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Generalised Choquet Integral Algorithm for Subcontractor Selection in the Textile Industry – A Case Study for Turkey

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Abstract
Turkish textile firms work under a heavily competitive atmosphere in terms of prices due to globalisation. Firms have to take into consideration several criteria in order to survive the global market conditions and to maintain profitability. Contractor companies have to select the optimal subcontractor in order to meet these criteria and in business. Therefore the decision to choose subcontractors is of great importance for the success of enterprises. In solving the problem of subcontractor selection, multiple criteria should be considered, for which multi-criteria decision-making methods are used. This paper presents a case study which regards the selection of the optimal subcontractor for a Turkish textile firm. In order to solve the selection problem generalized Choquet integral methodology was used based on a hierarchical decision model. In the conclusion section of the study, optimal subcontractor selection results are presented.

Key words: *subcontractor selection, Turkish textile industry, generalised Choquet integral methodology.*

Introduction

Industrialisation efforts of the sixties and seventies gave birth to the modern textile industry in Turkey. In the beginning, this sector operated as small workshops. In time the sector showed rapid development and during the seventies began exporting. Currently it is one of the most important sectors in the Turkish economy, employment and exports. Turkey has an important role in the world textile industry, being the fourth largest supplier in the world. The Turkish textile industry is in the world's top ten exporters [1]. In recent years, Turkish textile firms have been obliged to compete in terms of price with companies from China, India, Pakistan and other far-eastern countries. Therefore in order to survive and remain profitable, firms have to subcontract part of the orders they receive by considering various criteria such as cost, quality and delivery-on-time [2].

Optimal subcontractor selection is one of the main decisions made by firms [3]. Subcontractor selection is a typical multiple criteria decision making (MCDM) problem that includes both quantitative and qualitative criteria [4, 5]. Subcontractor selection is generally assumed to depend on an assessment of the quality, price, capability and performance that the subcontractor can provide [5]. When facing such problems, decision-makers have to base their judgments on both quantitative data and subjective assessments [4].

Subcontractor selection decisions are complicated by the fact that various criteria have to be considered in the decision-making process. There are methods to select subcontractors by using various selection criteria including MCDM, multi-attribute analysis, multi-attribute utility theory, multiple regression, cluster analysis, fuzzy set theory and multivariate discriminant analysis. Among those well-known methods, MCDM is relatively new to select subcontractors [3].

There is only one study in literature regarding subcontractor selection conducted by Kargı and Ozturk [2]. In this study, the material was Turkish Yeşim textile for the Nike firm, which was their customer, where the Analytical Hierarchical Process (AHP) method was used in optimum subcontractor selection and a list of the alternative subcontractors was obtained. Then the results were evaluated regarding subcontractor selection and sensitivity analyses were carried out, where the effects of changes in some criteria on selecting an alternative subcontractor were seen.

Minchin and Smith [6] proposed a model called the Quality-Based Performance Rating (QBPR) system for subcontractor selection. Holt et al. [7] carried out a survey of 53 major UK construction client organisations to determine the decision criteria used for subcontractor selection and the importance of these criteria in terms of influencing their selection of subcontractors. Enyinda et al. [8] in their paper used a decision support system such as AHP methodology to model the subcontractor selection problem in a government procurement supply chain. The methodology proposed used a set of criteria for the selection and evaluation of the best subcontractor. Juan et al. [5] in their study proposed a hybrid approach combining fuzzy set theory and quality function deployment (QFD) to establish a housing refurbishment subcontractor selection model. To test the effectiveness of the model proposed, a known MCDM method, PROMETHEE, was applied to compare the results of subcontractor selections.

In this study, for a company functioning in the textile sector in Turkey, from three alternative subcontractors *(A, B, C)* the selection of the optimum onewas handled as a MCDM problem. In solving the problem generalised Choquet integral methodology was used and the optimal subcontractor was chosen by taking the defuzzified total performance value obtained into account. For this purpose, in the study steps of applying the Generalized Choquet Integral Methodology were introduced. Then main information about the textile company where the application was performed for the problem that the company wanted to be solved was introduced; a hierarchical decision model for selection of the optimum subcontractor firm was defined, and by following the steps of generalized Choquet integral methodology for the problem solving, selection of the optimal subcontractor was realised.

Generalised Choquet integral methodology

The Choquet integral is a fuzzy integral with a numerical structure which is used to evaluate the selection criteria by dividing them into parts [9]. To establish a choquet integral successfully depends on results that the fuzzy criteria impose, which establishes the importance of each criteria or their combination [10].

In this study, the selection of the optimum subcontractor for the criteria determined from the alternative subcontractors for a company operating in the textile sector in Turkey was handled as a MCDM problem, generalized Choquet integral methodology was used in solving the problem. Below are the steps of applying this methodology [11, 12].

Step 1. Given criterion *i,* respondents' linguistic preferences for the degree of importance, perceived importance levels of alternative subcontractors and the tolerance zone are surveyed.

