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Augmented reality goggles selection by using neutrosophic MULTIMOORA method

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Abstract

Purpose – The purpose of this paper is to present the augmented reality (AR) eyeglass selection problem based on Neutrosophic MULTIMOORA method which is a very new multi-objective method.
Design/methodology/approach – The author evaluates five AR goggles according to six different criteria. Criteria have different weights and determined by analytic hierarchy process. The author used neutrosophic MULTIMOORA method in order to evaluate AR eyeglasses.
Findings – Five different AR eyeglasses were evaluated and the best one was selected according to six different criteria (benefit and non-benefit). According to Neutrosophic MULTIMOORA method, Sony AR eyeglass is selected as the best one. Neutrosophic MULTIMOORA method uses simple computational equations and it handles multi-objective decision making problems effectively.
Originality/value – Evaluating AR goggles by using the Neutrosophic MULTIMOORA method for the first time is the originality of this paper.

Keywords Industry 4.0, Augmented reality goggles, Multicriteria decision making, Multimoora, Neutrosophic
Paper type Research paper

1. Introduction

The term "Industry 4.0" is put forward by the German Government to promote the computerization of manufacturing (Sung, 2017). Industry 4.0 represents the fourth industrial revolution in production; manufacturing and industry. The first industrial revolution (1.0) introduced mechanical production systems using water and steam power. With the second industrial revolution (2.0), mass production was brought about with the help of electric power. In the third industrial revolution (3.0), production was further automated by the use of digital revolution, use of electronics and development of information technology. The purpose of Industry 4.0 is to provide an interaction between people, machines and products by using network-linked intelligent systems.

Industry 4.0 connects new technologies in order to provide flexibility in manufacturing where the conditions change rapidly. Some of these technologies are autonomous robots, system integration, internet of things, simulation, additive manufacturing, cloud computing, augmented reality (AR), Big Data, and cyber-security, respectively (Zhong *et al.*, 2017). All these technologies aim to realize communication between people, machines and products in order to provide maximum efficiency according to the customer demands.

AR has been defined as a technology that allows for visualization of computer graphics placed in the real environment (Yew *et al.*, 2016). AR simply gathers real-time graphics, sound and other sensory enhancements to the real-world environment. AR consists of four processes; capture the scene, scene recognition, scene procession, scene display, respectively (Horejsi, 2015). AR is a tremendous technology that can be used in daily life and make it easier, as well as having common application in industry. In the virtual world, operators can click a button to change the parameters to interact with a machine and receive operational data and maintenance instructions. AR uses many new technologies such as: hardware components (sensors, processors, etc.), displays, goggles, contact lenses, virtual retinal displays, handheld displays, head-up displays, generation-2 goggles, software and algorithms, computers, input devices.

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In this paper, we evaluate the usability of AR goggles. AR goggles aim to bring internet, location services, and social media directly in front of our eyes. The first reported application of goggles in the field had been released as a head-up display in military. This technology has begun to be used with battlefield pilots on cockpit screen with glasses integrated into their helmets. Some informative data were transmitted easily, thanks to these glasses. AR goggles are used in many fields such as: education, healthcare, marketing, manufacturing, retail, etc.

In this study, we aim to evaluate the usability of AR goggles with respect to the determined criteria. Usability evaluation can be named as a multi-objective decision making problem. Multi-objective decision making methods optimize many conflicting criteria which can be both beneficial and non-beneficial. Therefore, we adopted MULTIMOORA method which is an effective multi-objective optimization solution method. MULTIMOORA provides many advantages: the method has an easy implementation process; it is based on the ratio analysis, the reference analysis, the full multiplicative analysis all of which have simple calculations and give effective results; the method is not affected by the introduction of any extra parameter (Jana *et al.*, 2013).

Sometimes, experts need natural language expressions rather than crisp numerical values in the evaluation of decision matrix. Because of this requirement, the fuzzy set theory can be handled in decision making problems. The fuzzy set theory was developed by Zadeh (1965) to overcome vagueness in human thoughts and perceptions. The fuzzy set theory is widely used in order to solve multi-objective decision making problems because of its ability to quantify the subjectivity in human judgments.

In recent years, the fuzzy set theory has been extended to new types. Neutrosophic set is one of the extensions of fuzzy sets proposed by Smarandache (1998). A neutrosophic set is expressed by three parameters, which are called "truthiness," "indeterminacy" and "falsity." A neutrosophic set carries more information than fuzzy set. Each proposition is estimated to have a percentage of truth in subset "T", a percentage of indeterminacy in subset "I", and a percentage of falsity in subset "F", where T, I, F are subsets of real numbers in [0, 1].

Neutrosophic set and MULTIMOORA method were combined in Neutrosophic MULTIMOORA by Stanujkic *et al.* (2017). The recently developed Neutrosophic MULTIMOORA method can easily handle multi-objective decision making problems with uncertainty. In this paper, we used Neutrosophic MULTIMOORA method to evaluate AR goggles due to its simplicity and effectiveness. Evaluating AR goggles by using the Neutrosophic MULTIMOORA method for the first time is the originality of this paper.

The rest of the paper is organized as follows: literature review on AR is presented in Section 2. In Section 3, neutrosophic sets are introduced. In Section 4, the application steps of the Neutrosophic MULTIMOORA are introduced. In Section 5, an application is given and findings are explained. In Section 6, a sensitivity analysis is presented in order to check the stability of the results. In Section 7, a comparative analysis is given. The conclusions are presented in the final section.

