and products.</td>
</tr>
<tr>
<td>Eco-design</td>
<td>Eco-design is supplier approach to design products with special consideration for the environmental impacts of the products during its whole lifecycle.</td>
</tr>
<tr>
<td>Energy Consumption</td>
<td>Energy consumption is the amount of energy or power that supplier’s products use.</td>
</tr>
<tr>
<td>Production of Electricity</td>
<td>The supplier’s products ability to emission or transfer energy into form of waves or particles through space or through a material medium.</td>
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</table>

However, there are three problematic areas with this method. First, Andersen and Petersen refer to the DEA objective function value as a rank score for all units, despite the fact that each unit is estimated according to different weights. This value in fact describes the proportion of the maximum efficiency score that each unit $k$ attained with its chosen weights in relation to a virtual unit closest to it on the frontier. Furthermore, it is assumed that the weights return prices, then each unit has different prices for the same set of inputs and outputs within the same organization. Second, the super-efficient methodology can give “specialized” DMUs an excessively high ranking. To avoid this problem,[44] introduced specific bounds on the weights in a super-efficient ranking model as described in Eqs. (3).

\[
\begin{align*}
    v_i & \geq 1 / (m + s) \max_j (x_{ij}) \\
    u_r & \geq 1 / (m + s) \max_j (y_{rj})
\end{align*}
\]  \hspace{1cm} (3)

Furthermore, in order to limit the super-efficient scores to a scale with a maximum of 2, Sueyoshi [44] developed an Adjusted Index Number (AIN) formulation, as follows in Eq. (11).

\[
\text{AIN}_k = 1 + (\delta_k - \min_{E} \delta_j^*) / (\max_{E} \delta_j^* - \min_{E} \delta_j^*),
\]  \hspace{1cm} (4)

Where $E$ is the set of efficient units.

The third problem lies with an infeasibility issue, which if it occurs, means that the super-efficient technique cannot provide a complete ranking of all DMUs. Thrall [45] used the model to identify extreme efficient DMUs and noted that the super efficiency CCR model may be infeasible. Zhu [46], Dula and Hickman [47] and Seiford and Zhu [48] prove under which conditions numerous super-efficient DEA models are infeasible. Mehrabian et al. [49] presented a modification to the dual formulation in order to ensure feasibility, as specified in model (5).

\[
\begin{align*}
    \text{Min } & f_k \\
    \text{Subject to } & -\sum_{j \in J} L_{kj} x_{ij} + x_{ik} - f_k \geq 0 \quad \text{for } i = 1, \ldots, m, \\
    & \sum_{j \in J} L_{kj} y_{rj} \geq y_{rk} \quad \text{for } r = 1, \ldots, s, \\
    & L_{ij} \geq 0 \quad \text{for } j = 1, \ldots, n
\end{align*}
\]  \hspace{1cm} (5)

Despite these drawbacks, possibly because of the simplicity of the concept, many published papers have used this approach. For example, Hashimoto [50] developed a DEA super-efficient model with assurance regions in order to rank the DMUs completely. Using model (6), Hashimoto avoided the need for compiling additional preference information in providing a complete ranking of $n$ candidates.

\[
\begin{align*}
    h_i = & \max \sum_{r=1}^s u_{iy_{rk}} \\
    \text{Subject to } & \sum_{r=1}^s u_{ry_{rj}} \leq 1 \quad \text{for } j = 1, \ldots, n, j \neq k.
\end{align*}
\]  \hspace{1cm} (6)
where \( u_r \) is the sequence of weights given to the \( r \)-th place vote. The use of assurance regions avoids the specialization pitfall of the standard super-efficiency model. In this paper, MAUT is used as a second approach, to calculate utility function. MAUT is determined as follows:

