International Journal of Small Economies
Vol. 4 No. 1 Year 2013 Pages 9-22

www.MaldivesResearch.org/ijse

SELECTING E-PROCUREMENT DECISION MODELS BY EVALUATING MCDA METHODS ACCORDING TO THE REQUIREMENTS OF THE MALDIVIAN PUBLIC SECTOR

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ABSTRACT

Public sector procurement is governed by laws and regulations enforcing a rigid structure with multiple criteria for assessing and selecting suppliers. This paper analyses legal and operational requirements of public sector e-procurement of the Maldives. The research was based on a desktop review of traditional academic sources as well as gray literature to identify legal and fiscal constraints and regulations, followed by an evaluation study that applied the findings of the previous study in selecting an appropriate Multi-Criteria Decision Analysis (MCDA) method for that specific context. For the purpose of this comparison and selection the paper grouped MCDA methods into five categories; linear weighting methods, single synthesising criterion or utility theory, outranking methods, fuzzy methods and mixed methods. More than 80 MCDA methods were grouped under these major categories and considered as potential candidates to support e-procurement for the Maldives. After a thorough analysis two methods – TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) and COPRAS (COmplex PRoportional Assessment) – emerged as applicable for the Maldivian context and capable of meeting both operational and legal constraints. The paper provides an extensive discussion justifying this choice, as well as rationale for the rejection of the other major candidate MCDA methods.

Keywords: MCDA, Public Procurement Policy, e-Procurement, Decision Model, Public Sector Procurement,

1. INTRODUCTION

Multi-Criteria Decision Analysis (MCDA) is one of the well-known branches of decision making (Triantaphyllou, 2000). MCDAs are important in decision making when a wide number of factors or criteria are required for decision (Amponsah, 2011). Even though there are a wide variety of MCDA methods, they all have common features, namely the concepts of alternatives for decision making and a set number of attributes that need to be assessed (Triantaphyllou, 2000). MCDA methods are the core of modern procurement and have generated significant amount of research, controversy and discussion.

The research reported in this paper focuses on identifying and selecting suitable MCDA models that can be used in the design and development of an e-Procurement Decision Support System (DSS) for the public sector in Maldives. This process of selection revealed itself as both complex and fastidious. Fastidious because of the sheer number of available and very different MCDA models (e.g. linear weighting methods, single synthesising criterion or utility theory, outranking methods, fuzzy methods and mixed methods). Complex because public sector procurement has a rigid structure enforced by law and National regulations. The features and characteristics of public sector procurement are based on major public sector principles such as non-discrimination, equality, transparency and proportionality. This results in an organised step-by-step procedure for public sector procurement. However, this research focuses only on decisions that are based on the performances of the suppliers against a preset list of criteria. These criteria allow public sector institutions to state differentiated priorities when they announce for bids or tenders. This situation creates a context in which MCDA techniques can be applied to the evaluation.

The research design involves comparative analysis of characteristics of MCDA methods against legal requirements and operational requirements of the research context. After an initial literature review that enabled the identification of the most commonly used MCDA methods, the research was divided into three different steps. First, a review of gray literature on legal and fiscal aspects of procurement in the Maldives public sector was undertaken. Second, a literature review of MCDA methods was conducted. Finally, an evaluation analysis was performed on the group of MCDA methods, by applying the constraints identified in the previous study. This paper presents the findings of this research in detail.

2. PROCUREMENT IN PUBLIC SECTOR

Public sector procurement is also referred as government procurement, which is based on the perspective of the WTO (World Trade Organisation) and defined as: "the purchase of goods, construction service and other services required by government bodies" (Arrowsmith & Anderson, 2011:1)

There are four major principles in public procurement. They are non-discrimination, equality, transparency and proportionality (Weele, 2010). The features and characteristics of public sector procurement are based on these principles.

2.1 Procurement Objectives in Public Sector

The objectives of public sector procurement is the same as in the private sector (Leenders & Fearon, 1997) and many authors define procurement objective as to purchase the right quality of material, at the right time, in the right quantity, from the right source, at the right price (Baily *et al*, 1994; England, 1967; Leenders & Fearon, 1997; Weele, 2000). Leenders & Fearon (1997:539) provides the following objectives for government procurement:

- Assurance of continuity of supply to meet the service needs.
- Avoidance of duplication and waste through standardisation.
- Maintenance and improvement of quality standards in goods and services purchased.
- Development of a cooperative environment between supply and agencies and departments served.
- Obtaining maximum savings through innovative supply and application of value analysis techniques.
- Administering the supply function with internal efficiency.
- Purchase at the lowest life cycle cost, consist with quality, performance and delivery requirements.

These objectives given by Leenders & Fearon (1997) reiterates that the public procurement is the best interest for the organisation as in the private sector.

2.2 Key Characteristics of Public Sector Procurement

Public sector procurement has a rigid structure and it is difficult to make changes in public purchasing as it is established by law or regulation (Leenders & Fearon, 1997). Public procurement must adhere to the guidelines provided by public authorities. In every country, public procurement must comply with specific legislative requirements (Falagario, Sciancalepore, Costantino, & Pietroforte, 2012).

The public purchasing laws require the contract to be awarded to the lowest capable bidder who fits into the requirements laid by invitation for bid (Brown *et al*, 1984; Falagario *et al*, 2012; Leenders & Fearon, 1997). Public procurement has limited flexibility and narrow evaluation criteria when dealing with bid evaluation as it has legal bindings (Leenders & Fearon, 1997).

Public sector spends on planned and approved budget (Leenders & Fearon, 1997; Weele, 2000) and any changes need to be approved by legislative body making it time consuming, resulting in difficulty to take advantage of spot buys of high quantity price deals (Leenders & Fearon, 1997).

Public procurement funds come from taxpayers. Being a taxpayer, a supplier may attempt to influence through the political process to give them preference for procurement of materials as they have been paying higher amount of tax (Leenders & Fearon, 1997).

Reports on how a public sector institution spends its funding are open to the public (Weele, 2000). More specifically, all information of prices submitted by suppliers and the amount ultimately rewarded to the supplier must be provided to any taxpayer who wants it (Leenders & Fearon, 1997). Because of the issue of confidentiality, as the competitors can get the information, the suppliers are cautious to provide price deals to the public sector (Leenders & Fearon, 1997).

Clear and accurate specification is required to provide information to bidders to get competitive bids without varying interpretations (Leenders *et al*, 2006; Lysons & Gillingham, 2003). The development of good specification requires a lot of time (Leenders & Fearon, 1997). In fact, public sector procurement emphasise on the bid process with a rigid structure: invitation to bid, bid opening, evaluation and awarding (Leenders & Fearon, 1997). The extensive authorization process makes procurement a dull, difficult and time-consuming process (Weele, 2000).