2. Literature review

Industry 4.0 is a relatively new term in the world of science, therefore academic survey on the subject is scarce. In the literature review section we focus on Industry 4.0 application and use of neutrosophic MULTIMOORA method.

Pan *et al.* (2015) proposed a model which uses Industry 4.0 technologies in order to design and optimize the eco-industrial park in Singapore. Mosterman and Zander (2016) presented a set of examples of cyber-physical systems challenges. Kans and Ingwald (2016) developed business model for service management 4.0. The model offered connecting technological development with service needs, O level and M level service, maintenance, etc. Ivanov *et al.* (2014) developed a dynamic model and algorithm for short-term supply chain scheduling in Industry 4.0. Long *et al.* (2016) used stochastic Petri nets in order to model the production system in industry 4.0. Shamim *et al.* (2017) proposed the Industry 4.0 framework to promote the environment of innovation and learning in an organization. Pei *et al.* (2017) build a high-level digitization for intelligent continuous production line. Ojstersek and Buchmeister (2017) optimized production line by using concept of Industry 4.0 based on automated and robotic production systems. Caricato and Grieco (2017) realized an application of Industry 4.0 to the production of packaging films. They proposed a new software tool to use in making production plan. Liebrecht *et al.* (2017) proposed an approach based on fuzzy set theory and stochastic model to evaluate Manufacturing Systems 4.0. They used quantitative and qualitative criteria for evaluation.

Stoltz *et al.* (2017) investigated advantages and disadvantages of using AR technologies in warehouse management. They designed a set of experiment to sort packages by using AR goggles. Turkan *et al.* (2017) offered using 3D visualization features in order to improve students' learning and performance in structural analysis. Tsai and Huang (2018) presented a user-behavior-driven augmented content display approach. They investigated the behaviors of smart-glasses wearers when operating an AR browser. Lee and Lee (2018) investigate the effects of AR in biomedical field. They focused on using AR technologies on treatment strategies.

As for the Neutrosophic MULTIMOORA method, Zavadskas *et al.* (2017) developed a neutrosophic MULTIMOORA method for residential house and material selection. Stanujkic *et al.* (2017) proposed a new extension of the MULTIMOORA method with neutrosophic set. They evaluated the three commination circuit designs according to five different criteria. As Neutrosophic MULTIMOORA method is a relatively new method, there is no further research presented on this field.

3. Neutrosophic sets

Neutrosophic logic was developed by Smarandache (1998) as a generalization of fuzzy logic. Smarandache represented a new term of "indeterminacy" which carries more information than fuzzy logic. A neutrosophic set A in a universal set X is characterized by a truth-membership function $T_A(x)$, an indeterminacy membership function $I_A(x)$, a falsity-membership function $F_A(x)$. The functions $T_A(x)$, $I_A(x)$, $F_A(x)$ in X are three subsets of the nonstandard interval$]^-0, 1^+[$i.e. $T_A(x) \subseteq]^-0, 1^+[I_A(x) \subseteq]^-0, 1^+[$, and $F_A(x) \subseteq]^-0, 1^+[$There is no restriction on the sum of $T_A(x)$, $I_A(x)$, $F_A(x)$, i.e. $\overline{0} \leqslant \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \leqslant 3^+$ (Ye, 2014).

However, it is difficult to apply the neutrosophic set and set-theoretic operators in the real application. Therefore, Wang *et al.* (2010), proposed a single valued neutrosophic sets which is an extension of neutrosophic sets. For each point x in X, we have $T_A(x)$, $I_A(x)$, $F_A(x) \in [0, 1]$, and $0 \leqslant T_A(x), I_A(x), F_A(x) \leqslant 3$.

3.1 Preliminaries of the single valued neutrosophic set

Step 1: let X be a space of objects, with a generic element in X denoted by x.

The Neutrosophic set A in X is as follows:

$$A = \{\langle x, T_A(x), I_A(x), F_A(x) \rangle | x \in X\}, \tag{1}$$

where $T_A(x)$ is characterized by the truth-membership function, $I_A(x)$ is the indeterminacy membership function and $F_A(x)$ is the falsity-membership function:

$$T_A(x) : X \to]^-0, 1^+[I_A(x) : X \to]^-0, 1^+[F_A(x) : X \to]^-0, 1^+[. \tag{2}$$

There is no restriction on the sum of $T_A(x)$, $I_A(x)$ and $F_A(x)$, so $^{-}0 \leqslant \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \leqslant 3^{+}$.

Step 2: if the functions $T_A(x)$, $I_A(x)$ and $F_A(x)$ are singleton subintervals/subsets in the real standard [0, 1], that is $T_A(x)$: X→[0, 1], $I_A(x)$: X→[0, 1], $F_A(x)$: X→[0, 1] Then, a simplification of neutrosophic set A is denoted by:

$$A = \{\langle x, T_A(x), I_A(x), F_A(x)\rangle | x \in X\}, \tag{3}$$

which is called a single valued neutrosophic set. It is subclass of neutrosophic sets:

$$0 \leqslant T_A(x), I_A(x), F_A(x) \leqslant 3. \tag{4}$$

Step 3: for a single valued neutrosophic set A in X, the triple $\langle t_A, i_A, f_A \rangle$ is called the single valued neutrosophic number.