**2-4- Multi-Attribute Utility Theory (MAUT)**

Multi-attribute utility theory (MAUT) attempts to identify relevant objectives for any given decision. Where a decision is typified by multiple objectives it can be difficult to quantitatively compare these objectives one against another. In order to provide insight into this problem a utility function is assessed for each of the relevant objectives. This allows for an appropriate multiple-objective utility function that is then used to identify trade-offs and compare the various objectives in a consistent manner. The basis of utility theory and its underlying quantitative axioms were initially established. This early work established a normative decision theory that focused on the way that individuals should make decisions. Further study and refinement of utility assessments were later added to establish the quantitative foundations of objective function creation. The establishment of these normative decision theories takes a more pragmatic turn through the MAUT process. MAUT methods use similar utility maximization in order to determine normative action yet the primary difference is the use of subjective utility gathered through an elicitation process. The importance of the qualitative portion of MAUT cannot be underestimated as it is during this stage that normative axioms are verified and utility functions assessed. This process is especially relevant where substantial historical data is not available or where multiple, competing attributes must be considered. MAUT theories are used extensively in policy analysis and health services where decisions are sensitive to not only economic costs but also more subjective goals such as quality-of-life or environmental concerns. The functional form and necessary axioms for the utility function remain the same between traditional normative theories and MAUT. The primary difference is the flexibility given the researcher in modeling the utility function [40]. UTASTAR is one of the MAUT’s approaches.

UTASTAR method which is suggested by Jacquet-Lagrèze and E. a. Y. Siskos [51] is an advanced version (recipe) of original (primary) UTA. In original UTA of Jacquet-Lagrèze and Siskos, there is an independent error for each alternative \( a \in A_R \) which should be minimized. This independent error is called \( \sigma(a) \). Error function is not adequate for complete minimization of point’s distribution around the curve in figure (3).

\[
\begin{align*}
&u_r - u_{r+1} \geq \varepsilon \quad \text{for} \quad r = 1, \ldots, s-1, \\
&u_s \geq \varepsilon \\
&u_r - 2u_{r+1} + u_{r+2} \geq 0 \quad \text{for} \quad r = 1, \ldots, s-2.
\end{align*}
\]

Where \( u_r \) is the sequence of weights given to the \( r \)-th place vote. The use of assurance regions avoids the specialization pitfall of the standard super-efficiency model. In this paper, MAUT is used as a second approach, to calculate utility function. MAUT is determined as follows:

**2-4- Multi-Attribute Utility Theory (MAUT)**

Multi-attribute utility theory (MAUT) attempts to identify relevant objectives for any given decision. Where a decision is typified by multiple objectives it can be difficult to quantitatively compare these objectives one against another. In order to provide insight into this problem a utility function is assessed for each of the relevant objectives. This allows for an appropriate multiple-objective utility function that is then used to identify trade-offs and compare the various objectives in a consistent manner. The basis of utility theory and its underlying quantitative axioms were initially established. This early work established a normative decision theory that focused on the way that individuals should make decisions. Further study and refinement of utility assessments were later added to establish the quantitative foundations of objective function creation. The establishment of these normative decision theories takes a more pragmatic turn through the MAUT process. MAUT methods use similar utility maximization in order to determine normative action yet the primary difference is the use of subjective utility gathered through an elicitation process. The importance of the qualitative portion of MAUT cannot be underestimated as it is during this stage that normative axioms are verified and utility functions assessed. This process is especially relevant where substantial historical data is not available or where multiple, competing attributes must be considered. MAUT theories are used extensively in policy analysis and health services where decisions are sensitive to not only economic costs but also more subjective goals such as quality-of-life or environmental concerns. The functional form and necessary axioms for the utility function remain the same between traditional normative theories and MAUT. The primary difference is the flexibility given the researcher in modeling the utility function [40]. UTASTAR is one of the MAUT’s approaches.

UTASTAR method which is suggested by Jacquet-Lagrèze and E. a. Y. Siskos [51] is an advanced version (recipe) of original (primary) UTA. In original UTA of Jacquet-Lagrèze and Siskos, there is an independent error for each alternative \( a \in A_R \) which should be minimized. This independent error is called \( \sigma(a) \). Error function is not adequate for complete minimization of point’s distribution around the curve in figure (3).

\[
\begin{align*}
&\Delta(a_k, a_{k+1}) = u(g[a_k]) - u(g[a_{k+1}]) \\
&\Delta(a_k, a_{k+1}) = u(g[a_k]) - u(g[a_{k+1}]) \\
&\sum_{i=1}^{m} wi = 1
\end{align*}
\]

This problem results from the points which are placed at the right side of the curve. So it is better to subtract an amount or value from total (whole) amount to prevent growth (increase) of other amounts or values.

