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Ergonomic Glove Design by Using an Integrated Approach

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Abstract: Hand injuries in work accidents frequently occur in firm. The use of gloves as personal protective equipment is recommended by experts to reduce or prevent hand injuries. While these gloves increase the safety of employees against hand injuries, it is aimed not to have a negative impact on their performance. This study has determined 15 criteria for an ergonomic glove that will not decrease the performance of the employees, taking into consideration the literature research and expert opinions. The most suitable ergonomic glove was chosen among five alternative gloves by taking the opinions of three experts. This study aims to select the most suitable glove using the interval type-2 fuzzy (IT2F) number based TOPSIS approach. IT2F number is proposed to reduce the loss of information in expert opinions. Type-1 fuzzy number is shown with a single membership degree. IT2F number consists of two membership degrees unlike type-1 fuzzy number. The part between these two membership degrees expresses the expert opinion. The judgments of three experts were collected by employing the IT2F number and hand dexterity criterion was defined as the most significant criterion for an ergonomic glove. This paper also uses Bayesian network to analyze the customer satisfaction level based on four performance indicators. The biggest exchange for high customer satisfaction of alternative 1 is caused from finger root circumference between four performance indicators. This study ensures to the literature a new perspective by proposing multi-criteria decision making technique and Bayesian network to form an ergonomic glove.

Keywords: TOPSIS, bayesian network, ergonomic glove design, interval type-2 fuzzy number

Bir bütünleşik yaklaşım kullanarak ergonomik eldiven tasarımı

Özet: İş kazalarında el yaralanmaları firmalarda sıklıkla meydana gelmektedir. El yaralanmalarını azaltmak veya önlemek için kişisel koruyucu ekipman olarak eldiven kullanılması uzmanlar tarafından önerilmektedir. Bu eldivenler çalışanların el yaralanmalarına karşı güvenliğini artırırken performanslarını olumsuz etkilememesi amaçlanmaktadır. Bu çalışmada, literatür araştırması ve uzman görüşleri de dikkate alınarak çalışanların performansını düşürmeyecek ergonomik eldiven için 15 kriter belirlenmiştir. Üç uzman görüşü alınarak beş alternatif eldiven arasından en uygun ergonomik eldiven seçilmiştir. Bu çalışma, aralıklı tip-2 bulanık (AT2B) sayı tabanlı TOPSIS yaklaşımını kullanarak en uygun eldiveni seçmeyi amaçlamaktadır. Uzman görüşlerinde bilgi kaybını azaltmak için AT2B numarası önerilmiştir. Tip-1 bulanık sayı, tek üyelik derecesi ile gösterilir. AT2B sayısı, tip-1 bulanık sayıdan farklı olarak iki üyelik derecesinden oluşur. Bu iki üyelik derecesi arasında kalan kısım uzman görüşünü ifade etmektedir. AT2B sayısı kullanılarak üç uzmanın görüşleri toplanmış ve ergonomik eldiven için en önemli kriter olarak el becerisi kriteri belirlenmiştir. Bu makale ayrıca dört performans göstergesine dayalı olarak müşteri memnuniyet düzeyini analiz etmek için Bayes ağını kullanmaktadır. Alternatif 1'in yüksek müşteri memnuniyeti için en büyük değişimi, dört performans göstergesi arasındaki parmak kökü çevresinden kaynaklanmaktadır. Bu çalışma, ergonomik bir eldiven oluşturmak için çok kriterli karar verme tekniği ve Bayes ağı önererek literatüre yeni bir bakış açısı sağlamaktadır.

Anahtar Kelimeler: TOPSIS, Bayes ağı, ergonomik eldiven tasarımı, aralık tip-2 bulanık sayı

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1. INTRODUCTION

Most of the reflexes which people give against external dangers are realized with hand protection. An object splashed against the face, something falling from a height, etc. cases are usually due to the manual protection instinct. One of the most commonly used body organs in the office or workplace is the hand. Writing, cargo handling, drawing of any design, deal in trade, almost all have hand organs. Although the hand plays an active role in eliminating many dangers, it must be protected by protective measures. Of course, protective measures should be adequately evaluated ergonomically so as not to cause further harm. Protection from the environment is extremely important. The hand must be protected from dangerous factors such as physical, chemical [1].

In some cases, gloves can be used to avoid from risk. Gloves are a personal protector commonly used to protect human hands. Gloves provide maximum protection against specific dangerous situations. Although the utilization of gloves is an obligation in many workplaces, it includes some disadvantages.

In many studies, it has been stated that gloves affect the performance of employees in the working environment positively or negatively. Some studies about glove design in the literature are given in Table 1.