Step 4: let $X_1 = \langle t_1, i_1, f_1 \rangle$ and $X_2 = \langle t_2, i_2, f_2 \rangle$ be two single valued neutrosophic number and $\lambda > 0$; then the basic operators are as follows:

$$x_1 + x_2 = \langle t_1 + t_2 - t_1 t_2, i_1 i_2, f_1 f_2 \rangle, \tag{5}$$

$$x_1 . x_2 = \langle t_1 t_2, i_1 + i_2 - i_1 i_2, f_1 + f_2 - f_1 f_2 \rangle, \tag{6}$$

$$\lambda x_1 = \left\langle 1 - (1 - t_1)^{\lambda}, i_1^{\lambda}, f_1^{\lambda} \right\rangle, \tag{7}$$

$$x_1^{\lambda} = \left\langle t_1^{\lambda}, 1 - (1 - i_1)^{\lambda}, 1 - (1 - f_1)^{\lambda} \right\rangle. \tag{8}$$

Step 5: let $X_1 = \langle t_1, i_1, f_1 \rangle$ be a single valued neutrosophic number; then the score function s_x of x can be as follows:

$$s_x = (1 + t_x - 2 i_x - f_x)/2, \tag{9}$$

where $S_x \in [-1, 1]$.

Step 6: let $x_1 = \langle t_1, i_1, f_1 \rangle$, and $x_2 = \langle t_2, i_2, f_2 \rangle$, are single valued neutrosophic numbers and the maximum distance between x_1 and x_2 is as follows:

$$d_{\max}(x_1, x_2) = \begin{cases} |t_1 - t_2|, & x_1, x_2 \in \Omega_{\max}, \\ |f_1 - f_2|, & x_1, x_2 \in \Omega_{\min}. \end{cases} \tag{10}$$

Step 7: let $A_j = \langle t_j, i_j, j_j \rangle$ be a collection of single valued neutrosophic sets and $W = (w_1, w_2, \ldots, w_n)^T$ be an associated weighting vector. Then the single valued neutrosophic weighted average operator of A_j is as follows.

Single valued neutrosophic weighted average $(A_1, A_2, \ldots, A_n)$:

$$= \sum_{j=1}^{n} w_j A_i = \left(1 - \prod_{j=1}^{n} (1 - t_j)^{w_j}, \prod_{j=1}^{n} (i_j)^{w_j}, \prod_{j=1}^{n} (f_j)^{w_j} \right). \tag{11}$$

where w_j is the element j of the weighting vector, $w_j \in [0, 1]$ and $\sum_{j=1}^{n} w_j = 1$.

Step 8: let $A_j = \langle t_j, i_j, j_j \rangle$ be a collection of single valued neutrosophic sets and $W = (w_1, w_2, \ldots, w_n)^t$ be an associated weighting vector. Then the single valued neutrosophic weighted geometric operator of A_j is as follows.

Single valued neutrosophic weighted geometric $(A_1, A_2, \ldots, A_n)$:

$$= \prod_{j=1}^{n} (A_j)^{w_j} = \left(\prod_{j=1}^{n} (A_j)^{w_j}, 1 - \prod_{j=1}^{n} (1-i_j)^{w_j}, 1 - \prod_{j=1}^{n} (1-f_j)^{w_j} \right). \tag{12}$$

where w_j is the element j of the weighting vector, $w_j \in [0, 1]$ and $\sum_{j=1}^{n} w_j = 1$.

4. Neutrosophic MULTIMOORA method

In this section, only Neutrosophic MULTIMOORA method will be discussed due to space limitation. If researcher wants to examine classical MULTIMOORA, the paper by Stanujkic *et al.* (2017) may be a good resource for review.

4.1 Neutrosophic MOORA–Ratio method

Step 1: calculate Y_i^+ and Y_i^- by using the single valued neutrosophic weighted average operator, as follows:

$$Y_i^+ = \left(1 - \prod_{j \in \Omega_{\max}} (1-t_j)^{w_j}, \prod_{j \in \Omega_{\max}} (i_j)^{w_j}, \prod_{j \in \Omega_{\max}} (f_j)^{w_j} \right). \tag{13}$$

$$Y_i^- = \left(1 - \prod_{j \in \Omega_{\min}} (1-t_j)^{w_j}, \prod_{j \in \Omega_{\min}} (i_j)^{w_j}, \prod_{j \in \Omega_{\min}} (f_j)^{w_j} \right). \tag{14}$$

where Y_i^+ and Y_i^- denote the importance of the alternative i obtained based on the benefit and cost criteria, respectively; Y_i^+ and Y_i^- are single valued neutrosophic numbers.

Step 2: find score function of Y_i^+ and Y_i^- as follows:

$$y_i^+ = s(Y_i^+), \tag{15}$$

$$y_i^- = s(Y_i^-), \tag{16}$$

$$s(Y_i) = \left(1 + t_{y_i} - 2i_{y_i} - f_{y_i}\right)/2, \tag{17}$$

$$s(Y_i) \in [-1, 1].$$

Step 3: the overall importance of each alternative can be calculated as follows:

$$y_i = y_i^+ - y_i^-. \tag{18}$$

Step 4: alternatives can be ranked according to value of Y_i in descending order and the alternative with the highest value is the best alternative.