2.3 Guidelines for Public Sector Procurement

It is evident that the procurement function can have a critical consequence on the security of an organisation, an industry and an economy of a country as a whole (England, 1967). Therefore, countries have developed guidelines for public sector procurement or government procurement. These guidelines can be general guidelines for specific countries or work categories, developed through best practice (Rowlinson & McDermott, 1999).

The guidelines provide systematic approaches for tender evaluation. Rowlinson & McDermott (1999) discouraged the design of a universal evaluation system of tenderers due to the complexity and the range of the potential performance criteria and indicators of tenderers. On the other hand, they believed that a basic model and guidelines can be established based on which specific criteria and indicators could be identified for every specific case.

As explained by Falagario *et al* (2012), European Directives state to use either Lowest Price (LP) or the Most Economically Advantageous Tender (MEAT) approach. LP is used when features of the material or service other than price are identical to differentiate suppliers, otherwise tenders are awarded using MEAT (Falagario *et al*, 2012), similarly in the UK it is to maximise the 'value for money' (Brown *et al*, 1984) and in the USA it is the lowest responsible and responsive bidder (Leenders *et al*, 2006) in choosing a supplier.

2.4 Tender Evaluation Criteria for Public Sector Procurement

Price, quality and delivery are the three primary criteria used by most organisations to rate suppliers (Liu *et al*, 2000; Luo *et al*, 2009; Mahdi *et al*, 2002; Monczka *et al*, 2010; Rowlinson & McDermott, 1999). It has also been shown in the results of the review of literature done by Ho *et al* (2010) on evaluation criteria appearing in the international journals from year 2000 to 2008 that price, quality and delivery are the three most used evaluation criteria. However, there are several other criteria used by organisations and listed in theory, depending on the type of procurement. To add to the complexity of this process, different criteria may be applied in the selection of suppliers in different procurement processes in the same organisation.

3. PUBLIC SECTOR PROCUREMENT IN THE MALDIVES

Dhaulathuge Maaliyyathu Gaanoonu, 2006 (literally, Public Finance Act, 2006) and Dhaulathuge Maaliyyathuge Gavaaidhu, 2009 (literally, Public Finance Regulation, 2009) are the governing laws and regulations for the public sector procurement in Maldives (Dhaulathuge Maaliyyathu Gaanoonu, 2006). The responsible body for governing public sector finance is assigned by the President of Maldives (Dhaulathuge Maaliyyathu Gaanoonu, 2006) to the Ministry of Finance and Treasury (MoFT) (Dhaulathuge Maaliyyathuge Gavaaidhu, 2009). The MoFT has created these regulations in 2009, according to a decree from 2006, and is now responsible for any amendments that may be required to the Public Finance Regulation requirements (Dhaulathuge Maaliyyathu Gaanoonu, 2006).

However, the method of procurement in public sector in the Maldives is consistent with what happens elsewhere in the public sector, that is, the regulations contain a number of exceptional clauses that allow the method to vary depending on the product, value, urgency, location and supplier's capability (Brown *et al*, 1984; Dhaulathuge Maaliyyathuge Gavaaidhu, 2009). However, in normal circumstances the method of procurement should only depend on the value of the procured product as described by Leenders & Fearon (1997) and also based on public finance regulations of Maldives (Dhaulathuge Maaliyyathuge Gavaaidhu, 2009).

3.1 Government Guidelines for Procurement

Dhaulathuge Maaliyyathuge Gavaaidhu 2009 prescribes a standard guideline for public sector procurement. The main points in the guidelines provided by the public finance regulation in context of the research dictate that public procurement should:

- be a transparent process;
- be able to create competitive biddings in order to provide fair opportunities to all capable suppliers;
- done according to the National regulation and be the same for all bidders;
- be able to use modern technology to support the process;
- be led by a clearly identifiable and responsible person for the procurement;
- request that whenever imported products are to be purchased, the suppliers must have an import licence, be in continued business and conform with Maldivian regulations;
- requesting a formal disclosure document to be submitted with the bid indicating if a supplier has any family or business relationship with any senior official;
- request that in case of buying bulk of materials, a wholesale rate must be provided by the supplier, rather than the retail; and
- strictly follow the approved budget and any deviations can only be justified if it risks a person's life or if it stops any basic public service.

Moreover, every public department should submit their annual budget in advance for the next year and procurements should be listed and approved in this budget.

3.2 Public Tendering

Dhaulathuge Maaliyyathuge Gavaaidhu, 2009 prescribes that any procurement of material or service which amounts more than MVR 25,000 should be announced for public tender. The procurement should be made based on the bids or tenders submitted (Dhaulathuge Maaliyyathuge Gavaaidhu, 2009). The research focuses on this higher band of procurement.

In this case, procurement specification should be publically and provided in writing to the potential bidders. This information should also provide information on selection guide by providing the evaluation criteria including weights and how points will be allocated (Dhaulathuge Maaliyyathuge Gavaaidhu, 2009).

There must be a Bid Evaluation Committee (BEC) in every public office that requires procurement. The names and job titles of the BEC members should be recorded in writing. Additionally, BEC members need to notify in writing and that notification needs also to be recorded. The minutes of the BEC meeting should be recorded in writing (Dhaulathuge Maaliyyathuge Gavaaidhu, 2009). If the procurement value is more than MVR1500,000, the tender must be evaluated by the National Tender Board (NTB) under MoFT, but the same procedure is applied.

Both BEC and NTB need to have a justified reason for choosing a particular supplier and it should be signed by an authorised person (Dhaulathuge Maaliyyathuge Gavaaidhu, 2009). The justification is the evaluated results of the tenders by the BEC or NTB. This is the main focus of this research, that is, to provide a good MCDA method that can guarantee a good basis for this justification.

3.3 Enforced Tender Evaluation Criteria

Even though there are number of criteria used in public sector procurement, there are compulsory criteria that must be used in supplier selection in public sector in Maldives (Dhaulathuge Maaliyyathuge Gavaaidhu, 2009). Dhaulathuge Maaliyyathuge Gavaaidhu, 2009 assigns the responsibility to BEC or NTB to evaluate the bids or tenders based on price and duration. In addition, it prescribes to look for the following criteria:

- Financial capability of the supplier;
- Technical capability of the supplier;
- Justifiability of the prices submitted by suppliers compared to estimated price of the procurement material or service;
- Similar past experiences of the suppliers in terms of size and its execution;
- Any other important criteria perceived by the public sector department.