Step 2. The parameters are created corresponding to *j,* main criteria *(j* = 1, 2, *..., m); i,* sub criteria based on the main criteria (*i* = 1, 2, ..., n_j), and *t* decision maker *(t* = 1, 2, 3, ..., *k)* for the *i* criteria; fuzzy number $\widetilde{A}_i^t$, degree of importance, fuzzy number $\widetilde{P}_i^t$, perceived subcontractor performance and fuzzy number $\widetilde{e}_i^t$, expected subcontractor performance tolerance zone.

Step 3. By using ***Equation 1*** $\widetilde{A}_i$, $\widetilde{P}_i$ & $\widetilde{e}_i$ values were found, respectively.

$$\widetilde{A}_i^t = \frac{\sum_{t=1}^{k} \widetilde{A}_i^t}{k} \qquad \widetilde{P}_i^t = \frac{\sum_{t=1}^{k} \widetilde{P}_i^t}{k} \qquad \widetilde{e}_i^t = \frac{\sum_{t=1}^{k} \widetilde{e}_i^t}{k} \tag{1}$$

Step 4. $\widetilde{f}_i \in \widetilde{F}(S)$ being a fuzzy function, the effect of both criteria on subcontractor performance is normalised by ***Equation 2***.

$$\widetilde{f}_i = \|_{\alpha\in[0,1]} \widetilde{f}_i^{\alpha} = \|_{\alpha\in[0,1]} \left[f_{i,\alpha}^{-}, f_{i,\alpha}^{+} \right] \tag{2}$$

Here all the fuzzy valued $\widetilde{f}$ function groups become $\widetilde{F}(S)$ and for $\alpha \in [0,1]$ $\widetilde{P}_i$ and $\widetilde{e}_i$ α section level $\overline{P}_i^{\alpha}$ and $\overline{e}_i^{\alpha}$, the following equation was found.

$$\widetilde{f}_i^{\alpha} = \left[\widetilde{f}_{i,\alpha}^{-}, \widetilde{f}_{i,\alpha}^{+} \right] = \frac{\overline{p}_i^{\alpha} - \overline{e}_i^{\alpha} + [1,1]}{2} \tag{3}$$

Step 5. By taking sub criteria *j* under consideration, the subcontractor performance is found by using ***Equation 4***.

$$(C)\int \widetilde{f} d\widetilde{g} = \|[(C)\int f_{\alpha}^{-} dg_{\alpha}^{-}, \; (C)\int f_{\alpha}^{+} dg_{\alpha}^{+}] \tag{4}$$

Here; $\overline{g}_i : P(S) \to I(R^+)$, $\overline{g}_i = [g_i^{-}, g_i^{+}]$, $\overline{g}_i^{\alpha} = [g_{i,\alpha}^{-}, g_{i,\alpha}^{+}]$, $\overline{f}_i : S \to I(R^+)$ & $f_i = [f_i^{-}, f_i^{+}]$ expressions are valid for i = 1, 2, ..., n_j. To calculate the subcontractor performance there is a need for λ and fuzzy measures, $g(A_{(i)})$. Here fuzzy values $g(A_{(i)})$ and λ can be solved by using ***Equations 5 - 7***.

$$g(A_{(n)}) = g(\{s_{(n)}\}) = g_{n}, \tag{5}$$

$$g(A_{(i)}) = g_{i} + g(A_{(i+1)}) + \lambda g_i g(A_{(i+1)}), \quad \text{for } 1 \le i \le n \tag{6}$$

$$g(S) = 1 = \begin{cases} \frac{1}{\lambda}\left\{ \prod_{i=1}^{n} [1 + \lambda g(A_i)] - 1 \right\} & \text{if} \quad \lambda \neq 0 \\ \sum_{i=1}^{n} g(A_i) & \text{if} \quad \lambda = 0 \end{cases} \tag{7}$$

Equation 7.

Choquet integral function,

$$f : S \to [0,1], 0 \le f(s_{(1)}) \le \le f(s_{(2)}) \le \dots f(s_{(n)}) \le \le 1, f(s_{(0)}) = 0$$

and

$A_{(i)} = \{ s_{(1)}, \dots, s_{(n)} \}$ as expressed below.

$$(C)\int f dg = \sum_{i=1}^{n} (f(s_{(i)}) - f(s_{(i-1)})) \, g(A_{(i)}) \tag{8}$$

Then the total subcontractor performance obtained from all the sub criteria is reduced to a fuzzy $\widetilde{Y}$ number by application of the Choquet integral two step hierarchical process.