4.2 Neutrosophic MOORA–Reference point method

Step 1: each coordinate of the reference point $r^* = \{r_1^*, r_2^*, \ldots, r_n^*\}$ is a single valued neutrosophic number, $r_j^* = \langle t_j^*, i_j^*, f_j^* \rangle$, and r_j^* can be calculated as follows:

$$r_j^* = \begin{cases} \left\langle \max_i t_{ij}, \min_i i_{ij}, \min_i f_{ij} \right\rangle, & j \in \Omega_{\max}, \\ \left\langle \min_i t_{ij}, \min_i i_{ij}, \max_i f_{ij} \right\rangle, & j \in \Omega_{\min}. \end{cases} \tag{19}$$

Step 2: calculate the maximum distance from each alternative to reference point as follows:

$$d_{i,j}^{\max} = d_{\max}\left(r_{ij}, r_j^*\right) w_j. \tag{20}$$

where $d_{i,j}^{\max}$ denotes the maximum distance of the alternative i obtained based on the criterion j determined by Equation (10).

Step 3: determine the maximum distance of each alternative, as follows:

$$d_i^{\max} = \max_j d_{i,j}^{\max}. \tag{21}$$

Step 4: alternatives can be ranked according to value of the $d_{\max}$ in descending order and the alternative with the lowest value is the best alternative.

4.3 Neutrosophic MOORA–Full multiplicative form

Step 1: let $A_i = \langle t_{Ai}, i_{Ai}, f_{Ai} \rangle$ and $B_i = \langle t_{Bi}, i_{Bi}, f_{Bi} \rangle$ are single valued neutrosophic numbers:

$$A_i = \left(\prod_{j \in \Omega_{\max}} (t_j)^{w_j}, 1 - \prod_{j \in \Omega_{\max}} (1 - i_j)^{w_j}, 1 - \prod_{j \in \Omega_{\max}} (f_j)^{w_j} \right), \tag{22}$$

$$B_i = \left(\prod_{j \in \Omega_{\max}} (t_j)^{w_j}, 1 - \prod_{j \in \Omega_{\max}} (1 - i_j)^{w_j}, 1 - \prod_{j \in \Omega_{\max}} (f_j)^{w_j} \right). \tag{23}$$

Step 2: calculate the score function of A_i and B_i as follows:

$$a_i = s(A_i)$$

$$b_i = s(B_i). \tag{24}$$

Step 3: calculate the overall utility for each alternative as follows:

$$u_i = \frac{a_i}{b_i}. \tag{25}$$

Step 4: alternatives can be ranked according to value of the u_i descending order and the alternative with the highest value is the best alternative.

4.4 Dominance theory

The final ranking of the alternatives can be calculated based on dominance theory. Dominance theory was developed by Brauers and Zavadskas (2011) based on dominance, being dominated, transitivity and equability. The theory is employed to summarize the three ranks provided by respective parts of MULTIMOORA into a single one.

5. Application

In the application section, we evaluate recently-produced AR goggles according to determined criteria. We evaluate five different AR goggles which are candidate for much more using in future. The determined AR goggles are as follows: Sony Smart Goggles, Meta Pro, Optinvent Ora-1, Vuzix M100, Epson Moverio BT-200. Specifications of the glasses are found on the internet.

Then we determine six criteria as follows: C_1–Functionality (benefit), C_2–Ease of use (benefit), C_3–Design standards (benefit), C_4–Effectiveness (benefit), C_5–Portability (benefit), C_6–Price (non-benefit). Weights of alternatives are determined by using classical Analytical Hierarchy Process (Saaty, 1980). The weights are: 0.20, 0.16, 0.14, 0.16, 0.13, 0.19, respectively. Alternatives are evaluated by the ergonomist, and the ratings obtained are shown in Table I.

The ranking orders of the alternatives obtained on the basis of the Neutrosophic MOORA–Ratio method are shown in Table II.

Then we applied Neutrosophic MOORA–Reference Point method. Table III shows the reference point and Table IV shows deviation from the reference points.

	C_1	C_2	C_3	C_4	C_5	C_6
	0.20	0.16	0.14	0.16	0.13	0.19
Weight	max.	max.	max.	max.	max.	min.
A_1	$\langle 0.8, 0.2, 0.1 \rangle$	$\langle 0.9, 0.1, 0.2 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.9, 0.1, 0.2 \rangle$	$\langle 0.9, 0.1, 0.2 \rangle$	$\langle 0.7, 0.3, 0.2 \rangle$
A_2	$\langle 0.7, 0.3, 0.3 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.8, 0.1, 0.2 \rangle$	$\langle 0.5, 0.2, 0.2 \rangle$	$\langle 0.5, 0.2, 0.3 \rangle$
A_3	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.8, 0.2, 0.1 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.8, 0.1, 0.2 \rangle$	$\langle 0.6, 0.3, 0.1 \rangle$
A_4	$\langle 0.9, 0.1, 0.2 \rangle$	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.7, 0.3, 0.3 \rangle$
A_5	$\langle 0.8, 0.2, 0.1 \rangle$	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.4, 0.3, 0.2 \rangle$	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.5, 0.2, 0.2 \rangle$	$\langle 0.8, 0.2, 0.1 \rangle$