The bids or tenders should cover the above mentioned information requested by tender announcement through a bid or tender submission form. The bids or tenders also should cover a summary of the current work undertaken elsewhere by the supplier and its value (Dhaulathuge Maaliyyathuge Gavaaidhu, 2009).

There must be a minimum of three bids or tenders for any public procurement tendering for evaluation. If minimum three bids or tenders are not received, it should be re-announced for tendering. If the second attempt fails to receive three tenders, procurement should be negotiated with the existing bidders in order to reach an understanding on how to proceed (Dhaulathuge Maaliyyathuge Gavaaidhu, 2009).

Every public sector institution, BEC and NTB is bound to follow these criteria and guidelines for public sector procurement.

Since the public sector procurement requires more than one criterion to be considered in the evaluation of bids or tenders, an MCDA method needs to be used for evaluation.

4. EVALUATION METHODOLOGY

In order to identify a suitable MCDA method that fits the Maldivian context as discussed above, the research design for this study involves an evaluation approach in three phases as shown in Figure 1. In the first phase of the evaluation, a critical literature review identified all of the most common MDCA methods used in procurement which were distilled into the 52 potential candidates out of more than 80 found, as presented in Appendix I. Secondly, a second literature review, that also included gray and legal literature, was then undertaken in order to identify the legislation, fiscal regulations and operational directives for procurement among the public sector in the Maldives. Finally, a third step involved a criteria based evaluation as defined by Chen *et al* (2012) as an "evaluation that is conducted according to predefined checklists, heuristics or principles". These same authors state that these criteria stem from "specific theories, as well as sets of guidelines, standards or even legal requirements". In the case of this research, the criteria based evaluation of the MCDA methods is performed against legal requirements of the Maldivian context described above. The aim of this evaluation analysis check which of the identified MCDA methods comply with public sector requirements and could become good candidates for the design and development of a new e-Procurement Decision Support System.

For the analysis, the MCDA methods were grouped into five categories as shown in Appendix I and as a result of propositions found in the literature (Figueira *et al*, 2005; Guitouni & Martel, 1998; Ho *et al*, 2010). The characteristics of the groups were then compared against operational and legal requirements established above. The individual methods of the groups which satisfy public sector requirements where then further compared with legal requirements to select suitable methods from the group. No individual method was further considered if its parent group does not meet public sector requirements.

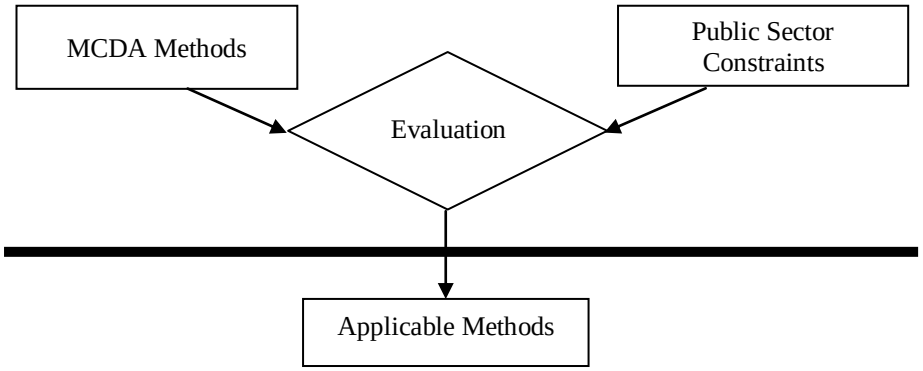

Figure 1**:** Evaluation Model

The findings of the literature reviews of MCDA methods and public sector procurement requirements were presented above as part of the literature review for the paper. The remainder of the paper will discuss the evaluation analysis.

5. REVIEW OF MCDA METHODS

The MCDA methods used in this research are categorized to five groups: linear weighting methods, single synthesising criterion or utility theory, outranking methods, fuzzy methods and mixed methods. This section will discuss each of these groups in relation to their potential application to the Maldivian tender evaluation context.

5.1 Linear Weighting and Elementary Methods

This group includes two major families of methods: elementary linear weighting. Elementary methods are more appropriate for single decision-maker problems with few alternatives and criteria (Linkov *et al*, 2004). List of methods under this category, identified as elementary methods are, lexicographic method, conjunctive method, disjunctive method and maximin method (Guitouni & Martel, 1998). These methods choose the alternatives based on the performance of prioritised or chosen criteria without the aggregation of performances of all the criteria. Ignoring some of the established criteria is contrary the regulations of major public sector, namely the principles of proportionality, equality and non-discrimination. Therefore, these methods should not be considered applicable for the research context.

Linear weighting, are generally elementary methods without a predefined level of achievement per criteria, that is the number and type of criteria, as well as the weight assigned to each of these is to be determined by the buyer according to perceived importance to the tender. For every supplier, the buyer assigns a score for each criterion which indicates supplier's performance in that aspect. The scores can be based on quantitative data or qualitative values also determined by the buyer (Monczka *et al*, 2010).

Weighted sum is likely to be the most common method for supplier evaluation (Mateus, Ferreira, & Carreira, 2010). It is a compensatory method (Guitouni & Martel, 1998). This method calculates the ratio for each attribute for every supplier by dividing the performance values of the attribute by the maximum value of the attribute, in case of input factors, subtracting these ratios from 1. Next, the allocated weight for each attribute is multiplied by the ratio calculated to get the weights for individual attributes. Finally, all the calculated weights for each individual attribute for every supplier is added to get the total figure for the supplier (Falagario *et al*, 2012). There are other alternative equations that can be used to calculate the weighted sum such as the equation by Mateus *et al* (2010), which ultimately do very similar calculations and give the same result.

Due to the rationale followed by the weighting, most people would, at first glance, accept that the procedure is logical and commonsensical. However, the use of this weighted sum procedure is in fact the most common mistake in public procurement procedures (Mateus *et al*, 2010). Mateus *et al* (2010) further explained with an example that the definition of weights is completely arbitrary and inconsistent with the real preferences of the procurement authority. With regard to compensation, these authors provide the following example:

> In a case of only two criteria selected, if 75% weight for one criterion (A) is defined and 25% weight for another criterion (B) then losing 10 partial points on criterion A (75% x -10 = -7.5 overall points) is equivalent to gaining 30 partial points on criterion B (25% x +30 = +7.5 overall points). Since the weights embody trade-offs, the assignment of weights will have to take into account the way those values were identified, that is, the performance levels set for each criterion (Mateus *et al*, 2010).