Table 1 Literature review

Topics	Papers
Skill	Bradley [2], Bishu and Klute [3], Krausman and Nussbaum [4], Dianat [5]
Task time	Muralidhar and Bishu [6]
Grip strength	Bishu and Klute [3], Dianat [5], Ramadan [8], Widodo et al. [16], Buhman et al. [18], Muralidhar and Bishu [19], Kerner et al. [24], Yoshikawa et al. [27], Efe and Efe [28]
Range of motion	Muralidhar and Bishu, [6], Dianat [5], Korona et al. [7], Efe and Efe [28], Aguiar Salazar et al. [29]
Vibration tolerance	Jetzer et al. [9], Rajabpour et al. [17], Awantha et al. [23], Yu and Sukigara [26]
Perception of touch	Bishu and Klute [3], Griffin et al. [10], Dianat [5], Dianat et al. [20], Dianat et al. [22], Wells et al. [21], Efe and Efe [28]
Thermal tolerance	Ramadan [8], Hou et al. [25], Yu and Sukigara [26]

There are some considerations in an ergonomic glove design. Occupational safety and operational performance are the most important factors. The coverage between hand and glove has a significant effect in compromising performance on the glove. Endless anthropometric variations in hand size are combined with the need to standardize glove manufacturing to keep reasonable the costs [10]. Hand injuries are common among occupational accidents and many of these cases are not recorded [11]. The research purpose of this study has emerged as a result of these concerns.

This study aims to select the most suitable glove by employing interval type-2 fuzzy (IT2F) number based TOPSIS method. 15 evaluation criteria are determined in glove design by considering the literature research and expert opinions. Five alternative gloves are evaluated based on 15 identified criteria. The opinions of three experts are consulted for this evaluation. In order to reduce the loss of information while taking expert opinions, IT2F number is preferred. Type-1 fuzzy number is represented by a single membership degree. IT2F number consists of two degrees of membership unlike the type-1 fuzzy number. The part between these two membership degrees expresses expert opinion. This study contributes to the literature using IT2F number based TOPSIS approach for glove design application. In addition, the criteria to be given priority to design the glove with the most appropriate ergonomic features in order to reduce hand injuries are determined by using IT2F numbers. Based on these criteria, the most suitable ergonomic glove has been selected with the help of the proposed method. The selected alternative is evaluated in terms of four performance indicators. These performance indicators provide to improve the customer satisfaction level. Three customer satisfaction levels are defined as high, medium and low. This study contributes the below situations to the literature.

- IT2F number based TOPSIS approach and Bayesian network is integrated.
- The proposed integrated method is implemented to glove design area.

This study consists of four sections. In the second section, IT2F number, TOPSIS approach and Bayesian network used in the proposed method are presented. In the third section, the criteria and alternatives examined for the application of ergonomic glove selection are presented. In addition, the results obtained from the application are described in this section. In the last section, the conclusion of the study is mentioned.

2. THE PROPOSED METHOD

$\tilde{\tilde{A}}_1$ and $\tilde{\tilde{A}}_2$ are trapezoidal IT2F numbers, where and

$$\tilde{\tilde{A}}_1 = (\tilde{A}_1^U, \tilde{A}_1^L) = \begin{pmatrix} \left(a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U)\right) \\ , \left(a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L)\right) \end{pmatrix}$$

$$\tilde{\tilde{A}}_2 = (\tilde{A}_2^U, \tilde{A}_2^L) = \begin{pmatrix} \left(a_{21}^U, a_{22}^U, a_{23}^U, a_{24}^U; H_1(\tilde{A}_2^U), H_2(\tilde{A}_2^U)\right) \\ , \left(a_{21}^L, a_{22}^L, a_{23}^L, a_{24}^L; H_1(\tilde{A}_2^L), H_2(\tilde{A}_2^L)\right) \end{pmatrix}$$

[12].

Some operations are presented below [12]

$$\tilde{\tilde{A}}_1 \oplus \tilde{\tilde{A}}_2 = (\tilde{A}_1^U, \tilde{A}_1^L) \oplus (\tilde{A}_2^U, \tilde{A}_2^L) = \Big(\big(a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U; min\{H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U)\}\big), \big(a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L; \min\{H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L)\}\big) \Big) \quad (1)$$

$$\tilde{\tilde{A}}_1 \otimes \tilde{\tilde{A}}_2 = (\tilde{A}_1^U, \tilde{A}_1^L) \otimes (\tilde{A}_2^U, \tilde{A}_2^L) = \Big(\big(a_{11}^U \times a_{21}^U, a_{12}^U \times a_{22}^U, a_{13}^U \times a_{23}^U, a_{14}^U \times a_{24}^U; min\{H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U)\}\big), \big(a_{11}^L \times a_{21}^L, a_{12}^L \times a_{22}^L, a_{13}^L \times a_{23}^L, a_{14}^L \times a_{24}^L; \min\{H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L)\}\big) \Big) \quad (2)$$

$$k \times \tilde{\tilde{A}}_1 = k \times (\tilde{A}_1^U, \tilde{A}_1^L) = \begin{pmatrix} \left(k \times a_{11}^U, k \times a_{12}^U, k \times a_{13}^U, k \times a_{14}^U; H_1(\tilde{A}_1^U)\right) \\ , \left(k \times a_{11}^L, k \times a_{12}^L, k \times a_{13}^L, k \times a_{14}^L; H_1(\tilde{A}_1^L)\right) \end{pmatrix} \quad (3)$$

where k is a crisp number and k>0.