Step 6. If $g_{\widetilde{Y}}(x)$ is accepted as a member of $\widetilde{Y}$, by using ***Equation 8*** fuzzy number $\widetilde{Y}$ can be simplified to a y absolute value and alternative subcontractors' simplified total performance compared. The alternative with the highest defuzzified total performance value will be chosen as the best.

$$F(\widetilde{A}) = \frac{a_1 + a_2 + a_3 + a_4}{4} \tag{9}$$

A case study in the Turkish textile industry

In this section, the selection of the optimum subcontractor for the criteria determined from alternative subcontractors for a company which functions in the textile sector in Turkey was handled as a MCDM problem. Generalized Choquet Integral Methodology was used in the solving of the problem. For the purpose of evaluating the alternative subconstractors, selection criteria were determined by taking into account the view of the decision team, which involved one responsible person from the purchasing, production planning and marketing departments. The hierarchical desicion model was then established and in solving the problem the Choquet integral was used. Optimal subcontructor selection

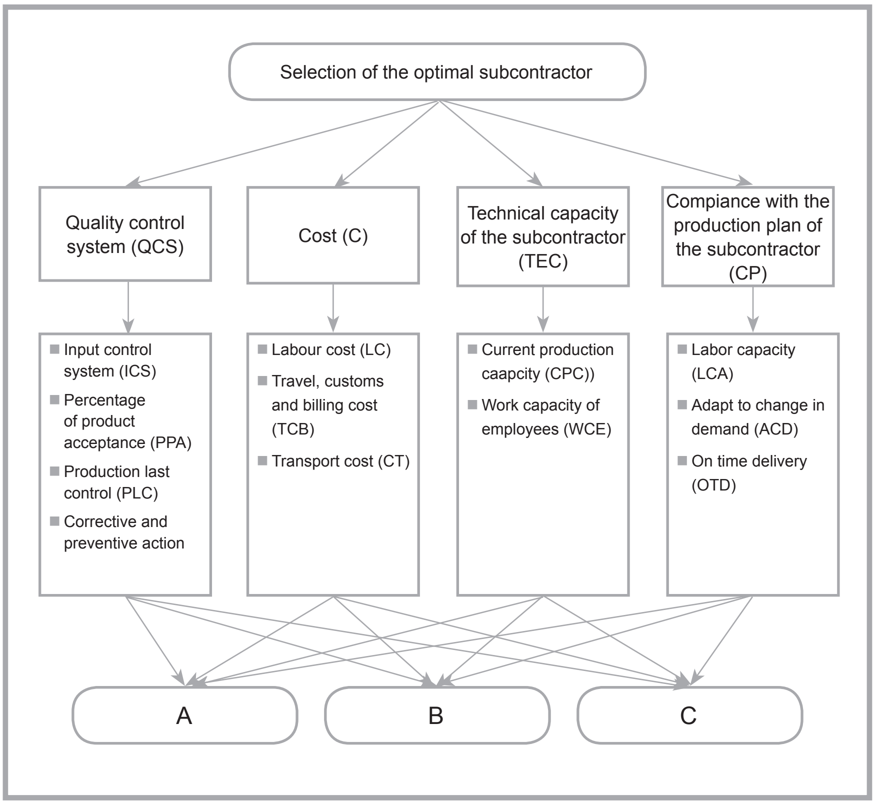

***Figure 1.** Hierarchical decision model for selection of the optimal subcontractor.*

***Table 1.** Relationship between trapezoidal fuzzy numbers and degrees of linguistic importance on a nine-linguistic-term scale [13].*

Low/high levels		Degrees of importance		Trapezoidal fuzzy numbers
Label	Linguistic terms	Label	Linguistic terms	
EL	Extra low	EU	Extra unimportant	(0, 0, 0, 0)
VL	Very low	VU	Very unimportant	(0.00, 0.01, 0.02, 0.07)
L	Low	U	Unimportant	(0.04, 0.10, 0.18, 0.23)
SL	Slightly low	SU	Slightly unimportant	(0.17, 0.22, 0.36, 0.42)
M	Middle	M	Middle	(0.32, 0.41, 0.58, 0.65)
SH	Slightly high	SI	Slightly important	(0.58, 0.63, 0.80, 0.86)
H	High	HI	High important	(0.72, 0.78, 0.92, 0.97)
VH	Very high	VI	Very important	(0.93, 0.98, 0.98, 1.00)
EH	Extra high	EI	Extra important	(1, 1, 1, 1)

***Table 2.** Individual importance of criteria, tolerance zones, and each subcontractor's linguistic evaluation.*

Criteria	Individual importance of criteria	Tolerance zone	Linguistic evaluation		
			A	B	C
QCS	HI				
ICS	SI	[SH, VH]	SH	VH	H
PPA	HI	[M, SH]	M	SH	M
PLC	SI	[M, H]	H	M	SH
RPA	HI	[SL, SH]	SL	M	SH
C	VI				
LC	HI	[SH, VH]	SH	H	SH
TCB	SI	[SH, H]	SH	H	H
CT	HI	[M, H]	H	SH	M
TEC	HI				
CPC	VI	[SH, VH]	H	H	VH
WCE	HI	[M, H]	H	M	SH
CP	VI				
LCA	SI	[SH, VH]	H	VH	H
ACD	HI	[SH, VH]	VH	H	H
OTD	VI	[H, EH]	H	EH	VH

was made according to defuzzified performance values at the end of the solving process.