Keeney (2002) also identified the same issue and listed 12 common mistakes in making value trade-offs. Boer *et al* (2006) have also discussed five common mistakes using weighted sum in public sector procurement namely; (i) same weights, undesirable outcome; (ii) good procedure, wrong offer; (iii) the devil is in the detail; (iv) the runner up does not run up, and (v) with a little help from my friend. The examples shown by Boer *et al* (2006) showed undesirable outcomes in all the 5 cases.

Despite being one of the most commonly used methods in procurement; weighted sum does not seem to be ideal for public sector procurement in the Maldives due to all the criticisms described above. This is especially so due to the vulnerability of the method to manipulation by both suppliers and buyers, as well as the very high risk of the tendered products or services approved not meeting the public sector principles and standards behind regulations. Nonetheless, and for the sake of clarity in this discussion this is currently the method used in the Maldivian public sector. This represents, of course, a dissonant finding with reality of practice and it is expected that this study may contribute to a rectification discussion on current procurement practices.

5.2 Single Synthesizing Criterion or Utility Theory

This is the most conventional approach (Roy, 2005). The assumption of these methods is that there exists a utility (or a value) function U to represent the decision-maker's (DM) preferences. Based on this assumption, such a function is assessed and therefore the ranking of the choices is straightforward. The assessment of this function can be achieved in an additive, multiplicative, distributional mode and many other methodologies were developed with the premise that there exists a partial utility functions u_j according to each attribute j (Guitouni & Martel, 1998). This is in general terms a much better approach that fits both the principles and regulations of the Maldivian public sector, taking into account the differences and utility of the different criteria, rather than just aggregating these around perception and often prejudice based assigned weights.

However, there are a number of methods under this family and therefore a closer inspection of these is necessary in order to assess their applicability in this research context.

5.2.1 TOPSIS

TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) is an MCDA method to rank alternatives from a finite set of alternatives. The basic principle is to minimize the distance to the ideal solution while maximizing the distance to the negative-ideal solution for the chosen alternative (Jahanshahloo *et al*, 2009; Olson, 2004).

TOPSIS method is criticised due to the issue of the satisfactory level for both criteria of the shortest distance from the ideal solution and the farthest distance from the negative ideal solution, because TOPSIS does not consider the relative importance of those distances (Opricovic & Tzeng, 2004). In addition to this, with Euclidean distance as used in TOPSIS, the closest alternative to the positive ideal solution is not necessarily the farthest alternative from the negative ideal solution (Aghajani & Hadi-Vencheh, 2011; Chamodrakas *et al*, 2011).

Bottani & Rizzi (2006) state that the major weakness in TOPSIS could be the need for monotonic criteria. However, they believe that TOPSIS works well for a one tier decision tree. A further drawback stated by Tsaur (2011) is that a narrow gap between the performed measures is derived in the normalized scale for each criterion due to the operation of normalized decision matrix. Therefore, a narrow gap in the method cannot reflect the true dominance of the alternatives.

When drawbacks are compared to public sector procurement as discussed above, having monotonic criteria could be considered as public sector requires pre-announced criteria with its weights for each bid or tender which cannot be changed later in the procurement process. The next drawback of having a narrow gap between the performance measures after normalisation still provides relative comparative figures, even though small, which can still be used for calculation. Finally, even though the closest alternative to the positive ideal solution is not necessarily the farthest alternative from the negative ideal solution, public sector looks for the best alternative which is, in TOPSIS the closest to the ideal solution. Therefore, even if the alternative which is closest to ideal solution may not happen to be the farthest from negative ideal solution, public sector meets it requirement based on TOPSIS.

An analysis of these drawbacks shows that TOPSIS's known drawbacks would not apply to the public sector requirements. Moreover, the method provides a clear definition of the closest alternative to the ideal expected and therefore guarantees, by comparison with a weighted sum method, a lesser vulnerability to manipulation of the tendering process by boosting higher weighted criteria. Therefore, TOPSIS was selected as one of the applicable methods for the research context.

5.2.2 MAVT

MAVT (multi-attribute value theory) is firmly grounded in von Neumann and Morgenstern's utility theory and assumes an existence of a value function, based on utility maximisation (Ananda & Herath, 2003).

MAVT is built up of a few basic axioms and starts from the basis that all things are comparable. DM preferences are represented as a set of estimated scores for the performance of the alternatives on the measurement criteria. Weights must be created based on the relative importance of criteria. This approach fits well with scientific methods and it is a transparent technique (Simpson, 1996).

MAVT places all the potential alternatives onto the same scale making it possible to make comparisons globally. MAVT enforces comparability across criteria. MAVT has a strict mathematical basis, therefore the data input into the model must satisfy specific conditions, such as transitivity (Simpson, 1996). This issue of common scale of comparability in every criterion is not in line with public sector regulations as any procurement can have diverse criteria mentioned in 3.3. In fact, some criteria may not even be possible to represent in a scale, such as Boolean or nominal criteria. Therefore, MVAT was not applicable for public sector procurement for the research context.

5.2.3 UTA

The UTA (UTilités Additives) method ranks alternatives and it is an ordinal regression method. The method aims to develop an additive utility function according to the decision maker's judgment strategy. The method requires a set of reference alternatives *A'*. The decision maker has to provide global evaluation for each reference alternative to form a total pre-order of the alternatives in $A'\colon a_1 \succ a_2 \succ \cdots \succ a_m$. If the developed utility model reproduces the given pre-order of the reference alternatives as consistently as possible, then the utility model is believed to be consistent. As such, the utility model should be developed so that: $U(a_1) > U(a_2) > \cdots > U(a_m)$ (Spronk *et al*, 2005).

Spronk *et al* (2005) highlighted that there are two possible types of errors which may occur. The first error is under-estimation, which occurs when the developed model assigns a reference alternative to a lower

(better) rank than the one specified in the given pre-order (the alternative is under-estimated by the decision maker). The second error is the over-estimation error when the developed model assigns a reference alternative to a higher (worse) rank than the one specified in the given pre-order (the alternative is over-estimated by the decision maker). Beuthe & Scannella (2001) also stated that if estimation errors exist or if the utility function is applied to a different set of projects it will lead to different rankings.

There is no guarantee in UTA method to provide a utility function which is consistent with the available information. This shortcoming is due to the inherent utility model of UTA (Angilella *et al*, 2004).

Based on the public sector procurement principles and requirements as discussed in 2, it is not advisable to use a method with known chance of errors in estimation and also without any guarantee to find a utility function coherent with available information. Therefore, UTA is considered not applicable for the research context.