$$\left(\tilde{\tilde{A}}_1\right)^k = \left(\tilde{A}_1^U, \tilde{A}_1^L\right)^k = \begin{pmatrix} \left(\left(a_{11}^U\right)^k, \left(a_{12}^U\right)^k, \left(a_{13}^U\right)^k, \left(a_{14}^U\right)^k; H_1\left(\tilde{A}_1^U\right)\right) \\ ,\left(\left((a_{11}^L)^k, (a_{12}^L)^k, (a_{13}^L)^k, (a_{14}^L)^k; H_1\left(\tilde{A}_1^L\right)\right)\right) \end{pmatrix} \quad (4)$$

2.1. Interval Type-2 Fuzzy Topsis Method

Hwang and Yoon [13] developed TOPSIS method. It handles simultaneously positive (maximization of benefit criteria) and negative (minimization of cost criteria) ideal solutions. The presented TOPSIS approach is as follows [14]:

$$W_l = \left(\tilde{\tilde{w}}_i^l\right)_{1\times m} = \begin{matrix} f_1 & f_2 & \cdots & f_m \\ [\tilde{\tilde{w}}_1^l & \tilde{\tilde{w}}_2^l & \cdots & \tilde{\tilde{w}}_m^l] \end{matrix} \quad (1)$$

$$\tilde{\tilde{\boldsymbol{w}}}_{\boldsymbol{\iota}} = \sum_{l=1}^{k} \boldsymbol{w}_l \tilde{\tilde{\boldsymbol{w}}}_i^l \quad (6)$$

W_l shows the weight of the criteria. w_l is the weight of the $D_l \tilde{\tilde{w}}_i^l$ is the weight of criteria f_i according to expert D_l.

$$Y_l = (\tilde{\tilde{f}}_{ij}^l)_{mxn} = \begin{matrix} \\ f_1 \\ f_2 \\ \vdots \\ f_m \end{matrix} \begin{matrix} x_1 & x_2 & \cdots & x_n \\ \begin{bmatrix} \tilde{\tilde{f}}_{11}^l & \tilde{\tilde{f}}_{12}^l & \cdots & \tilde{\tilde{f}}_{1n}^l \\ \tilde{\tilde{f}}_{21}^l & \tilde{\tilde{f}}_{22}^l & \cdots & \tilde{\tilde{f}}_{2n}^l \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\tilde{f}}_{m1}^l & \tilde{\tilde{f}}_{m2}^l & \cdots & \tilde{\tilde{f}}_{mn}^l \end{bmatrix} \end{matrix} \quad (7)$$

$$\overline{Y} = \left(\tilde{\tilde{f}}_{ij}\right)_{m\times n} \quad (8)$$

$$\tilde{\tilde{f}}_{ij} = \sum_{l=1}^{k} w_l . \tilde{\tilde{f}}_{ij}^l \quad (9)$$

Y_l illustrates the judgments of expert D_l. $\overline{Y}$shows the average decision matrix. $w_l$is the weight of $D_l \tilde{\tilde{f}}_{ij}^l$ is the judgment of D_l for $\tilde{\tilde{f}}_{ij}$.

$$\overline{W} = (\tilde{\tilde{v}}_{ij})_{mxn} = \begin{matrix} \\ f_1 \\ f_2 \\ \vdots \\ f_m \end{matrix} \begin{matrix} x_1 & x_2 & \cdots & x_n \\ \begin{bmatrix} \tilde{\tilde{v}}_{11} & \tilde{\tilde{v}}_{12} & \cdots & \tilde{\tilde{v}}_{1n} \\ \tilde{\tilde{v}}_{21} & \tilde{\tilde{v}}_{22} & \cdots & \tilde{\tilde{v}}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\tilde{v}}_{m1} & \tilde{\tilde{v}}_{m2} & \cdots & \tilde{\tilde{v}}_{mn} \end{bmatrix} \end{matrix} \quad (10)$$

where $\tilde{\tilde{v}}_{ij} = \tilde{\tilde{w}}_\iota \otimes \tilde{\tilde{f}}_{ij}, 1 \le i \le m$, and $1 \le j \le n$. $\overline{W}$ shows the average weighted matrix.