The general information about the company and hierarchical decision model

The textile company where the application was performed is a fully integrated company operating in Bursa. In the company 85% of the clothing and home textile products are exported, made from raw material, following the process of knitting, dyeing and finishing. The company, with a focus on high quality, has a daily knitting capacity of 50 tons, a dyeing capacity of 100 tons, and a printing capacity of 100.000 meters. The company has a daily capacity of 150.000 pieces of clothing and 100.000 pieces of home textiles. It commissions 65% of its products tosubcontractors. The main reason forcing the company into this situation is the cost of production and the size of orders from overseas.

The companies which have a strategic partnership with this textile firm give orders with the condition of meeting their own criteria along with the price of the products. In the cases of overwhelming orders, the firm works with subcontractors. The problem the firm faces here is determining the optimum subcontractor to produce products meeting the criteria set by the companies ordering. In order to choose the optimum subcontractor out of three suitable subcontractors, by taking into account the view of the decision team, selection criteria were determined and a hierarchical model created, as seen in ***Figure 1***.

The steps of generalised choquet integral methodology for problem solving

In solving the MCDM problem that the firm faced, the steps of generalised choquet integral methodology, explained below, were carried out using the hierarchical decision model of ***Figure 1***.

Step 1. To solve the optimal subcontractor selection problem, the decision making team established at the firm evaluated the three alternative subcontractors by means of the hierarchical decision criteria and gave their common opinion, shown in ***Table 2***, using the scale given in ***Table 1***.

Table 3. Compromised evaluations of three experts.

Criteria	Individual importance of criteria	Combined tolerance zone	Perceived performance levels of alternative subcontractors		
			A	B	C
QCS	(0.72, 0.78, 0.92, 0.97)				
ICS	(0.58, 0.63, 0.80, 0.86)	(0.58, 0.63, 0.98, 1)	(0.58, 0.63, 0.8, 0.86)	(0.93, 0.98, 0.98, 1)	(0.72, 0.78, 0.92, 0.97)
PPA	(0.72, 0.78, 0.92, 0.97)	(0.32, 0.41, 0.8, 0.86)	(0.32, 0.41, 0.58, 0.65)	(0.58, 0.63, 0.8, 0.86)	(0.32, 0.41, 0.58, 0.65)
PLC	(0.58, 0.63, 0.80, 0.86)	(0.32, 0.41, 0.92, 0.97)	(0.72, 0.78, 0.92, 0.97)	(0.32, 0.41, 0.58, 0.65)	(0.58, 0.63, 0.8, 0.86)
RPA	(0.72, 0.78, 0.92, 0.97)	(0.17, 0.22, 0.8, 0.86)	(0.17, 0.22, 0.36, 0.42)	(0.32, 0.41, 0.58, 0.65)	(0.58, 0.63, 0.8, 0.86)
C	(0.93, 0.98, 0.98, 1.00)				
LC	(0.72, 0.78, 0.92, 0.97)	(0.58, 0.63, 0.98, 1)	(0.58, 0.63, 0.8, 0.86)	(0.72, 0.78, 0.92, 0.97)	(0.58, 0.63, 0.8, 0.86)
TCB	(0.58, 0.63, 0.80, 0.86)	(0.58, 0.63, 0.92, 0.97)	(0.58, 0.63, 0.8, 0.86)	(0.72, 0.78, 0.92, 0.97)	(0.72, 0.78, 0.92, 0.97)
CT	(0.72, 0.78, 0.92, 0.97)	(0.32, 0.41, 0.92, 0.97)	(0.72, 0.78, 0.92, 0.97)	(0.58, 0.63, 0.8, 0.86)	(0.32, 0.41, 0.58, 0.65)
TEC	(0.72, 0.78, 0.92, 0.97)				
CPC	(0.93, 0.98, 0.98, 1.00)	(0.58, 0.63, 0.98, 1)	(0.72, 0.78, 0.92, 0.97)	(0.72, 0.78, 0.92, 0.97)	(0.93, 0.98, 0.98, 1)
WCE	(0.72, 0.78, 0.92, 0.97)	(0.32, 0.41, 0.92, 0.97)	(0.72, 0.78, 0.92, 0.97)	(0.32, 0.41, 0.58, 0.65)	(0.58, 0.63, 0.8, 0.86)
CP	(0.93, 0.98, 0.98, 1.00)				
LCA	(0.58, 0.63, 0.80, 0.86)	(0.58, 0.63, 0.98, 1)	(0.72, 0.78, 0.92, 0.97)	(0.93, 0.98, 0.98, 1)	(0.72, 0.78, 0.92, 0.97)
ACD	(0.72, 0.78, 0.92, 0.97)	(0.58, 0.63, 0.98, 1)	(0.93, 0.98, 0.98, 1)	(0.72, 0.78, 0.92, 0.97)	(0.72, 0.78, 0.92, 0.97)
OTD	(0.93, 0.98, 0.98, 1.00)	(0.72, 0.78, 1, 1)	(0.72, 0.78, 0.92, 0.97)	(1, 1, 1, 1)	(0.93, 0.98, 0.98, 1)

Step 2. The evaluation made using the verbal expression in ***Table 2***. was converted into corresponding trapezoidal fuzzy numbers and ***Table 3***. was created. As the opinion of the decision making team was expressed as a common decision, there was no need for Step 3, showing average values of the degree of importance, the subcontractor performance tolerance zone expected and subcontractor performance values perceived.