5.2.4 SMART

This type of method evolved from a first proposition by Edwards (1977) entitled SMART (Simple Multi-Attribute Rating Technique). However, and from very early on it was recognised that there was a logical error in SMART (Jeffreys, 2004). This led Edwards to *officially declare SMART as dead* and propose a revised version (Edwards & Barron, (1994) - SMARTS (Simple Multi-Attribute Rating Technique with Swings). SMARTS uses swing weighting which is done in two steps. First step gives the rank order of the weights and the second step gives the weights themselves (Edwards & Barron, 1994). This in turn was heavily criticised due to the monolithic equidistance of the swing weight assignment. This resulted in the same authors revising their proposition and developing SMARTER (Simple Multi-Attribute Rating Technique Exploring Ranks). SMARTER uses rank weights which are calculated using the ranking of attributes and the equations for the weights have a convenient computational form (Edwards & Barron, 1994). However, there are still weaknesses in this SMARTER method.

The discussion on SMART methods has been long and controversial. Hutchinson & Kotonya (2006) stated that SMART have a further limitation in the way the technique have been applied. SMART explicitly consist of steps for sensitivity analysis, in which a provisional decision is examined to determine its strength to changes in the measures (and weights) assigned during the decision making process. However in public sector procurement as mentioned in 3, the weights are announced and made public in advance and, even if the initial decision was not deemed to be favourable based on sensitivity analysis during evaluation, it would not be possible to make changes to publically announced weights. Therefore, SMART methods are considered not applicable for the research context.

5.2.5 MAUT

MAUT (Multi-Attribute Utility Theory) proposed by Keeney and Raiffa in 1976, centred around the utility concept in order to systematically analyse the complex decision making problems associated with multiple attributes and multiple conflicting goals. Huang (2011) explains the MAUT as a quantitative method which has an orderly process to identify and analyse multiple variables in order to find an optimal solution. By applying the developed MAU (multi-attribute utility) function, a decision maker can find the utility of every alternative, to identify and select the alternative with the highest utility. Thus, the method aims to obtain the maximum overall utility considering trade-offs between the attainments of some objectives against each other. The method develops a utility function based on decision maker's preference structure and the utility function is used to find the optimal solution (Sanayei *et al*, 2008).

Sensitivity analysis is a part of MAUT procedure (Min, 1994) similarly to SMART. If inconsistency is found in MAUT, the preference information of the decision maker has to be changed. (Moshkovich, Mechitov, & Olson, 2005). Therefore, the similar weakness and contradiction to public sector procurement mentioned with SMART exists in MAUT with sensitivity analysis.

4.2.6 AHP and ANP

AHP (Analytic Hierarchy Process) and its new extension, the ANP (Analytic Network Process) are well known methodologies to build utility functions, presented by Thomas Saaty in the 1970s (Figueira *et al*, 2005). In essence, AHP procedure trims down complex multi-criteria decisions to a sequence of one-on-one comparisons, and then synthesizing is done (Chatterjee *et al*, 2011).

AHP uses pairwise comparisons together with expert judgment to assign values to qualitative criteria. The ANP is used to derive composite priority ratio scales from individual ratio scales that represent relative measurements of the influence of elements that interact with respect to control criteria. The ANP considers the outcome of dependence and feedback within and between clusters of elements. AHP with its dependence assumptions on clusters and elements is a special case of the ANP. (Figueira *et al*, 2005)

AHP also provides a methodology to standardize the numeric scale for the measurement of quantitative as well as qualitative performances. The least value for the scale is 1/9 and the highest value is 9 to compare alternatives and value 1 is used when alternatives are equal (Vaidya & Kumar, 2006).

Chatterjee *et al* (2011) believe that the major weaknesses in AHP are the use of the 9-point scale giving a scale limitation and "phenomenon of rank reversal which occurs when indifferent criteria (for which all the alternatives perform in an equal manner) is added to the decision matrix causing a significant alteration of the aggregate priorities of the alternatives, with important undesirable consequence". The weakness of addition of indifferent criteria causing alteration of the aggregate priorities are also discussed (Pérez *et al*, 2006).

AHP approach accommodates 7±2 attributes and additionally through hierarchical decomposition it is possible to accommodate a number of alternatives also limited to 7±2 (Shih *et al*, 2007).

The major concerns in AHP approach with regard to public sector procurement are the possibility of lack of transparency, complexity of its calculation (Chatterjee *et al*, 2011) and time consuming (Chatterjee *et al*, 2011; Forman, 1993). One of the core principles of public sector procurement is transparency as described above and likely obstacles to this principle through the decision analysis approach should be avoided. Another concern in public sector procurement with AHP is the limitation of the number of criteria and the number of alternatives (Shih *et al*, 2007) because public sector procurement cannot be limited by law to neither maximum number of suppliers nor a maximum number of criteria, as described in 3.3. Therefore, AHP and ANP are considered not applicable to the research context.

5.2.7 DEA

Charnes *et al* (1978) introduced the DEA (Data Envelopment Analysis) concept (Falagario *et al*, 2012; Li & Reeves, 1999; San Cristóbal, 2011) as a linear programming based technique to evaluate the efficiency of a group of decision making units (DMUs) that use multiple inputs (costs to the organisation) to produce multiple outputs (benefits to the organisation) (Falagario *et al*, 2012; Wang *et al*, 2011). Performances of the DMUs are calculated by maximising the efficiency of every DMUs having the constraint that no efficiencies of the DMU can be greater than one (Wang *et al*, 2011). In supplier selection, suppliers are evaluated on the performance of benefit criteria (outputs) and performance of cost criteria (inputs) (Wu, 2009).

Weights are not pre-defined in DEA method by DM (Falagario *et al*, 2012). DEA model internally derives weights when applied. Optimal weights for the criteria are automatically calculated based on performance scores of the supplier. There is no control or involvement of decision makers in the importance of the criteria in DEA approaches (Ng, 2008).

The DEA approach does not meet the requirements of the Maldivian regulations as weights or priority ranking are not predefined, but allocated internally. Therefore, DAE is not considered applicable for the research context.

5.2.8 COPRAS

COPRAS (COmplex PRoportional ASsessment) was developed by Zavadskas and Kaklauskas in 1996 for determining the priority and the utility degree of alternatives (Chatterjee *et al*, 2011; Zavadskas & Antucheviciene, 2007).

COPRAS method is a structured approach for MCDA which evaluates the alternatives in terms of significance and degree of utility (Zavadskas *et al*, 2008). COPRAS has since then been applied to solve various tendering problems as well as construction and engineering multi-objective and multi-attribute problems (Zavadskas & Antucheviciene, 2007).

The method assumes "direct and proportional dependence of the significance and utility degree of the investigated versions in a system of criteria adequately describing the alternatives and of values and weights of the criteria" (Kaklauskas *et al*, (2007).