Let be $\tilde{\tilde{v}} = (\tilde{v}^U, \tilde{v}^L) = \left((v_1^U, v_2^U, v_3^U, v_4^U; h_U), (v_1^L, v_2^L, v_3^L, v_4^L; h_L)\right)$.: The approximate positive and negative ideal solution $x^+ = (v_1^+, v_2^+, \dots, v_m^+)$ and$x^- = (v_1^-, v_2^-, \dots, v_m^-)$according to benefit (F_1) and cost criteria $(F_2)$are introduced as follows:

$$\tilde{\tilde{v}}_i^+ = \begin{cases} \vee_{j=1}^n \tilde{\tilde{v}}_{1ij}^L, \vee_{j=1}^n \tilde{\tilde{v}}_{2i}^L, \vee_{j=1}^n \tilde{\tilde{v}}_{3ij}^L, \vee_{j=1}^n \tilde{\tilde{v}}_{4ij}^L, \wedge_{j=1}^n \{H(\tilde{A}_{ij}^L)\}, \\ \vee_{j=1}^n \tilde{\tilde{v}}_{1ij}^U, \vee_{j=1}^n \tilde{\tilde{v}}_{2ij}^U, \vee_{j=1}^n \tilde{\tilde{v}}_{3ij}^U, \vee_{j=1}^n \tilde{\tilde{v}}_{4i}^U, \wedge_{j=1}^n \{H(\tilde{A}_{ij}^U)\}, if\ f_i \in F_1 \\ \wedge_{j=1}^n \tilde{\tilde{v}}_{1ij}^L, \wedge_{j=1}^n \tilde{\tilde{v}}_{2ij}^L, \wedge_{j=1}^n \tilde{\tilde{v}}_{3ij}^L, \wedge_{j=1}^n \tilde{\tilde{v}}_{4ij}^L, \wedge_{j=1}^n \{H(\tilde{A}_{ij}^L)\}, \\ \wedge_{j=1}^n \tilde{\tilde{v}}_{1ij}^U, \wedge_{j=1}^n \tilde{\tilde{v}}_{2ij}^U, \wedge_{j=1}^n \tilde{\tilde{v}}_{3ij}^U, \wedge_{j=1}^n \tilde{\tilde{v}}_{4ij}^U, \wedge_{j=1}^n \{H(\tilde{A}_{ij}^U)\},\ if\ f_i \in F_2 \end{cases} \quad (11)$$

$$\tilde{\tilde{v}}_i^- = \begin{cases} \wedge_{j=1}^n \tilde{\tilde{v}}_{1ij}^L, \wedge_{j=1}^n \tilde{\tilde{v}}_{2ij}^L, \wedge_{j=1}^n \tilde{\tilde{v}}_{3ij}^L, \wedge_{j=1}^n \tilde{\tilde{v}}_{4ij}^L, \wedge_{j=1}^n \{H(\tilde{A}_{ij}^L)\}, \\ \wedge_{j=1}^n \tilde{\tilde{v}}_{1i}^U, \wedge_{j=1}^n \tilde{\tilde{v}}_{2ij}^U, \wedge_{j=1}^n \tilde{\tilde{v}}_{3ij}^U, \wedge_{j=1}^n \tilde{\tilde{v}}_{4ij}^U, \wedge_{j=1}^n \{H(\tilde{A}_{ij}^U)\},\ if\ f_i \in F_1 \\ \vee_{j=1}^n \tilde{\tilde{v}}_{1ij}^L, \vee_{j=1}^n \tilde{\tilde{v}}_{2ij}^L, \vee_{j=1}^n \tilde{\tilde{v}}_{3ij}^L, \vee_{j=1}^n \tilde{\tilde{v}}_{4ij}^L, \wedge_{j=1}^n \{H(\tilde{A}_{ij}^L)\}, \\ \vee_{j=1}^n \tilde{\tilde{v}}_{1ij}^U, \vee_{j=1}^n \tilde{\tilde{v}}_{2ij}^U, \vee_{j=1}^n \tilde{\tilde{v}}_{3ij}^U, \vee_{j=1}^n \tilde{\tilde{v}}_{4ij}^U, \wedge_{j=1}^n \{H(\tilde{A}_{ij}^U)\}, if\ f_i \in F_2 \end{cases} \quad (12)$$