Step 4. By using ***Equation 2***, the performance criteria of the alternative subcontractors were normalised and the results given in ***Tables 4*** and ***5***.

For α = 0, results evaluated by the generalised Choquet integral given in ***Table 4***, were calculated using ***Equation 3***. For example, subcontractor *A* and the subcriterion "ICS" [0.29,0.64] value is calculated as follows:

$$\tilde{f}_i^{\alpha} = \left[\tilde{f}_{1,0}^{-}, \tilde{f}_{1,0}^{+}\right] = \frac{\overline{p}_i^0 - \overline{e}_i^0 + [1,1]}{2} =$$

$$= \frac{[0.58,0.86]-[0.58,1]+[1,1]}{2} = [0.29,0.64]$$

Step 5. By taking sub-criteria into consideration, subcontractor performance calculations for the main criterion 'QCS' are given below:

Firstly take "subcontractor *A"* and subcriterion "ICS, PPA, PLC and RPA" values from ***Table 4***, $f_{i,0}^{-}$ listed as:

$$f_{(1)\,0}^{-} = 0.155 < f_{(2)\,0}^{-} =$$

$$= 0.23 < f_{(3)\,0}^{-} = 0.29 < f_{(4)\,0}^{-} = 0.375$$

Table 4. Evaluation results using the generalised choquet integral for α = 0.

Criteria	Individual importance of criteria	Normalised subcontractor performance		
		A	B	C
QCS		[0.33; 0.802]	[0.41; 0.769]	[0.356; 0.842]
ICS	[0.58; 0.86]	[0.29; 0.64]	[0.465; 0.71]	[0.36; 0.695]
PPA	[0.72; 0.97]	[0.23; 0.665]	[0.36; 0.77]	[0.23; 0.665]
PLC	[0.58; 0.86]	[0.375; 0.825]	[0.175; 0.665]	[0.305; 0.77]
RPA	[0.72; 0.97]	[0.155; 0.625]	[0.23; 0.74]	[0.36; 0.845]
C		[0.354; 0.819]	[0.363; 0.768]	[0.345; 0.695]
LC	[0.72; 0.97]	[0.29; 0.64]	[0.36; 0.695]	[0.29; 0.64]
TCB	[0.58; 0.86]	[0.305; 0.64]	[0.375; 0.695]	[0.375; 0.695]
CT	[0.72; 0.97]	[0.375; 0.825]	[0.305; 0.77]	[0.175; 0.665]
TEC		[0.371; 0.821]	[0.347; 0.695]	[0.454; 0.768]
CPC	[0.93; 1]	[0.36; 0.695]	[0.36; 0.695]	[0.465; 0.71]
WCE	[0.72; 0.97]	[0.375; 0.825]	[0.175; 0.665]	[0.305; 0.77]
CP		[0.436; 0.709]	[0.495; 0.708]	[0.458; 0.695]
LCA	[0.58; 0.86]	[0.36; 0.695]	[0.465; 0.71]	[0.36; 0.695]
ACD	[0.72; 0.97]	[0.465; 0.71]	[0.36; 0.695]	[0.36; 0.695]
OTD	[0.93; 1]	[0.36; 0.625]	[0.5; 0.64]	[0.465; 0.64]

Table 5. Evaluation results using the generalised choquet integral for α = 1.

Criteria	Individual importance of criteria	Normalised subcontractor performance		
		A	B	C
QCS		[0.386; 0.721]	[0.459; 0.694]	[0.407; 0.781]
ICS	[0.63; 0.8]	[0.325; 0.585]	[0.5; 0.675]	[0.4; 0.645]
PPA	[0.78; 0.92]	[0.305; 0.585]	[0.415; 0.695]	[0.305; 0.585]
PLC	[0.63; 0.8]	[0.43; 0.755]	[0.245; 0.585]	[0.355; 0.695]
RPA	[0.78; 0.92]	[0.21; 0.57]	[0.305; 0.68]	[0.415; 0.79]
C		[0.411; 0.741]	[0.416; 0.691]	[0.385; 0.633]
LC	[0.78; 0.92]	[0.325; 0.585]	[0.4; 0.645]	[0.325; 0.585]
TCB	[0.63; 0.8]	[0.355; 0.585]	[0.43; 0.645]	[0.43; 0.645]
CT	[0.78; 0.92]	[0.43; 0.755]	[0.355; 0.695]	[0.245; 0.585]
TEC		[0.423; 0.746]	[0.397; 0.644]	[0.497; 0.693]
CPC	[0.98; 0.98]	[0.4; 0.645]	[0.4; 0.645]	[0.5; 0.675]
WCE	[0.78; 0.92]	[0.43; 0.755]	[0.245; 0.585]	[0.355; 0.695]
CP		[0.477; 0.671]	[0.499; 0.668]	[0.488; 0.644]
LCA	[0.63; 0.8]	[0.4; 0.645]	[0.5; 0.675]	[0.4; 0.645]
ACD	[0.78; 0.92]	[0.5; 0.675]	[0.4; 0.645]	[0.4; 0.645]
OTD	[0.98; 0.98]	[0.39; 0.57]	[0.5; 0.61]	[0.49; 0.6]

Table 6. *Fuzzy measures and λ values for* $\alpha = 0$.