Since COPRAS evaluates the alternatives based on its significance and utility degree, and the method is applied in various MCDA problems (Zavadskas & Antucheviciene, 2007), it is very appealing to apply in public sector procurement.

However, there are some critics of the method. Podvezko (2011) stated that stability of COPRAS is also less compared to other methods when data variation is considered as it may have a huge degree of change in ranks of the alternatives due to changes in data unlike other methods (Podvezko, 2011).

However, public sector requires considering any difference in data results in a relevant difference in output, in order to respect the principles of proportionality and non-discrimination. This makes COPRAS extremely attractive for public sector procurement.

5.3 Outranking Methods

Outranking methods are originally developed to solve real-world problem regarding decisions dealing with the development of new activities in firms (Figueira *et al*, 2005).

Outranking methods compare each criterion of two or more alternatives at a time to identify the degree of preference over the other. Based on the collected preference information for all relevant criteria of all the alternatives, the outranking method tries to show the substantiation of choice of one alternative over the other. For example, by choosing the alternative that has more number of criteria with a greater degree of preference compared to other alternatives (Linkov *et al*, 2004).

Outranking methods are regarded as partially compensatory methods which also has capability of dealing with situations in which imprecision is present (Boer *et al*, 1998). Outranking models are suitable when criteria metrics are difficult to combine, variety of measurement scales are used, and units are unequal (Linkov *et al*, 2004).

Figueira *et al* (2005) provided the contexts where the basic outranking methods are applicable. Figueira *et al* (2005) state that basic outranking methods are applicable when the decision-maker (DM) wants to include in the model at least three criteria. However, aggregation procedures are more adapted in situations when decision models include more than five criteria (up to twelve or thirteen). This compulsory condition provided above by Figueira *et al* (2005) limits the number of criteria to be used in the outranking methods. However, based on enforced procurement criteria in public sector procurement discussed in 3.3, we cannot have a definite number of criteria in public sector procurement. The number of criteria may vary based on the material or service under procurement consideration.

Therefore, outranking should not be considered in public sector procurement in the context of this research. This is recognised by authors such as Boer *et al* (1998) who state that the use of outranking methods in procurement decision is not recommended in purchasing or operations research literature. These authors defend that outranking models should not be considered as a substitute of existing supplier selection methods, but could however be used as a supplemental method.

5.4 Fuzzy Methods

Fuzzy logic came to existence from the concept of a fuzzy set. A fuzzy set has no crisp, clear defined boundary (Parthiban, Dominic, & Dhanalakshmi, 2010). Kahraman *et al* (2003) defined fuzzy set as "a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one." Elements in a fuzzy set have only a partial membership. An element with a value of zero is not counted to be a member of the fuzzy set and an element with a value of one is a full member. Fuzzy members hold values between 0 and 1(Parthiban *et al*, 2010).

Fuzzy set theory was introduced by (Zadeh, 1965), to deal with vague parameters (Kahraman *et al*, 2003; Kumar *et al*, 2006). The theory of fuzzy set is one of the best tools in decision making when a high degree of uncertainties are involved, due to imperfections and complications of the information process (Amid *et al*, 2006; Kumar *et al*, 2006; Parthiban *et al*, 2010).

Some authors such as Kumar *et al* (2006) and Kahraman *et al* (2003) suggested supplier selection models using fuzzy theories combined with other models. The fuzzy theories were employed due to the presence of vagueness and imprecision of information in the supplier selection problem which was intended for the private sector.

Based on the results of the review of literature done by Ho *et al* (2010) on MCDA approaches for supplier selection appearing in the international journals from year 2000 to 2008, fuzzy theories were used mainly in hypothetical cases and only one suggestion for application in high-technology manufacturing exists. There was no evidence found in the literature of cases of application of fuzzy theories in the public sector (Ho *et al*, 2010).

Moreover, public sector procurement decisions are to be done based on prescribed information provided by the suppliers in response to precise and unambiguous tendering calls. Therefore, public procurement operates on crisp data and fuzzy methods are not best applicable in public sector. Since fuzzy methods are not the best applicable methods and are not been suggested by literature (Ho *et al*, 2010), fuzzy models in supplier selection in public sector are not considered.

5.5 Mixed Methods

Mixed methods use a combination of more than one approach for MCDA. Based on the review of literature done by Ho *et al* (2010) on MCDA approaches for supplier selection appearing in the international journals from year 2000 to 2008, there are 20 mixed methods listed in literature in 32 publications. 15 methods out of the 20 methods are intended for manufacturing firms, whilst one was also suggested for pharmaceutical industry and the rest are hypothetical cases. None of these methods are suggested for public sector procurement (Ho *et al*, 2010).

Most of the mixed methods are context specific and no literature suggested applying mixed methods in the public sector (Ho *et al*, 2010). Mixed methods are also more complex than other single methods and the complexity may cause difficulty for public sector suppliers to understand and submit best offers. Therefore,

due to this complexity and a lack of evidence of applicability in the public sector, mixed methods are not considered for the research context.

6. CONCLUSION

This paper has discussed major MCDA methods and its characteristics against public sector procurement requirements and legal constraints. The specific context of the discussion was the Maldivian public procurement process and associated legislation and regulations. The aim was to identify methods that could meet the regulations and were applicable to the Maldivian context. The resulting evaluation research process resulted in the identification of only 2 out of more than 80 methods that could meet the rigid procedures, regulations and expected outcomes of the decision making for the Maldivian public procurement, namely: TOPSIS and COPRAS. The results of this research are applicable to procurement in general and e-procurement in particular.

TOPSIS provides the best alterative in terms of the closest distance from the ideal solution and making it possibly the farthest from the negative ideal solution. This approach helps public sector to find the best possible solution from the available alternatives.

COPRAS provides alternatives based on the priority and the utility degree of alternatives. The priorities are set by public sector, on which the method provides alternatives with different utility degree in proportion to the other alternatives. This approach helps the public sector to select the best alternative base on the utility of the alternative.

These findings are significant as they are in conflict with the current reality of practice in that country where weighted sum is used. In fact, and despite being one of the most commonly used methods in procurement; weighted sum, as discussed above, does not seem to be ideal for public sector procurement in the Maldives due to the vulnerability of the method to manipulation by both suppliers and buyers, as well as the very high risk of the tendered products or services approved not meeting the public sector principles and the standards behind the regulations. This dissonance between these research finding and the reality of practice are expected to contribute to a discussion that may lead to the rectification of current procurement practices at National level.