Table I. Decision matrix for the AR eyeglasses selection problem

	Y_i^+	Y_i^-	y_i^+	y_i^-	y_i	Rank
A_1	$\langle 0.78, 0.21, 0.24 \rangle$	$\langle 0.20, 0.80, 0.74 \rangle$	0.564	−0.562	1.126	1
A_2	$\langle 0.61, 0.27, 0.30 \rangle$	$\langle 0.12, 0.74, 0.80 \rangle$	0.382	−0.573	0.955	4
A_3	$\langle 0.63, 0.26, 0.22 \rangle$	$\langle 0.16, 0.80, 0.74 \rangle$	0.450	−0.584	1.033	3
A_4	$\langle 0.65, 0.24, 0.21 \rangle$	$\langle 0.20, 0.80, 0.80 \rangle$	0.476	−0.591	1.067	2
A_5	$\langle 0.54, 0.30, 0.20 \rangle$	$\langle 0.26, 0.74, 0.65 \rangle$	0.375	−0.428	0.803	5

Table II. Overall performances of the alternatives

	C_1	C_2	C_3	C_4	C_5	C_6
r_j^*	$\langle 0.9, 0.1, 0.1 \rangle$	$\langle 0.9, 0.1, 0.1 \rangle$	$\langle 0.8, 0.2, 0.1 \rangle$	$\langle 0.9, 0.1, 0.1 \rangle$	$\langle 0.9, 0.1, 0.1 \rangle$	$\langle 0.5, 0.2, 0.3 \rangle$

Table III. Reference points

	r_1^*	r_2^*	r_3^*	r_4^*	r_5^*	r_6^*	$d_i^{\max}$	Rank
A_1	0.02	0.00	0.01	0.00	0.00	0.02	0.020	1
A_2	0.04	0.03	0.01	0.02	0.05	0.00	0.052	3
A_3	0.06	0.03	0.00	0.03	0.01	0.02	0.060	5
A_4	0.00	0.05	0.03	0.03	0.04	0.00	0.048	2
A_5	0.02	0.05	0.06	0.05	0.05	0.04	0.056	4

Table IV. Weighted deviations from the reference point

For the Neutrosophic MOORA–Full Multiplicative form, the degree of the utility value of each alternative is computed. The computed utility value and ranking order of each alternative are in Table V.

The final ranking of alternatives based on dominance theory is shown in Table VI.

As seen in Table VI, the ranking of AR goggles based on the dominance theory is as follows: Sony Smart Goggles, Vuzix M100, Optinvent Ora-1, Meta Pro, Epson Moverio BT-200.

6. Sensitivity analysis

In this section a sensitivity analysis was performed. Different weights were assigned to criteria and were analyzed to observe how much it would influence the final rankings of alternatives. In the first case, we chanced the weights of criteria as follows: 0.5, 0.1, 0.1, 0.1, 0.1, and the best alternative is Vunix Goggles. In the second case, we changed the weights of criteria as follows: 0.1, 0.5, 0.1, 0.1, 0.1, and the best alternative is Sony Smart Goggles. In the third case, 0.1, 0.1, 0.5, 0.1, 0.1 are used, respectively and the best alternative is Optinvent Goggles. In the fourth case, we modified the weights as follows: 0.1, 0.1, 0.1, 0.5, 0.1, the best alternative is Sony Smart Goggles, again. In the last case, 0.1, 0.1, 0.1, 0.1, 0.5 are used and the best alternative is Sony Smart Goggles, again. For all the case, all alternatives' ranking can be seen in Table VII.

Sensitivity analysis shows that the rankings are robust to weight changes. It is observed that the ranking of alternatives are changing according to different criteria weights. Sony Smart Goggles has been chosen the best alternative for three times for different case. We can explain that Sony Smart Goggles has many advantages and technological

Table V. Utility values of alternatives

	A_i	B_i	a_i	b_i	u_i	Rank
A_1	$\langle 0.87, 0.12, 0.14\rangle$	$\langle 0.93, 0.07, 0.04\rangle$	0.747	0.881	0.848	1
A_2	$\langle 0.74, 0.17, 0.18\rangle$	$\langle 0.88, 0.04, 0.07\rangle$	0.609	0.864	0.705	4
A_3	$\langle 0.76, 0.15, 0.13\rangle$	$\langle 0.91, 0.07, 0.04\rangle$	0.667	0.867	0.769	3
A_4	$\langle 0.74, 0.14, 0.12\rangle$	$\langle 0.93, 0.07, 0.07\rangle$	0.671	0.869	0.772	2
A_5	$\langle 0.65, 0.18, 0.11\rangle$	$\langle 0.96, 0.04, 0.02\rangle$	0.595	0.928	0.641	5

Table VI. The final ranking order

	NMRM	NMRPM	NMFMF	Rank
A_1	1	1	1	1
A_2	4	3	4	4
A_3	3	5	3	3
A_4	2	2	2	2
A_5	5	4	5	5

Table VII. Ranking of the alternatives

	Sony Smart Goggles	Meta Pro	Optinvent Ora-1	Vuzix M100	Epson Moverio BT-200
			Ranking		
Case 1	2	5	3	1	4
Case 2	1	4	3	2	5
Case 3	2	4	1	3	5
Case 4	1	4	3	2	5
Case 5	1	4	3	2	5

superiority compared to other goggles, so it has been less affected by changes in criteria weights. Vuzix M 100 goggles has been chosen the best alternative for one time, and Optinvent Ora-1 has been chosen the best alternative for one time. Vuzix M 100 goggles has more advantages compared to other goggles on functionality criteria, and Optinvent Ora-1 goggles more advantages compared to other goggles on design criteria. It can be said that Meta Pro and Epson Moverio BT-200 have less advantages and technological superiority compared to other goggles, because they are less robust to weight changes.