A		B		C	
$g^-(A_{(i)})$	$g^+(A_{(i)})$	$g^-(A_{(i)})$	$g^+(A_{i)})$	$g^-(A_{(i)})$	$g^+(A_{(i)})$
$\lambda = -0.912$	$\lambda = -0.999$	$\lambda = -0.912$	$\lambda = -0.999$	$\lambda = -0.912$	$\lambda = -0.999$
$g^-(A_{(1)}) = 1.000$	$g^+(A_{(2)}) = 0.999$	$g^-(A_{(4)}) = 0.580$	$g^+(A_{(2)}) = 0.999$	$g^-(A_{(4)}) = 0.580$	$g^+(A_{(2)}) = 0.999$
$g^-(A_{(3)}) = 0.853$	$g^+(A_{(3)}) = 0.999$	$g^-(A_{(3)}) = 0.919$	$g^+(A_{(4)}) = 0.970$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$
$g^-(A_{(4)}) = 0.580$	$g^+(A_{(4)}) = 0.860$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(2)}) = 0.999$	$g^+(A_{(3)}) = 0.995$
$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(2)}) = 0.999$	$g^+(A_{(3)}) = 0.999$	$g^-(A_{(1)}) = 0.920$	$g^+(A_{(4)}) = 0.970$
$\lambda = -0.957$	$\lambda = -0.999$	$\lambda = -0.957$	$\lambda = -0.999$	$\lambda = -0.957$	$\lambda = -0.999$
$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(2)}) = 0.900$	$g^+(A_{(2)}) = 0.999$	$g^-(A_{(2)}) = 0.944$	$g^+(A_{(1)}) = 1.000$
$g^-(A_{(2)}) = 0.910$	$g^+(A_{(2)}) = 0.998$	$g^-(A_{(3)}) = 0.580$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(3)}) = 0.999$
$g^-(A_{(3)}) = 0.720$	$g^+(A_{(3)}) = 0.970$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(3)}) = 0.970$	$g^-(A_{(3)}) = 0.720$	$g^+(A_{(2)}) = 0.999$
$\lambda = -0.971$	$\lambda = -0.999$	$\lambda = -0.971$	$\lambda = -0.999$	$\lambda = -0.971$	$\lambda = -0.999$
$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(2)}) = 0.930$	$g^+(A_{(2)}) = 0.999$	$g^-(A_{(2)}) = 0.930$	$g^+(A_{(1)}) = 1.000$
$g^-(A_{(2)}) = 0.720$	$g^+(A_{(2)}) = 0.970$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(2)}) = 0.970$
$\lambda = -0.990$	$\lambda = -0.999$	$\lambda = -0.990$	$\lambda = -0.999$	$\lambda = -0.990$	$\lambda = -0.999$
$g^-(A_{(2)}) = 0.886$	$g^+(A_{(2)}) = 0.995$	$g^-(A_{(2)}) = 0.975$	$g^+(A_{(3)}) = 0.860$	$g^-(A_{(2)}) = 0.975$	$g^+(A_{(3)}) = 0.860$
$g^-(A_{(3)}) = 0.720$	$g^+(A_{(3)}) = 0.970$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(2)}) = 0.995$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(2)}) = 0.995$
$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(3)}) = 0.930$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(3)}) = 0.930$	$g^+(A_{(1)}) = 1.000$

Table 7. *Fuzzy measures and λ values for* $\alpha = 1$.