The UTASTAR algorithm is summarized according to these steps:

**Step (2):** Reckon overestimation and underestimation errors \( \sigma^+, \sigma^- \) for \( A_R \) in relation to each consecutive pair of key alternatives in ranking of functions key alternatives.

\[
\Delta(a_k, a_{k+1}) = u(g[a_k]) - u(g[a_{k+1}])
\]

\[
\Delta(a_k, a_{k+1}) = u(g[a_k]) - u(g[a_{k+1}])
\]

\[
\sum_{i=1}^{m} wi = 1
\]

\[
W_0 \geq 0, \quad \sigma^+(a_k) \geq 0, \quad \sigma^-(a_k) \geq 0; \forall \ i, j
\]

**Step (3):** Solve linear programming model according to formula number (9).

\[
\delta \text{ is a very small positive amount} \ (\text{usually} < 0/02 \text{ or} \ 0/02)
\]

\[
\min z = \sum_{i=1}^{m} \sigma^+(a_k) + \sigma^-(a_k)
\]

Subject to

\[
\sum_{i=1}^{m} wi = 1
\]

\[
W_0 \geq 0, \quad \sigma^+(a_k) \geq 0, \quad \sigma^-(a_k) \geq 0; \forall \ i, j
\]
Step (4): In this step by use of linear program (9), you can test the existence of multiple or near optimal solutions (stability analysis).

In case of incoherence, you can identify utility additive function of optimal solutions according to maximization of goal (target) function and by use of below formula:

\[
u_i(g^*_j) = \sum_{j=1}^{n} w_i j = 1, 2, ..., n \quad (10)\]

So polyhedron which is resulted from limitations of linear program, will be smaller because of new limitation:

\[\sum_{k=1}^{m} \sigma^+(a_k) + \sigma^-(a_k) | \leq Z^* + \varepsilon \quad (11)\]

In this limitation, Z* is an optimal value for linear program of step (3), and \(\varepsilon\) is a small positive number.

3- Results and Discussion

3-1- Case Study

In order to assess the performance of the proposed model and answer to this question how this proposed model can be adjusted to real cases, this section presents findings from its implementation in a hospital. This hospital’s search for appropriate suppliers to provide its special medical equipment concluded 8 suppliers. In order to serve its patients and customers, it engages the services of these 8 suppliers.

Electrocardiograph is selected, an important equipment in any hospital and in this research, the best supplier for this equipment is expected to be selected. An electrocardiogram is a painless method that captures the electrical activity of the heart and detects the physical condition and probable heart diseases in people using the electrocardiograms of the heart. Using the ECG is one of the safest and simplest steps that gives the doctor valuable information about the heart. Figure 4 shows 8 candidate suppliers’ locations:

![Figure 4: Candidate suppliers' locations](image)

3-2- Identifying sustainable supplier selection criteria

Now appropriate criteria and sub-criteria must be selected for evaluating candidate suppliers which are mentioned later in figure 2. Cost, lead time and quality goals of the buyer, along with the capabilities of the suppliers to satisfy all those goals, are usually selected as important criteria. In Section 3, 13 economic, environmental and social sub-criteria are mentioned and Selection of these criteria and their sub-criteria are based on previous related papers which are described in Table 1. The linguistic terms for ranking the alternatives are provided in Table 3. According to this table, qualitative values of Table 4 could be changed to quantitative values.

<table>
<thead>
<tr>
<th>Linguistic terms</th>
<th>IFNs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely high (EH)</td>
<td>10</td>
</tr>
<tr>
<td>Very very high (VVH)</td>
<td>9</td>
</tr>
<tr>
<td>Very high (VH)</td>
<td>8</td>
</tr>
<tr>
<td>High (H)</td>
<td>7</td>
</tr>
<tr>
<td>Medium high (MH)</td>
<td>6</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>5</td>
</tr>
<tr>
<td>Medium low (ML)</td>
<td>4</td>
</tr>
<tr>
<td>Low (L)</td>
<td>3</td>
</tr>
<tr>
<td>Very low (VL)</td>
<td>2</td>
</tr>
<tr>
<td>Very very low (VVL)</td>
<td>1</td>
</tr>
</tbody>
</table>
3-3- Sustainable Supplier Selection Based on Super-Efficiency Ranking Techniques DEA & MAUT

The information taken from the medical center and its candidate suppliers, is shown in Table 4. In this table there are 4 quantitative sub-criteria and 9 qualitative sub-criteria. This table is filled by numbers for quantitative sub-criteria and according to Table 3, letters for qualitative sub-criteria. Any letter(s) have one single number. In our studies, this letter(s) should be changed to number. Table 4 is shown above.

After converting all value to number, CIPLEX SOLVER should be used to find the best supplier. Table 5 shows CIPLEX SOLVER results and Table 6 shows each supplier efficiency and its rank.