7. Comparison with neutrosophic TOPSIS

In this section, the obtained results by the neutrosophic MULTIMOORA method are compared with the results of neutrosophic TOPSIS. Neutrosophic TOPSIS is a relatively method developed by Biswas *et al.* (2016). It is used to determine the best alternative which has the shortest distance from the positive ideal solution and the negative ideal solution. The AR goggles selection problem is solved by the following steps.

Step 1: construct the decision matrix.

The importance of each attribute for decision maker and weight of each attribute can be seen in Table VIII. The same data of neutrosophic MULTIMOORA are also used in neutrosophic TOPSIS.

Step 2: construct the weighted decision matrix.

The weighted decision matrix is shown in Table IX. For example, the element of weighted decision matrix for alternative A_1 with respect to attribute C_1 is determined by the following:

$$\left\langle T_{11}^{w}, I_{11}^{w}, F_{11}^{w} \right\rangle = \langle 0.8 \times 0.2, 0.2+0.2-0.2 \times 0.2, 0.2+0.2-0.2 \times 0.2 \rangle = \langle 0.16, 0.36, 0.28 \rangle.$$

Step 3: determine of the neutrosophic relative positive ideal solution (NRPIS) and the neutrosophic relative negative ideal solution (NRNIS).

According to attributes types, i.e. benefit type or cost type, the NRPIS can be calculated as follows:

$$Q_N^{+} = [\langle 0.18, 0.28, 0.28 \rangle, \langle 0.14, 0.24, 0.24 \rangle, \langle 0.11, 0.31, 0.22 \rangle, \langle 0.14, 0.24, 0.32 \rangle,$$
$$\langle 0.11, 0.21, 0.21 \rangle, \langle 0.09, 0.43, 0.43 \rangle],$$

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	$\langle 0.8, 0.2, 0.1 \rangle$	$\langle 0.9, 0.1, 0.2 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.9, 0.1, 0.2 \rangle$	$\langle 0.9, 0.1, 0.2 \rangle$	$\langle 0.7, 0.3, 0.2 \rangle$
A_2	$\langle 0.7, 0.3, 0.2 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.8, 0.1, 0.2 \rangle$	$\langle 0.5, 0.2, 0.2 \rangle$	$\langle 0.5, 0.2, 0.3 \rangle$
A_3	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.8, 0.2, 0.1 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.8, 0.1, 0.2 \rangle$	$\langle 0.6, 0.3, 0.2 \rangle$
A_4	$\langle 0.9, 0.1, 0.2 \rangle$	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.7, 0.2, 0.2 \rangle$	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.7, 0.3, 0.3 \rangle$
A_5	$\langle 0.8, 0.2, 0.1 \rangle$	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.4, 0.3, 0.2 \rangle$	$\langle 0.6, 0.2, 0.1 \rangle$	$\langle 0.5, 0.2, 0.2 \rangle$	$\langle 0.8, 0.2, 0.1 \rangle$
Weight	$\langle 0.20, 0.20, 0.20 \rangle$	$\langle 0.16, 0.16, 0.16 \rangle$	$\langle 0.14, 0.14, 0.14 \rangle$	$\langle 0.16, 0.16, 0.16 \rangle$	$\langle 0.13, 0.13, 0.13 \rangle$	$\langle 0.19, 0.19, 0.19 \rangle$

Table VIII. Neutrosophic decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	$\langle 0.16, 0.36, 0.28 \rangle$	$\langle 0.14, 0.24, 0.32 \rangle$	$\langle 0.09, 0.31, 0.31 \rangle$	$\langle 0.14, 0.24, 0.32 \rangle$	$\langle 0.11, 0.21, 0.30 \rangle$	$\langle 0.13, 0.43, 0.35 \rangle$
A_2	$\langle 0.14, 0.44, 0.44 \rangle$	$\langle 0.11, 0.32, 0.32 \rangle$	$\langle 0.09, 0.31, 0.31 \rangle$	$\langle 0.12, 0.24, 0.32 \rangle$	$\langle 0.06, 0.30, 0.30 \rangle$	$\langle 0.09, 0.35, 0.43 \rangle$
A_3	$\langle 0.12, 0.36, 0.28 \rangle$	$\langle 0.11, 0.32, 0.32 \rangle$	$\langle 0.11, 0.31, 0.22 \rangle$	$\langle 0.11, 0.32, 0.32 \rangle$	$\langle 0.10, 0.21, 0.30 \rangle$	$\langle 0.11, 0.43, 0.35 \rangle$
A_4	$\langle 0.18, 0.28, 0.36 \rangle$	$\langle 0.09, 0.32, 0.24 \rangle$	$\langle 0.08, 0.31, 0.22 \rangle$	$\langle 0.11, 0.32, 0.32 \rangle$	$\langle 0.07, 0.30, 0.21 \rangle$	$\langle 0.13, 0.43, 0.43 \rangle$
A_5	$\langle 0.16, 0.36, 0.28 \rangle$	$\langle 0.09, 0.32, 0.24 \rangle$	$\langle 0.05, 0.44, 0.31 \rangle$	$\langle 0.09, 0.32, 0.24 \rangle$	$\langle 0.06, 0.30, 0.30 \rangle$	$\langle 0.15, 0.35, 0.27 \rangle$