$\vee$ and $\wedge$ shows max and min, respectively, and $1 \le i \le m$. $p(\tilde{\tilde{v}}_i \succ \tilde{\tilde{v}}_i^+)$and $p(\tilde{\tilde{v}}_i \succ \tilde{\tilde{v}}_i^-)$ are presented as follows:

$$p(\tilde{\tilde{v}}_i \succ \tilde{\tilde{v}}_i^+) = min\left\{max\left(\frac{M^*(\tilde{\tilde{v}}_i) - M_*(\tilde{\tilde{v}}_i^+)}{M^*(\tilde{\tilde{v}}_i) - M_*(\tilde{\tilde{v}}_i) + M^*(\tilde{\tilde{v}}_i^+) - M_*(\tilde{\tilde{v}}_i^+)}, 0\right), 1\right\} \quad (13)$$

$$p(\tilde{\tilde{v}}_i \succ \tilde{\tilde{v}}_i^-) = min\left\{max\left(\frac{M^*(\tilde{\tilde{v}}_i) - M_*(\tilde{\tilde{v}}_i^-)}{M^*(\tilde{\tilde{v}}_i) - M_*(\tilde{\tilde{v}}_i) + M^*(\tilde{\tilde{v}}_i^-) - M_*(\tilde{\tilde{v}}_i^-)}, 0\right), 1\right\} \quad (14)$$

where

$$M_*(\tilde{\tilde{v}}_i) = \frac{1}{6}(v_{i1}^U + 2v_{i2}^U)H(\tilde{A}_i^U)^2 + \frac{1}{6}(v_{i1}^L + 2v_{i2}^L)H(\tilde{A}_i^L)^2 \quad (15)$$

and

$$M^*(\tilde{\tilde{v}}_i) = \frac{1}{6}(v_{i1}^U + 2v_{i2}^U)H(\tilde{A}_i^U)^2 + \frac{1}{6}(v_{i1}^L + 2v_{i2}^L)H(\tilde{A}_i^L)^2 \quad (16)$$

PC_i is calculated as follows:

$$PC_i = \frac{\sum_{j=1}^m p(\tilde{\tilde{v}}_i \succ \tilde{\tilde{v}}_i^-)}{\sum_{j=1}^m \left(p(\tilde{\tilde{v}}_i \succ \tilde{\tilde{v}}_i^-) + p(\tilde{\tilde{v}}_i \succ \tilde{\tilde{v}}_i^+)\right)} \quad (17)$$

where $1 \le i \le n$.

2.2. Bayesian Network

Bayesian theory is developed by Thomas Bayes. It includes a graph theory and the conditional probabilities. Bayesian theory ensures to detect the predictions about future situations [15]. Eq. (18) is used for the calculations of Bayesian network:

$$\boldsymbol{P(x) = P(x_1, \cdots, x_m) = \prod_{i=1}^m P(x_i|\pi_i)} \quad (18)$$

$\boldsymbol{\pi_i}$ and $\boldsymbol{x_i}$ mean $\boldsymbol{i^{th}}$parent and child nodes, respectively.

$\boldsymbol{P(x_i|\pi_i)}$The occurrence probability of $\boldsymbol{x_i}$when $\boldsymbol{\pi_i}$ is occurred

3. APPLICATION

A real life implementation about a pair of gloves selection is realized to ensure a better understanding of the handled method. This study tries to prioritize the alternative gloves by considering ergonomic criteria. First of all, with the help of three experts' opinions, the importance degrees of 15 ergonomic criteria will be determined by using the IT2F number. 5 alternative gloves will be evaluated taking into account the weights of 15 glove design criteria. TOPSIS method based on IT2F number is proposed for ranking the alternatives. After choosing the most suitable ergonomic glove, it is aimed to raise the customer satisfaction for the selected glove. 4 performance indicators were used to raise the customer satisfaction. The effect of these performance indicators on customer satisfaction has been examined at low, medium and high levels. A Bayesian approach is proposed to analyze the effect of each performance indicator on customer satisfaction. As a result of the Bayesian approach, it was determined which performance indicator had the most impact on customer satisfaction. A survey is introduced to fill three experts E1, E2 and E3 to determine the most suitable glove for employees. An occupational safety specialist (E1), an industrial engineer (E2), an academician (E3) with sufficient knowledge and experience in designing a pair of gloves are selected as the decision maker. They have worked at least 3 years in glove manufacturing. The evaluation criteria for a pair of gloves are determined as a result of the opinions of three experts and literature reviews. These criteria are radiation tolerance (C1), thermal tolerance (C2), vibration tolerance (C3), holding (C4), grip strength (C5), range of motion (C6), chemical resistance (C7), price (C8), tactile perception (C9), dexterity (C10), torque capacity (C11), tolerance to electrical energy (C12), manipulative ability (C13), abrasive trauma tolerance (C14), and biohazard tolerance (C15). Five pairs of gloves based on fifteen criteria are examined according to the opinions of three experts. Table 2 handles the IT2F numbers linguistic scale.