A		B		C	
$g^-(A_{(i)})$	$g^+(A_{(i)})$	$g^-(A_{(i)})$	$g^+(A_{i)})$	$g^-(A_{(i)})$	$g^+(A_{(i)})$
$\lambda = -0.992$	$\lambda = -0.999$	$\lambda = -0.992$	$\lambda = -0.999$	$\lambda = -0.992$	$\lambda = -0.999$
$g^-(A_{(3)}) = 0.866$	$g^+(A_{(3)}) = 0.960$	$g^-(A_{(4)}) = 0.630$	$g^+(A_{(2)}) = 0.999$	$g^-(A_{(3)}) = 0.922$	$g^+(A_{(2)}) = 0.997$
$g^-(A_{(2)}) = 0.975$	$g^+(A_{(2)}) = 0.997$	$g^-(A_{(3)}) = 0.922$	$g^+(A_{(4)}) = 0.920$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$
$g^-(A_{(4)}) = 0.630$	$g^+(A_{(4)}) = 0.800$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(2)}) = 0.975$	$g^+(A_{(3)}) = 0.984$
$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(2)}) = 0.988$	$g^+(A_{(3)}) = 0.994$	$g^-(A_{(4)}) = 0.780$	$g^+(A_{(4)}) = 0.920$
$\lambda = -0.978$	$\lambda = -0.998$	$\lambda = -0.978$	$\lambda = -0.998$	$\lambda = -0.978$	$\lambda = -0.998$
$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(2)}) = 0.929$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(2)}) = 0.929$	$g^+(A_{(1)}) = 1.000$
$g^-(A_{(2)}) = 0.929$	$g^+(A_{(2)}) = 0.985$	$g^-(A_{(3)}) = 0.630$	$g^+(A_{(2)}) = 0.985$	$g^-(A_{(3)}) = 0.630$	$g^+(A_{(3)}) = 0.800$
$g^-(A_{(3)}) = 0.780$	$g^+(A_{(3)}) = 0.920$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(3)}) = 0.920$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(2)}) = 0.985$
$\lambda = -0.994$	$\lambda = -0.998$	$\lambda = -0.994$	$\lambda = -0.998$	$\lambda = -0.994$	$\lambda = -0.998$
$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(2)}) = 0.980$	$g^+(A_{(2)}) = 0.980$	$g^-(A_{(2)}) = 0.980$	$g^+(A_{(1)}) = 1.000$
$g^-(A_{(2)}) = 0.780$	$g^+(A_{(2)}) = 0.920$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(2)}) = 0.920$
$\lambda = -0.998$	$\lambda = -0.999$	$\lambda = -0.998$	$\lambda = -0.999$	$\lambda = -0.998$	$\lambda = -0.999$
$g^-(A_{(2)}) = 0.919$	$g^+(A_{(2)}) = 0.984$	$g^-(A_{(3)}) = 0.630$	$g^+(A_{(3)}) = 0.800$	$g^-(A_{(2)}) = 0.993$	$g^+(A_{(3)}) = 0.800$
$g^-(A_{(3)}) = 0.780$	$g^+(A_{(3)}) = 0.920$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(2)}) = 0.984$	$g^-(A_{(1)}) = 1.000$	$g^+(A_{(2)}) = 0.984$
$g^-(A_{(1)}) = 1.000$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(2)}) = 0.994$	$g^+(A_{(1)}) = 1.000$	$g^-(A_{(3)}) = 0.980$	$g^+(A_{(1)}) = 1.000$

Corresponding importance levels (from ***Table 4***. ICS, PPA, PLC, RPA's individual importance of criteria taken as a foundation) are, respectively;

$$\bar{g}_{(1)\,0} = 0.72,\ \bar{g}_{(2)\,0} = 0.72,\ \bar{g}_{(3)\,0} = 0.58 \ \ \&\ \ \bar{g}_{(4)\,0} = 0.58.$$

For $\alpha = 0$, using ***Equation 7***;

$$1 = \frac{1}{\lambda}\{[(1+\lambda 0.72)(1+\lambda 0.72)$$

$$(1+\lambda 0.58)(1+\lambda 0.58)]-1\} \quad \lambda = -0.912$$

is found.

Using ***Equations 5*** and ***6***, when $\alpha = 0$, the following fuzzy values are found, respectively;

$$g(A_{(4)}) = g_4 = 0.58$$

$$g(A_{(3)}) = g_3 + g(A_{(4)}) + \lambda g_3 g(A_{(4)}) = 0.853$$

$$g(A_{(2)}) = g_2 + g(A_{(3)}) + \lambda g_2 g(A_{(3)}) = 0.999$$

$$g(A_{(1)}) = g_1 + g(A_{(2)}) + \lambda g_1 g(A_{(2)}) = 1.0$$

All of the fuzzy measures and λ values obtainedfor $\alpha = 0$ are listed in ***Table 6***. and for $\alpha = 1$ in ***Table 7***.

The aggregated Choquet integral values for the main criterion "QCS" are calculated using ***Equation 4*** as follows:

$$(QCS)\int f^-_{\alpha=0}\,dg^-_{\alpha=0} = 1\times 0.155 +$$

$$+\ 0.999(0.230-0.155) +$$

$$+0.853(0.290-0.230) +$$

$$+0.58(0.375-0.290) = 0.331$$

and $\quad (QCS)\int f^+_{\alpha=0}\,dg^+_{\alpha=0} = 0.803$

That is,

$$(QCS)\int \tilde{f}\,d\tilde{g} = [0.331,\, 0.803]$$

Similarly the same calculations were made for $\alpha = 0$ and $\alpha = 1$ for other criteria.

Step 6. Similar to Steps 4 and 5, by using the collecting process of the generalised Choquet integral total subcontractor value belonging to the three alternative subcontractors, ***Equation 9*** was simplified as shown in ***Table 8***.

Usingthe total simplified subcontractor performance in ***Table 8***, the evaluated list

$C = 0.641 > A = 0.618 > B = 0.612$ was obtained. According to this list, it was determined that the optimal subcontractor was "*C*". Subcontractor "*A*" was the second best alternative, "*B*" listed as the last.

When simplified values of the main criteria are taken into consideration, subcontractor "*C*" takes first place according to the "QCS" and "TEC" criteria; subcontractor "*A*" achieved the highest value for *C*, and subcontractor "*B*" only for the "CP" criteria.