Table IX. Weighted neutrosophic decision matrix where $d_1^{w+} = \left\langle T_1^{w+}, I_1^{w+}, F_1^{w+} \right\rangle$ is calculated as:

$$T_1^{w+} = \max\{0.16, 0.14, 0.12, 0.18, 0.16\} = 0.18,$$

$$I_1^{w+} = \min\{0.36, 0.44, 0.36, 0.28, 0.36\} = 0.28,$$

$$F_1^{w+} = \min\{0.28, 0.44, 0.28, 0.36, 0.28\} = 0.28.$$

And the other values of NRPIS can be calculated in same way.

Similarly, the NRNIS can be calculated as follows:

$$Q_N^- = [\langle 0.12, 0.44, 0.44\rangle, \langle 0.09, 0.32, 0.32\rangle, \langle 0.05, 0.44, 0.31\rangle, \langle 0.09, 0.32, 0.32\rangle, \langle 0.06, 0.30, 0.30\rangle, \langle 0.15, 0.35, 0.27\rangle].$$

where $d_1^{w-} = \left\langle T_1^{w-}, I_1^{w-}, F_1^{w-} \right\rangle$ is calculated as:

$$T_1^{w-} = \min\{0.16, 0.14, 0.12, 0.18, 0.16\} = 0.12,$$

$$I_1^{w-} = \max\{0.36, 0.44, 0.36, 0.28, 0.36\} = 0.44,$$

$$F_1^{w+} = \max\{0.28, 0.44, 0.28, 0.36, 0.28\} = 0.44.$$

And the other values are similarly calculated.

Step 4: determination of the distance measure of each alternative from the relative neutrosophic positive ideal solution and relative neutrosophic negative ideal solution.

Calculated distances and relative closeness coefficient is calculated in Table X.

According to relative closeness coefficient ranking of alternatives is as follows: $A_4 > A_1 > A_3 > A_2 > A_5$ (Vuzix M100, Sony Smart Goggles, Optinvent Ora-1, Meta Pro, Epson Moverio BT-200), respectively. It can be said that, the results are a little bit different with neutrosophic MULTIMOORA method. Only first and second alternatives are different. As seen in Table X, it is a very small numerical difference, and it can be ignored. So we can say that neutrosophic MULTIMOORA gives effective results.

8. Conclusion

Industry 4.0 is an industry term contains contemporary and modern automation systems, data exchange, and production technology. Industry 4.0 connects many new technologies and AR technology is one of them. AR has been defined as a technology that allows for visualization of computer graphics placed in the real environment. AR goggles, which are a newly adapted technology, bring internet, location services and social media directly in front of our eyes.

Table X.
Closeness coefficient of each alternative

Alternatives A_1	D_{Eucl}^{i+}	D_{Eucl}^{i-}	C_i^*
A_1	0.0497	0.0793	0.61
A_2	0.0817	0.0613	0.43
A_3	0.0565	0.0744	0.57
A_4	0.0484	0.0850	0.64
A_5	0.0869	0.0564	0.39

In this paper, the multi-objective decision making problem for AR goggles is handled and solved by Neutrosophic MULTIMOORA method. Five different AR goggles with the latest technology were evaluated according to six different criteria contains both benefit and non-benefit. Neutrosophic MULTIMOORA method uses simple computational equations, so it does not need to use a software package. We utilized Microsoft excel program for calculations. According to the final ranking of Neutrosophic MULTIMOORA method, Sony Smart Goggles has been selected the best goggles. Then, we applied sensitivity analysis in order to check the robustness of the given decision. Finally, we applied comparative analysis with neutrosophic TOPSIS method, and we got almost same results with Neutrosophic MULTIMOORA method's ranking. So, we can say that the method gives effective results.

Neutrosophic sets use "indeterminacy" parameter. Therefore, Neutrosophic sets are more flexible and carry more information than fuzzy sets. MULTIMOORA method uses simple operators and gives effective results in solving MCDM problem. Therefore, using Neutrosophic MULTIMOORA method, which combines Neutrosophic sets and MULTIMOORA method, for solving AR goggles selection problem gives satisfactory results.

In the future studies, the same problem can be solved by different multi-objective methods and the results can be compared. Some new evaluation criteria and new alternatives can be added to the problem.

References

Biswas, P., Pramanik, S. and Giri, B.G. (2016), "TOPSIS method for multi-attribute group decision-making under single-valued neutrosophic environment", *Neural Comput and Applic*, Vol. 27 No. 3, pp. 727-737.

Brauers, W.K.M. and Zavadskas, E.K. (2011), "Multimoora optimization used to decide on a bank loan to buy property", *Technological and Economic Development of Economy*, Vol. 17 No. 1, pp. 174-188.

Caricato, P. and Grieco, A. (2017), "An application of industry 4.0 to the production of packaging films", *Procedia Manufacturing*, Vol. 11, pp. 949-956.