Table 2 Linguistic scale

Linguistic terms	IT2F numbers
Very low (VL)	(0.08,0.11,0.15,0.18;0.8),(0.04,0.09,0.17,0.22;1)
Low (L)	(0.20,0.25,0.33,0.36;0.8),(0.17,0.22,0.38,0.43;1)
Medium (M)	(0.40,0.45,0.54,0.57;0.8),(0.30,0.40,0.60,0.66;1)
High (H)	(0.77,0.80,0.86,0.90;0.8),(0.72,0.75,0.90,0.95;1)
Very high (VH)	(0.95,0.97,0.98,0.99;0.8),(0.92,0.96,0.99,1.00;1)

The weights of 15 evaluation criteria for ergonomic glove design are presented by three decision makers in Table 3. The weights of E1, E2 and E3 experts are used to show the differences of decision makers in group decision making problem. The weights of E1, E2 and E3 are determined as (0.35, 0.25, 0.40), respectively.

Table 3 Linguistic scale

	Criteria														
Experts	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12	C 13	C 14	C 15
E1	VL	L	M	M	VH	H	L	H	M	VH	H	M	M	L	L
E2	L	L	L	M	VH	H	L	VH	H	H	M	L	M	VL	L
E3	L	M	M	M	H	H	L	H	M	VH	M	L	L	VL	VL

Subjective decisions of the experts are collected according to their importance. The judgments of three experts are combined to define the weights of criteria, which are presented in Table 4.

Table 4 The weights of criteria for the combining result

Criteria	IT2F numbers
C 1	((0.158,0.201,0.267,0.297;0.8),(0.125,0.175,0.307,0.357;1))
C 2	((0.280,0.330,0.414,0.444;0.8),(0.222,0.292,0.468,0.522;1))
C 3	((0.350,0.400,0.488,0.518;0.8),(0.268,0.355,0.545,0.603;1))
C 4	((0.400,0.450,0.540,0.570;0.8),(0.300,0.400,0.600,0.660;1))
C 5	((0.878,0.902,0.932,0.954;0.8),(0.840,0.876,0.954,0.980;1))
C 6	((0.770,0.800,0.860,0.900;0.8),(0.720,0.750,0.900,0.950;1))
C 7	((0.200,0.250,0.330,0.360;0.8),(0.170,0.220,0.380,0.430;1))
C 8	((0.815,0.843,0.890,0.923;0.8),(0.770,0.803,0.923,0.963;1))
C 9	((0.493,0.538,0.620,0.653;0.8),(0.405,0.488,0.675,0.733;1))
C 10	((0.905,0.928,0.950,0.968;0.8),(0.870,0.908,0.968,0.988;1))
C 11	((0.530,0.573,0.652,0.686;0.8),(0.447,0.523,0.705,0.762;1))
C 12	((0.270,0.320,0.404,0.434;0.8),(0.216,0.283,0.457,0.511;1))
C 13	((0.320,0.370,0.456,0.486;0.8),(0.248,0.328,0.512,0.568;1))
C 14	((0.122,0.159,0.213,0.243;0.8),(0.086,0.136,0.244,0.294;1))
C 15	((0.152,0.194,0.258,0.288;0.8),(0.118,0.168,0.296,0.346;1))

The TOPSIS approach under IT2F set environment is recommended for evaluation of gloves. The three experts employ the linguistic terms specified in Table 2 to evaluate the gloves according to each criterion. The evaluation of five pairs of gloves based on fifteen criteria by three decision makers is presented in Table 5.

Table 5 Evaluation of the alternatives

	E1					E2					E3				
	Alt1	Alt2	Alt3	Alt4	Alt5	Alt1	Alt2	Alt3	Alt4	Alt5	Alt1	Alt2	Alt3	Alt4	Alt5
C1	H	M	M	M	VL	M	L	L	L	L	H	H	M	L	L
C2	M	H	H	VH	H	L	H	H	H	M	L	VH	M	M	H
C3	L	VH	VH	VL	H	L	H	VH	M	M	M	VH	VH	H	H
C4	VH	M	H	H	VH	H	M	M	M	VH	VH	L	H	H	VH
C5	VL	L	M	L	H	M	H	H	H	VH	VL	L	L	M	H
C6	M	VL	M	H	VL	L	M	L	VH	L	H	VL	H	H	L
C7	M	M	M	M	H	M	L	L	L	H	L	VH	H	L	H
C8	VL	H	M	M	L	L	L	H	M	L	VL	M	L	H	L
C9	L	L	H	VH	VH	M	M	M	VH	VH	L	L	M	VH	M
C10	VH	L	M	M	H	VH	M	M	VH	M	H	L	M	L	VH
C11	VH	H	H	H	M	VH	M	H	H	L	H	M	H	VH	L
C12	M	H	L	M	M	L	H	M	L	M	L	M	H	L	M
C13	VL	M	VH	H	H	VL	L	VH	H	H	M	L	M	M	M
C14	VL	M	M	H	H	M	H	M	M	H	L	H	L	M	M
C15	M	VH	M	H	VL	M	VH	L	H	M	VL	VH	L	H	L

The linguistic evaluations shown in Table 5 were transformed using Table 2 to IT2F numbers. Group decision based on the importance degrees of the three decision makers is achieved employing IT2F number operations. Each alternative is evaluated for fifteen criteria. Table 6 presents the possibility degrees $p(\tilde{\tilde{v}}_i \succ \tilde{\tilde{v}}_i^+)$ and $p(\tilde{\tilde{v}}_i \succ \tilde{\tilde{v}}_i^-)$.