7. REFERENCES

Aghajani, M., & Hadi-Vencheh, A. (2011). *A multiple attribute decision making model in the presence of grey numbers*. Paper presented at the 3rd International Conference on Advanced Management Science, Singapore.

Amid, A., Ghodsypour, S. H., & O'Brien, C. (2006). Fuzzy multiobjective linear model for supplier selection in a supply chain. *International Journal of Production Economics, 104*(2), 394-407.

Amponsah, C. T. (2011). Application of multi-criteria decision making process to determine critical success factors for procurement of capital projects under public-private partnerships. *International Journal of the Analytic Hierarchy Process, 3*(2), 107-129.

Ananda, J., & Herath, G. (2003). Incorporating stakeholder values into regional forest planning: a value function approach. *Ecological Economics, 45*(1), 75-90.

Angilella, S., Greco, S., Lamantia, F., & Matarazzo, B. (2004). Assessing non-additive utility for multicriteria decision aid. *European Journal of Operational Research, 158*(3), 734–744.

Arrowsmith, S., & Anderson, R. D. (Eds.). (2011). *The WTO regime on government procurement: challenge and reform*. Cambridge: Cambridge University Press.

Baily, P., Farmer, D., Jessop, D., & Jones, D. (1994). *Purchasing Principles and Management* (7th ed.). London: Pitman Publishing.

Beuthe, M., & Scannella, G. (2001). Comparative analysis of UTA multicriteria methods. *European Journal of Operational Research, 130*(2), 246-262.

Boer, L. d., Linthorst, M. M., Schotanus, F., & Telgen, J. (2006). *An analysis of some mistakes, miracles and myths in supplier selection*. Paper presented at the 15th IPSERA Conference, SanDiego.

Boer, L. d., Wegen, L. v. d., & Telgen, J. (1998). Outranking methods in support of supplier selection. *European Journal of Purchasing & Supply Management, 4*, 109-118.

Bottani, E., & Rizzi, A. (2006). A fuzzy TOPSIS methodology to support outsourcing of logistics services. *Supply Chain Management: An International Journal, 11*(4), 294-308.

Brown, R. B., Wright, R. D. J., Cloke, C. G., Morris, T. B., & Trumper, I. F. S. (1984). *Government purchasing : a multi-department review of government contract and procurement procedures*. Londong: HMSO.

Chamodrakas, I., Leftheriotis, I., & Martakos, D. (2011). In-depth analysis and simulation study of an innovative fuzzy approach for ranking alternatives in multiple attribute decision making problems based on TOPSIS. *Applied Soft Computing, 11*(1), 900-907.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research, 2*(6), 429–444.

Chatterjee, P., Athawale, V. M., & Shankar, C. (2011). Materials selection using complex proportional assessment and evaluation of mixed data methods. *Materials and Design, 32*(2), 851–860.

Chen, S., Osman, M., & Peng, G. C. (2012). Information systems evaluation: methodologies and practical case studies. In P. Isaias & J. M. B. Nunes (Eds.), *Information systems research and exploring social artifacts: Approaches and methodologies*. Hershey, USA: IGI Global.

Dhaulathuge Maaliyyathu Gaanoonu, 03/2006 Stat. (2006).

Dhaulathuge Maaliyyathuge Gavaaidhu (2009).

Edwards, W. (1977). How to use multiattribute utility measurement for social decision making. *IEEE Transactions on Systems Man and Cybernetics, SMC-7*(5), 326–340.

Edwards, W., & Barron, F. H. (1994). SMARTS and SMARTER: Improved simple methods for multiattribute utility measurement. *Organizational Behavior and Human Decision Processes, 60*(3), 306–325.

England, W. B. (1967). *The purchasing system*. Homewood, Illinois.: Irwin.

Falagario, M., Sciancalepore, F., Costantino, N., & Pietroforte, R. (2012). Using a DEA-cross efficiency approach in public procurement tenders. *European Journal of Operational Research, 218*(2), 523-529.

Figueira, J., Greco, S., & Ehrgott, M. (Eds.). (2005). *Multiple criteria decision analysis : state of the art surveys*. Boston: Springer.

Figueira, J., Mousseau, V., & Roy, B. (2005). ELECTRE methods. In J. Figueira, S. Greco & M. Ehrgott (Eds.), *Multiple criteria decision analysis : state of the art surveys* (pp. 133-162). Boston: Springer.

Forman, E. H. (1993). Facts and fictions about the analytic hierarchy process. *Mathematical and Computer Modelling, 17*(4/5), 19-26.

Guitouni, A., & Martel, J.-M. (1998). Tentative guidelines to help choosing an appropriate MCDA method. *European Journal of Operational Research, 109*(2), 501-521.

Ho, W., Xu, X., & Dey, P. K. (2010). Multi-criteria decision making approaches for supplier evaluation and selection : A literature review. *European Journal of Operational Research, 202*(1), 16–24.

Huang, S.-l. (2011). Designing utility-based recommender systems for e-commerce: Evaluation of preference-elicitation methods. *Electronic Commerce Research and Applications, 10*(4), 398–407.

Hutchinson, J., & Kotonya, G. (2006). *A review of negotiation techniques in component based software engineering.* Paper presented at the 32nd EUROMICRO Conference on Software Engineering and Advanced Applications Cavtat, Croatia.

Jahanshahloo, G. R., Lotfi, F. H., & Davoodi, A. R. (2009). Extension of TOPSIS for decision-making problems with interval data: Interval efficiency. *Mathematical and Computer Modelling, 49*(5-6), 1137-1142.

Jeffreys, I. (2004). The use of compensatory and non-compensatory multi-criteria analysis for small-scale forestry. *Small-scale Forest Economics, Management and Policy, 3*(1), 99-117.

Kahraman, C., Cebeci, U., & Ulukan, Z. (2003). Multi-criteria supplier selection using fuzzy AHP. *Logistics Information Management, 16*(6), 382-394.

Kaklauskas, A., Zavadskas, E. K., & Trinkunas, V. (2007). A multiple criteria decision support on-line system for construction. *Engineering Applications of Artificial Intelligence, 20*(2), 163–175.

Keeney, R. L. (2002). Common mistakes in making value trade-offs. *Operations research, 50*(6), 935-945.

Kumar, M., Vrat, P., & Shankar, R. (2006). A fuzzy programming approach for vendor selection problem in a supply chain. *International Journal of Production Economics, 101*(2), 273-285.

Leenders, M. R., & Fearon, H. E. (1997). *Purchasing and supply management* (7th ed.). Chicago: Irwin.