Horejsi, V.P. (2015), "Augmented reality system for virtual training of parts assembly", *Procedia Engineering*, Vol. 100, pp. 699-706.

Ivanov, D., Dolgui, A., Sokolov, B., Werner, F. and Ivanova, M. (2014), "A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0", *International Journal of Production Research*, Vol. 54 No. 2, pp. 386-402.

Jana, T.K., Bairagi, Paul, B.S., Sarkar, B. and Saha, J. (2013), "Dynamic schedule execution in an agent based holonic manufacturing systems", *Journal of Manufacturing Systems*, Vol. 32 No. 4, pp. 801-819.

Kans, M. and Ingwald, A. (2016), "Business model development towards service management 4.0", *Procedia CIRP*, Vol. 47, pp. 489-494.

Lee, Y. and Lee, C.H. (2018), "Augmented reality for personalized nanomedicines", *Biotechnology Advances*, Vol. 36 No. 1, pp. 335-343.

Liebrecht, C., Jacop, A., Kuhnle, A. and Lanza, G. (2017), "Multi-criteria evaluation of manufacturing systems 4.0 under uncertainty", *The 50th CIRP Conference on Manufacturing Systems*, Vol. 63, pp. 224-229.

Long, F., Zeiler, P. and Bertsche, B. (2016), "Modelling the production systems in industry 4.0 and their availability with high-level petri-nets", *IFAC-PapersOnLine*, Vol. 49 No. 12, pp. 145-150.

Mosterman, P.J. and Zander, J. (2016), "Industry 4.0 as a cyber-physical system study", *Software & System Modeling*, Vol. 15 No. 1, pp. 17-29.

Ojstersek, R. and Buchmeister, B. (2017), "Use of simulation software environment for the purpose of production optimization", *28th Daaam International Symposium on Intelligent Manufacturing and Automation*, pp. 1202-1207.

Pan, M., Sikorski, J., Kastner, C.A., Akyord, J., Mosbach, S., Lau, R. and Kraft, M. (2015), "Applying industry 4.0 to the Jurong Island Eco-industrial Park", *The Seventh International Conference on Applied Energy*, Vol. 75, pp. 1536-1541.

Pei, F., Tong, Y., He, F. and Li, D. (2017), "Research on design of the smart factory for forging enterprise in the industry 4.0 environment", *Mechanika*, Vol. 23 No. 1, pp. 146-152.

Saaty, T.L. (1980), *The Analytic Hierarchy Process*, McGraw-Hill, New York, NY.

Shamim, S., Cang, S., Yu, H. and Li, Y. (2017), "Examining the feasibilities of industry 4.0 for the hospitality sector with the lens of management practice", *Energies*, Vol. 10 No. 4, pp. 499-518.

Smarandache, F. (1998), *A Unifying Field in Logics. Neutrosophy: Neutrosophic Probability, Set and Logic*, American Research Press, Rehoboth.

Stanujkic, D., Zavadskas, E.K., Smarandache, F. and Brauers, W. (2017), "A neutrosophic extension of the MULTIMOORA method", *Informatica*, Vol. 28 No. 1, pp. 181-192.

Stoltz, M.H., Giannikas, V., McFarlane, D., Strachan, J., Um, J. and Srinivasan, R. (2017), "Augmented reality in warehouse operations: opportunities and barriers", *IFAC PapersOnline*, Vol. 50 No. 1, pp. 12979-12984.

Sung, M.T.K. (2017), "Industry 4.0: Korea perspective", *Technological Forecasting & Social Change*, Vol. 132 No. 6, pp. 40-45.

Tsai, C.H. and Huang, J.Y. (2018), "Augmented reality display based on user behavior", *Computer Standards & Interface*, Vol. 55 No. 1, pp. 171-181.

Turkan, Y., Radkowski, R., Karabulut, I.A., Behzadan, A.H. and Chen, A. (2017), "Mobile augmented reality for teaching structural analysis", *Advanced Engineering Informatics*, Vol. 34 No. 10, pp. 90-100.

Ye, J. (2014), "A multicriteria decision-making method using aggregation operators for simplified neutrosophic sets", *Journal of Intelligent and Fuzzy Systems*, Vol. 26 No. 5, pp. 2459-2466.

Yew, A.W.W., Ong, S.K. and Nee, A.Y.C. (2016), "Towards a griddable distributed manufacturing system with augmented reality interfaces", *Robotics and Computer-Integrated Manufacturing*, Vol. 39 No. 6, pp. 43-55.

Wang, H., Smarandache, F., Zhang, Y.Q. and Sunderraman, R. (2010), "Single valued neutrosophic sets", *Multispace and Multistructre*, Vol. 4 No. 26, pp. 410-413.

Zadeh, T.K.L. (1965), "Fuzzy sets", *Information Control*, Vol. 8 No. 3, pp. 338-353.

Zavadskas, E.K., Bausys, R., Juodagalviene, B. and Sapranaviciene, I.G. (2017), "Model for residential house element and material selection by neutrosophic MULTIMOORA method", *Engineering Application of Artificial Intelligence*, Vol. 64 No. 9, pp. 315-324.

Zhong, R.Y., Xu, X., Klotz, E. and Newman, S.T. (2017), "Intelligent manufacturing in the context of Industry 4.0: a review", *Engineering*, Vol. 3 No. 5, pp. 616-630.

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