Table 6 The possibility degrees

	C1	C2	C3	C4	C5	…	C11	C12	C13	C14	C15
$p(\tilde{\tilde{v}}_{1i} \succ \tilde{\tilde{v}}_i^+)$	0,5	0	0	0,463	0	…	0,5	0,109	0	0,038	0
$p(\tilde{\tilde{v}}_{1i} \succ \tilde{\tilde{v}}_i^-)$	1	0,5	0,5	1	0,5	…	1	0,5	0,5	0,5	0,594
$p(\tilde{\tilde{v}}_{2i} \succ \tilde{\tilde{v}}_i^+)$	0,347	0,5	0,465	0	0	…	0,08	0,5	0	0,5	0,5
$p(\tilde{\tilde{v}}_{2i} \succ \tilde{\tilde{v}}_i^-)$	0,948	1	1	0,5	1	…	0,888	0,891	0,658	0,962	1
$p(\tilde{\tilde{v}}_{3i} \succ \tilde{\tilde{v}}_i^+)$	0,212	0,319	0,5	0,261	0	…	0,391	0,352	0,5	0,218	0
$p(\tilde{\tilde{v}}_{3i} \succ \tilde{\tilde{v}}_i^-)$	0,8	0,894	1	0,906	1	…	1	0,748	1	0,675	0,617
$p(\tilde{\tilde{v}}_{4i} \succ \tilde{\tilde{v}}_i^+)$	0,109	0,361	0	0,261	0	…	0,462	0,109	0,416	0,416	0,398
$p(\tilde{\tilde{v}}_{4i} \succ \tilde{\tilde{v}}_i^-)$	0,703	0,955	0,677	0,906	1	…	1	0,5	1	0,875	1
$p(\tilde{\tilde{v}}_{5i} \succ \tilde{\tilde{v}}_i^+)$	0	0,369	0,272	0,5	0,5	…	0	0,288	0,416	0,486	0
$p(\tilde{\tilde{v}}_{5i} \succ \tilde{\tilde{v}}_i^-)$	0,5	0,945	0,956	1	1	…	0,5	0,67	1	0,948	0,5

Table 7 explains the closeness coefficient for each glove alternative and its ranking. The most suitable glove in terms of ergonomic is defined as alternative 1. This paper defined 4 performance indicators (PI), which is presented in Table 8.

Table 7 The closeness coefficient

	Alt1	Alt2	Alt3	Alt4	Alt5
PC_i	0,7816	0,7327	0,7542	0,7348	0,7161
Rank	1	4	2	3	5

Table 8 Performance indicators

PI1	Hand circumference
PI2	Finger root circumference
PI3	Wrist circumference
PI4	Finger length (from fingertip to root)

Bayesian network is used to analyze the customer satisfaction for alternative 1 based on the performance indicators. Firstly, each performance indicator is handled %50 in terms of availability and nonavailability situations. This study aims to define the effect of each performance indicators to the customer satisfaction of alternative 1. The exchanges of availability and nonavailability situations are significant to observe this effect. Figure 1 shows Bayesian network structure for the relationship between the performance indicators and the customer satisfaction of alternative 1. Secondly, a sensitivity analysis is realized when each performance indicator is %100 for availability situation. This sensitivity analysis explains low, medium and high customer satisfaction levels for alternative 1. Figure 2 presents the sensitivity analysis when finger root circumference (PI2) for alternative 1 is %100. Table 9 introduces the customer satisfaction levels of alternative 1 when each performance indicator is availability %100 separately. Current situation means the result of alternative 1 in Figure 1. The biggest exchange for high customer satisfaction of alternative 1 is caused from PI2 (finger root circumference) between four performance indicators. The lowest exchange for high customer satisfaction of alternative 1 is caused from PI4 (finger length) between four performance indicators. The glove manufacturers of alternative 1 should focus on finger root circumference of the glove so that it increases the customer satisfaction.