Leenders, M. R., Johnson, P. F., Flynn, A. E., & Fearon, H. E. (2006). *Purchasing and supply management : with 50 supply chain cases* (13th ed.). New York: McGraw-Hill.

Li, X.-B., & Reeves, G. R. (1999). A multiple criteria approach to data envelopment analysis. *European Journal of Operational Research, 115*(3), 507-517

Linkov, I., Varghese, A., Jamil, S., Seager, T. P., Kiker, G., & Bridges, T. (2004). Multi-criteria decision analysis: A framework for structuring remedial decisions at contaminated sites. In I. Linkov & A. B. Ramadan (Eds.), *Comparative Risk Assessment and Environmental Decision Making* (pp. 15-54). Netherlands: Kluwer Academic Publishers.

Liu, J., Ding, F. Y., & Lall, V. (2000). Using data envelopment analysis to compare suppliers for supplier selection and performance improvement. *Supply Chain Management: An International Journal, 5*(3), 143-150.

Luo, X., Wu, C., Rosenberg, D., & Barnes, D. (2009). Supplier selection in agile supply chains: An information-processing model and an illustration. *Journal of Purchasing & Supply Management, 15*(4), 249-262.
Lysons, K., & Gillingham, M. (2003). *Purchasing and Supply Chain Management* (6 ed.). Harlow: Financial Times Prentice Hall.
Mahdi, I. M., Riley, M. J., Fereig, S. M., & Alex, A. p. (2002). A multi-criteria approach to contractor selection. *Engineering, Construction and Architectural Management, 9*(1).
Mateus, R., Ferreira, J. A., & Carreira, J. (2010). Full disclosure of tender evaluation models: Background and application in Portuguese public procurement. *Journal of Purchasing & Supply Management, 16*(3), 206-215.
Min, H. (1994). International supplier selection: A multi-attribute utility approach. *International Journal of Physical Distribution & Logistics Management, 24*(5), 24-33.
Monczka, R. M., Handfield, R. B., Guinipero, L. C., Patterson, J. L., & Waters, D. (2010). *Purchasing and Supply Chain Management*. Hampshire: Centage.
Moshkovich, H., Mechitov, A., & Olson, D. (2005). Verbal decision analysis. In J. Figueira, S. Greco & M. Ehrgott (Eds.), *Multiple criteria decision analysis : state of the art surveys* (pp. 609-637). Boston: Springer.
Ng, W. L. (2008). An efficient and simple model for multiple criteria supplier selection problem. *European Journal of Operational Research, 186*(3), 1059–1067.
Olson, D. L. (2004). Comparison of weights in TOPSIS models. *Mathematical and Computer Modelling, 40*, 721-727.
Opricovic, S., & Tzeng, G.-H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research, 156*(2), 445-455.
Parthiban, P., Dominic, P. D. D., & Dhanalakshmi, R. (2010). *A simulated annealing approach to solve fuzzy multi-objective linear model for supplier selection in a supply chain*. Paper presented at the Information Technology (ITSim), 2010 International Symposium in, Kuala Lumpur.
Pérez, J., Jimeno, J. L., & Mokotoff, E. (2006). Another potential shortcoming of AHP. *TOP, 14*(1), 99-111.
Podvezko, V. (2011). The comparative analysis of MCDA methods SAW and COPRAS. *Inzinerine Ekonomika-Engineering Economics, 22*(2), 134-146.
Rowlinson, S., & McDermott, P. (Eds.). (1999). *Procurement Systems: A guide to best practice in construction*. London: E & FN Spon.
Roy, B. (2005). Paradigms and chappenges. In J. Figueira, S. Greco & M. Ehrgott (Eds.), *Multiple criteria decision analysis : state of the art surveys* (pp. 3-24). Boston: Springer.
San Cristóbal, J. R. (2011). A multi criteria data envelopment analysis model to evaluate the efficiency of the renewable energy technologies. *Renewable Energy, 36*, 2742–2746.
Sanayei, A., Mousavi, S. F., Abdi, M. R., & Mohaghar, A. (2008). An integrated group decision-making process for supplier selection and order allocation using multi-attribute utility theory and linear programming. *Journal of the Franklin Institute, 345*(7), 731–747.
Shih, H.-S., Shyur, H.-J., & Lee, E. S. (2007). An extension of TOPSIS for group decision making. *Mathematical and Computer Modelling, 45*(7-8), 801-813.
Simpson, L. (1996). Do decision makers know what they prefer?: MAVT and ELECTRE II. *The Journal of the Operational Research Society, 47*(7), 919-929.
Siskos, Y., Grigoroudis, E., & Matsatsinis, N. F. (2005). UTA methods. In J. Figueira, S. Greco & M. Ehrgott (Eds.), *Multiple criteria decision analysis : state of the art surveys* (pp. 297-343). Boston: Springer.
Spronk, J., Steuer, R. E., & Zopounidis, C. (2005). Multicriteria decision aid/analysis in finance. In J. Figueira, S. Greco & M. Ehrgott (Eds.), *Multiple criteria decision analysis : state of the art surveys* (pp. 799-857). Boston: Springer.
Triantaphyllou, E. (2000). *Multi-criteria decision making methods : a comparative study*. Dordrecht ; Boston, Mass.: Kluwer Academic Publishers.
Tsaur, R.-C. (2011). Decision risk analysis for an interval TOPSIS method. *Applied Mathematics and Computation, 218*(8), 4295–4304.
Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process: An overview of applications. *European Journal of Operational Research, 169*(1), 1-29.
Wang, Y.-M., Chin, K.-S., & Luo, Y. (2011). Cross-efficiency evaluation based on ideal and anti-ideal decision making units. *Expert Systems with Applications, 38*, 10312–10319.
Weele, A. J. v. (2000). *Purchasing and supply chain management : analysis, planning and practice* (2nd ed.). London: Business Press.
Weele, A. J. v. (2010). *Purchasing and supply chain management : analysis, strategy, planning and practice* (5th ed.). Andover: Cengage Learning.

Wu, D. (2009). Supplier selection: A hybrid model using DEA, decision tree and neural network. *Expert Systems with Applications, 36*(5), 9105–9112.
Zadeh, L. A. (1965). Fuzzy sets. *Information and Control, 8*(3), 338-353.
Zavadskas, E. K., & Antucheviciene, J. (2007). Multiple criteria evaluation of rural building's regeneration alternatives. *Building and Environment, 42*(1), 436–451.
Zavadskas, E. K., Kaklauskas, A., Turskis, Z., & Tamosaitiene, J. (2008). *Contractor selection multi-attribute model applying COPRAS method with grey interval numbers.* Paper presented at the 20th EURO Mini Conference, Neringa, Lithuania.