According to Super-efficiency ranking techniques DEA result, supplier E is the best one with the highest efficiency. The suppliers ranking is shown in Table 6. After finding suppliers’ ranking, the utility function of DEA approach is obtained with JAVA based UTASTAR approach.

According to UTASTAR result, supplier C is the best one with the highest efficiency. The supplier ranking is shown in Table 7.

Our CIPLEX SOLVER result is shown in Table 6. UTASTAR approach is used to cover DEA approach errors. Our JAVA result is shown in Table 7 and it is obvious that our result has been changed. The results of 2 approaches is different and according to our results their correlation coefficient is 0.119.

Table 4: value table of the candidate suppliers

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Quality</th>
<th>Warranty</th>
<th>Training</th>
<th>Cost</th>
<th>Logistics Costs</th>
<th>Lead Time</th>
<th>Health and Safety Satisfaction</th>
<th>Responsiveness</th>
<th>Unsatisfied Customer</th>
<th>Recycling</th>
<th>Eco-Design</th>
<th>Energy Conservation</th>
<th>Production of Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Isfahan)</td>
<td>M</td>
<td>1 year</td>
<td>VL</td>
<td>47,000,000</td>
<td>2,750,000</td>
<td>2 days</td>
<td>L</td>
<td>H</td>
<td>H</td>
<td>VL</td>
<td>VL</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>B (Isfahan)</td>
<td>VH</td>
<td>3 years</td>
<td>L</td>
<td>75,000,000</td>
<td>3,500,000</td>
<td>1 day</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>M</td>
<td>VL</td>
<td>VL</td>
<td>M</td>
</tr>
<tr>
<td>C (Isfahan)</td>
<td>H</td>
<td>1 year</td>
<td>MH</td>
<td>69,000,000</td>
<td>3,200,000</td>
<td>2 days</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>VL</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>D (Tehran)</td>
<td>H</td>
<td>1 year</td>
<td>H</td>
<td>47,000,000</td>
<td>1,200,000</td>
<td>1 day</td>
<td>H</td>
<td>VH</td>
<td>H</td>
<td>VL</td>
<td>L</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>E (Tehran)</td>
<td>VH</td>
<td>1 year</td>
<td>M</td>
<td>84,000,000</td>
<td>1,900,000</td>
<td>1 day</td>
<td>VH</td>
<td>VH</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>F (Italy)</td>
<td>VH</td>
<td>1 year</td>
<td>H</td>
<td>150,000,000</td>
<td>37,550,000</td>
<td>2 weeks</td>
<td>H</td>
<td>VH</td>
<td>VL</td>
<td>H</td>
<td>VH</td>
<td>L</td>
<td>VL</td>
</tr>
<tr>
<td>G (China)</td>
<td>M</td>
<td>1 year</td>
<td>VHV</td>
<td>125,300,000</td>
<td>25,960,000</td>
<td>3 weeks</td>
<td>EH</td>
<td>H</td>
<td>MH</td>
<td>H</td>
<td>H</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>H (South Korea)</td>
<td>EH</td>
<td>2 years</td>
<td>VHV</td>
<td>149,700,000</td>
<td>30,000,000</td>
<td>3 weeks</td>
<td>EH</td>
<td>H</td>
<td>VVL</td>
<td>VH</td>
<td>VL</td>
<td>VL</td>
<td>VL</td>
</tr>
</tbody>
</table>

Table 6: CIPLEX SOLVER result (EFFICIENCY AND RANK)

<table>
<thead>
<tr>
<th>Supplier</th>
<th>DEA EFFICIENCY</th>
<th>RANK</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Isfahan)</td>
<td>1.09</td>
<td>8</td>
</tr>
<tr>
<td>B (Isfahan)</td>
<td>3.17</td>
<td>3</td>
</tr>
<tr>
<td>C (Isfahan)</td>
<td>1.26</td>
<td>6</td>
</tr>
<tr>
<td>D (Tehran)</td>
<td>2.37</td>
<td>4</td>
</tr>
<tr>
<td>E (Tehran)</td>
<td>4.32</td>
<td>1</td>
</tr>
<tr>
<td>F (Italy)</td>
<td>1.27</td>
<td>5</td>
</tr>
<tr>
<td>G (China)</td>
<td>1.23</td>
<td>7</td>
</tr>
<tr>
<td>H (South Korea)</td>
<td>3.72</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 5: CPLEX SOLVER result (WEIGHTS)