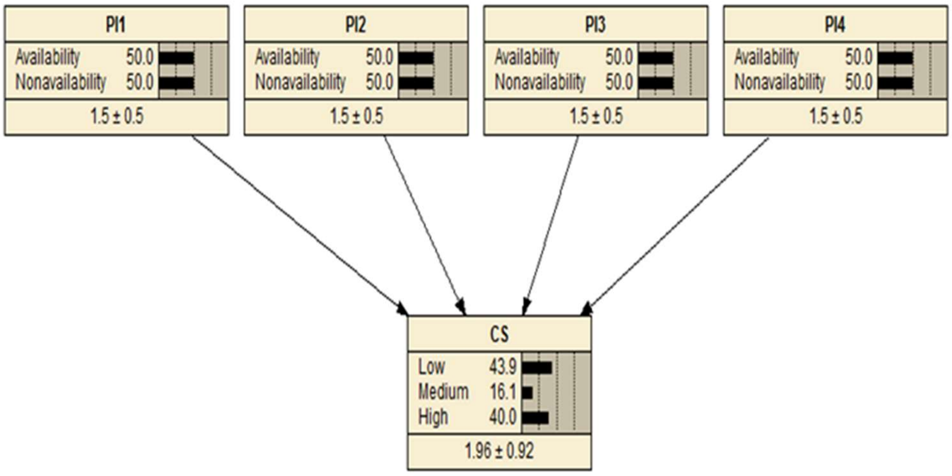

Figure 1 – The relationship between alternative 1 and performance indicators

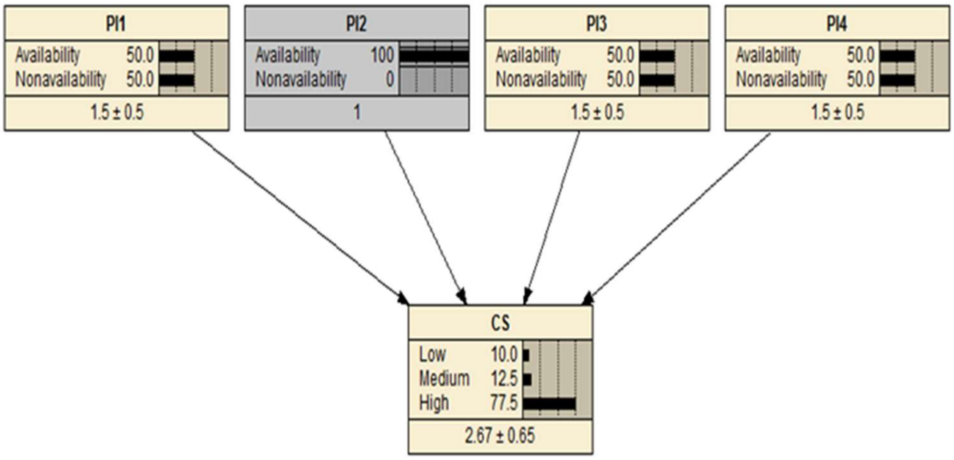

Figure 2 – Sensitivity analysis for Bayesian network structure

Table 9. Effect to alternative 1 of each PI exchange

	Low	Medium	High
Current	43.9	16.1	40.0
PI1	32.5	24.4	43.1
PI2	10.0	12.5	77.5
PI3	37.1	19.1	43.8
PI4	40.0	17.5	42.5

4. CONCLUSION

Decision making is one of the inevitable situations of daily life. If the problem encountered can be defined clearly and there is no uncertainty in it, it will be easy to solve. However, if the factors affecting the problem are more than one, constantly changing and contain serious uncertainties, the decision making situation becomes difficult. The use of fuzzy logic approach in solving these uncertainty problems will be useful.

In this study, the best product concept selection that meets glove design criteria was carried out. The selection of the most suitable alternative taking into account 15 evaluation criteria is made by using the IT2F number based TOPSIS method according to the information obtained from decision makers. In the IT2F number based TOPSIS method, group opinions are taken by using the importance of decision makers. Then, the weights of the criteria and the alternative based on the criteria are determined with linguistic variables and are transformed into IT2F numbers. IT2F number positive ideal solution and negative ideal solution are obtained. Positive and negative separation measures are calculated between alternatives and ideal solutions. Then, the closeness coefficients for the alternatives are calculated and the alternatives are ranked. In this study, IT2F set theory is applied to group decision problems. Bayesian network is used to measure the effect of each performance indicator exchange. The firm managers can focus on the most important performance indicator to improve the customer satisfaction of the selected glove. Since the proposed method is an effective method to better address experts' opinions, it can be implemented in various problems such as the investment selection, software selection, production system selection.

Product development and design activities will continue to gain more importance in the coming years. Therefore, many factors that will affect product design should be carefully examined. Obviously, all the issues mentioned involve considering multiple criteria for identifying and solving these issues. Various approaches can be proposed for this, but multi criteria decision making techniques can be applied as one of the best. IT2F set theory and multi criteria decision making methods help decision makers to achieve more robust results. The application of IT2F set to other methods is suggested for future studies.

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