Conclusion

Subcontractor selection is a kind of hierarchical MCDM problem that can be handled by several MCDM methods (AHP, TOPSIS, ANP e.g.). The generalised Chouqet integral is an alternative method to fuzzy ANP which can also handle the dependent criteria and hierarchical problem structure.

In this study, the selection of the optimum subcontractor for criteria determined from alternative subcontractors for a company operating in the textile sector in Turkey was handled as a MCDM problem. For evaluating the alternative subcontractors, taking into account the views of the decision team, four main criteria and 12 sub-criteria belonging to the main criteria, being a total of 16 criteria, were determined and a hierarchical decision model was created. In solving the problem the two phase collecting process of the generalized Choquet integral was used. After completing the steps of the solution algorithm, the overall subcontractor value of the three subcontractors was obtained and the selection of the subcontractor made by taking these values into consideration.

The generalized Choquet integral which was used in this study offers the opportunity to evaluate and explain all results regarding the evaluation of alternatives by decision makers with respect to the per-

Table 8. Defuzzified overall values of alternative subcontractors using Generalised Chouqet Integral.

Criteria	Subcontractor performance			Defuzzified		
	A	B	C	A	B	C
Overall subcontractor value	(0.431, 0.476, 0.746, 0.821)	(0.488, 0.498, 0.693, 0.769)	(0.455, 0.495, 0.774, 0.84)	0.618	0.612	**0.641**
QCS	(0.330, 0.386, 0.721, 0.802)	(0.41, 0.459, 0.694, 0.769)	(0.356, 0.407, 0.781, 0.842)	0.560	0.583	**0.597**
ICS	(0.290, 0.325, 0.585, 0.640)	(0.465, 0.5, 0.675, 0.71)	(0.36, 0.4, 0.645, 0.695)	0.460	0.588	0.525
PPA	(0.230, 0.305, 0.585, 0.665)	(0.36, 0.415, 0.695, 0.77)	(0.23, 0.305, 0.585, 0.665)	0.446	0.560	0.446
PLC	(0.375, 0.430, 0.755, 0.825)	(0.175, 0.245, 0.585, 0.665)	(0.305, 0.355, 0.695, 0.77)	0.596	0.418	0.531
RPA	(0.155, 0.210, 0.570, 0.625)	(0.23, 0.305, 0.68, 0.74)	(0.36, 0.415, 0.79, 0.845)	0.390	0.489	0.603
C	(0.354, 0.411, 0.741, 0.819)	(0.363, 0.416, 0.691, 0.768)	(0.345, 0.385, 0.633, 0.695)	**0.582**	0.559	0.515
LC	(0.290, 0.325, 0.585, 0.640)	(0.36, 0.4, 0.645, 0.695)	(0.29, 0.325, 0.585, 0.64)	0.460	0.525	0.460
TCB	(0.305, 0.355, 0.585, 0.640)	(0.375, 0.43, 0.645, 0.695)	(0.375, 0.43, 0.645, 0.695)	0.471	0.536	0.536
CT	(0.375, 0.430, 0.755, 0.825)	(0.305, 0.355, 0.695, 0.77)	(0.175, 0.245, 0.585, 0.665)	0.596	0.531	0.418
TEC	(0.371, 0.423, 0.746, 0.821)	(0.347, 0.397, 0.644, 0.695)	(0.454, 0.497, 0.693, 0.768)	0.590	0.521	**0.603**
CPC	(0.360, 0.400, 0.645, 0.695)	(0.36, 0.4, 0.645, 0.695)	(0.465, 0.5, 0.675, 0.71)	0.525	0.525	0.588
WCE	(0.375, 0.430, 0.755, 0.825)	(0.175, 0.245, 0.585, 0.665)	(0.305, 0.355, 0.695, 0.77)	0.596	0.418	0.531
CP	(0.436, 0.477, 0.671, 0.709)	(0.495, 0.499, 0.668, 0.708)	(0.458, 0.488, 0.644, 0.695)	0.573	**0.593**	0.571
LCA	(0.360, 0.400, 0.645, 0.695)	(0.465, 0.5, 0.675, 0.71)	(0.36, 0.4, 0.645, 0.695)	0.525	0.588	0.525
ACD	(0.465, 0.500, 0.675, 0.710)	(0.36, 0.4, 0.645, 0.695)	(0.36, 0.4, 0.645, 0.695)	0.588	0.525	0.525
OTD	(0.360, 0.390, 0.570, 0.625)	(0.5, 0.5, 0.61, 0.64)	(0.465, 0.49, 0.6, 0.64)	0.486	0.563	0.549

formance of the alternative subcontractors and the overall main criteria and sub criteria of subcontractor performances.

This study is the first study made in the textile sector by using the generalized Choquet integral method. This paper shows that when these criteria include interactions between each other the Choquet integral presents an excellent tool for the solution. For further research the selection problem in this paper can be solved by fuzzy ANP and fuzzy TOPSIS and the results obtained can be compared.

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