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Quality</th>
<th>Warranty</th>
<th>Training</th>
<th>Cost</th>
<th>Logistics</th>
<th>Lead Time</th>
<th>Health and Safety</th>
<th>Responsibility</th>
<th>Unsatisfied Customers</th>
<th>Recycling</th>
<th>Eco-design</th>
<th>Energy</th>
<th>Consumption</th>
<th>Production of electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>0</td>
<td>0.107</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.141</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.103</td>
</tr>
<tr>
<td>Supplier B</td>
<td>0</td>
<td>1.055</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.019</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Supplier C</td>
<td>0</td>
<td>0</td>
<td>0.039</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.205</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Supplier D</td>
<td>0</td>
<td>0</td>
<td>0.338</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Supplier E</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.617</td>
<td>0</td>
<td>0.239</td>
<td></td>
</tr>
<tr>
<td>Supplier F</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.307</td>
<td>0</td>
<td>0.159</td>
<td>0.193</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Supplier G</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.123</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Supplier H</td>
<td>0</td>
<td>1.611</td>
<td>0.056</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 7: JAVA result (EFFICIENCY AND RANK)

<table>
<thead>
<tr>
<th>Supplier</th>
<th>UTASTAR EFFICIENCY</th>
<th>RANK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>0.386</td>
<td>8</td>
</tr>
<tr>
<td>Supplier B</td>
<td>0.44</td>
<td>6</td>
</tr>
<tr>
<td>Supplier C</td>
<td>0.608</td>
<td>1</td>
</tr>
<tr>
<td>Supplier D</td>
<td>0.556</td>
<td>2</td>
</tr>
<tr>
<td>Supplier E</td>
<td>0.508</td>
<td>3</td>
</tr>
<tr>
<td>Supplier F</td>
<td>0.458</td>
<td>5</td>
</tr>
<tr>
<td>Supplier G</td>
<td>0.435</td>
<td>7</td>
</tr>
<tr>
<td>Supplier H</td>
<td>0.488</td>
<td>4</td>
</tr>
</tbody>
</table>

3.4- Sensitivity analysis:

After obtaining the final ranking, the sensitivity analysis is performed. This section is an answer to this question which sub-criteria can influence on results more than the others? There are 3 different scenarios in this section.

In the first scenario, an economically selected sub-criterion is kept constant and ranking changes are analyzed accordingly. The sub-criteria, cost, is selected for sensitivity analysis based on the first scenario and the curve for this scenario is blue on the chart.

In the second scenario, a social sub-criteria is taken to be fixed. In this scenario, with the constant consideration of the health and safety sub-criteria, the sensitivity analysis of the ranking changes is done and the curve for this scenario is red on the chart.

In the third scenario, an environmental sub-criteria is considered to be constant. The curve for this scenario is visible in green. Sensitivity analysis is shown in Figure 5.
As shown in the figure, the yellow curve represents the current ranking resulting from the use of MAUT. The blue curve is initially shown. This curve is a fixed cost result. As it is known, the blue curve does not differ much from the yellow curve. Therefore, the rankings have little sensitivity to changes of this economic sub-criteria. The next curve is the red curve, which is the result of fixing a social sub-criteria, health and safety. Clearly, the sensitivity of the ranking to this sub-criteria is high and keeping it fixed influences a lot on the rankings. The third color is the green one that corresponds to the environmental sub-criteria, recycling capability. Clearly, the ranking depends on this sub-criterion is very low and its stability for different suppliers does not achieve a significant change. All these analysis are obvious in Figure 5.

3-5- Managerial Insights:

It is suggested that the manager of the service department, instead of selecting suppliers empirically, attempts to selection of suppliers using scientific methods and decision making approaches.

4- Conclusion and future work

In this paper, the SSS problem was studied in a medical center with the objective of suggesting a practical approach for SSS decision-making process. A comprehensive literature survey was conducted to identify the most crucial criteria and sub-criteria associated with economic, environmental and social sustainability dimensions after finding appropriate sub-criteria and assessing suppliers according them by using a combining Super-Efficiency Ranking Techniques DEA & MAUT approach, the most sustainable supplier was selected.

In addition, the SSS procedure (Figure 1) can be applied to future practices in the medical centers. Although, applying the proposed framework to another type of industries might require changes. These changes can be obtained from experts’ opinions in those industries. For example, another industries users can change criteria and sub-criteria to adjust this model to assess their candidate sustainable suppliers. A further study could assess the suppliers according to criteria and sub-criteria in an uncertain environment.

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