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Evaluation and Selection of Products Based on the Quality Dimensions by Word of Mouth (Case Study: Brands of the Mobile Phone)

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Abstract: Today, mobile phones are at the center of many consumers' lives and a part of people's lives. Although this tool was considered a luxury initially, it has gradually become a necessary tool with the reduction of the price and the increase of its functions. Consumers choose specific models of mobile phones according to their needs. Mobile phones have quality features that are expressed in the form of quality dimensions. These dimensions are mostly expressed by word of mouth (WOM). In this research, first; we collected the opinions of 350 students about 4 brands of mobile phones based on Garvin's quality of dimensions, finally; the students' opinions about mobile phones were evaluated with integrated TOPSIS with interval-valued intuitionistic fuzzy numbers technique, and the priority of 4 phone brands was determined based on students' opinions.

Keywords: interval-valued intuitionistic fuzzy numbers (IVIFN) technique; mobile phone; Word-of-Mouth (WOM); Garvin's quality of dimensions

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1. Introduction

Today, consumers are more aware of the products or services they buy and consume. Before deciding to buy, they check the opinions of previous customers and do not just rely on product advertisements [1].

Product awareness increases with interpersonal communication because consumers often share opinions, news, and information with others and also discuss products, brands, and experiences with each other[2,3]. In marketing, these discussions are known as Word-of-Mouth (WOM) [3]. Word-of-mouth has been considered one of the most powerful forms of communication in the market today [4].

Word of mouth is a way of sharing ideas, beliefs, and experiences [5]. Word of mouth is a non-commercial, informal communication between consumers who discuss the use, performance, features, or ownership of a particular product or service [6,7].

Using word of mouth has increased among consumers before making a purchase decision [8]. A study by Bughin, Doogan, and Vetvik [9] found that 20 to 50 percent of all purchase decisions are due to word of mouth, generating more than twice as many sales as paid advertising. Consumers recognize WOM as an important source of information for making their purchasing decisions [10].

WOM is more important than other external sources of information [11]. Some studies have shown that consumers consider word of mouth as the most reliable source of information. Customers consider 90% of advertising to be non-credible while 90% of WOM is credible [12]. Consumers find the opinions of their peers more valid and reliable than marketers' messages [13]. WOM significantly influences consumers' decision-making processes [12].

The strength of purchaser reviews in influencing consumer choices is so prominent that many companies, such as Kia Motors, are now website hosting opinions on their websites to permit customers to speak about the quality of their products. Purchasers are more and more

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using WOM to find out about product quality [8]. People talk about quality. Everyone is concerned about the quality at least it seemed of goods and services consumed by them and the environment for life and work given to them [14]. Today consumers have become more inclined toward quality products [15]. Product quality is the product's ability to provide the needs and expectations of customers or even exceed the expectations of customers [16]. One of the more well-known frameworks for determining quality is that of David A. Garvin. Garvin believed that quality is multidimensional. The eight basic dimensions of quality according to Garvin are performance, features, reliability, conformity, durability, serviceability, aesthetics, and perceived quality [17].

Usually, people express their opinions verbally, such as excellent, good, etc. These verbal ideas are vague and do not express themselves exactly. In many phenomena where there is uncertainty, it is difficult to express certainty [18]. Zadeh solved these ambiguities to some extent by introducing fuzzy sets [18,19]. Fuzzy sets use numbers from zero to one to show how much each element belongs to the set which is called the degree of membership [20]. Classical fuzzy set theory has limitations because it doesn't provide enough information [21]. As a result, the theory of intuitionistic fuzzy sets (IFS) was introduced by Atanasov [22]. In this theory, Atanasov defined concepts such as non-membership degree and hesitation degree. Sometimes, it is not possible to specify information such as degree of membership and degree of non-membership with pseudo-exact values [21]. To solve this problem, Atanasov and Gargov further extended the intuitionistic fuzzy set and introduced the concept of interval-valued intuitionistic fuzzy set (IVIFS), and proposed the main algorithm of IVIFS [23]. IVIFS has received increasing attention among researchers and industrialists due to its ability to address the uncertainty and uncertainty of a real-world problem [24]. In IVIFS the membership function and non-membership function values are defined as intervals rather than exact numbers [25]. Therefore, this essential feature of interval-valued intuitionistic fuzzy numbers can provide a more accurate expression of the quality dimensions that are expressed by people.

Today, consumers are facing many challenges. One of these challenges is ‘over choice’. Consumers suffer from choice fatigue [26]. The presence of many products and multiple criteria makes it difficult to decide to choose the most suitable product. In such a situation, the use of decision-making methods and systems is very effective [27]. Multi-criteria decision-making (MCDM) ranks the alternatives or chooses the most appropriate alternatives from many alternatives, by looking at different criteria simultaneously [28]. MCDM is a powerful mathematical tool for modeling multi-criteria problems that are carried out by experts in the field of operations research [29]. With MCDM methods, it is possible to evaluate alternatives and make appropriate decisions according to different criteria [30].

The daily use of mobile phones has made it difficult for buyers or mobile phone users to make decisions [31]. Today, smartphones play an important role in personal and professional life [32] and have become one of the most essential electronic tools [33]. The widespread use of smartphones has caused companies to produce different and new models of mobile phones [34]. Every day people come across a vast quantity of better and more advanced capabilities in smartphones. This makes it difficult for users to choose an ideal smartphone [35].

The purpose of this article is to evaluate the quality dimensions of mobile phones by word of mouth. In this research, a mobile store wants to offer products that are good in terms of quality. By choosing Garvin's quality dimensions as a criterion to evaluate the quality of the product and the existence of different brands, the evaluation, and selection of a quality brand becomes a multiple-decision problem. Since people express their opinions verbally and there is no certainty in these opinions, in this situation, the use of interval-valued intuitive fuzzy numbers for verbal opinions can remove these ambiguities. Therefore, the use of multi-criteria decision-making methods with interval-valued intuitionistic fuzzy numbers can help to examine and choose a brand whose quality is famous among people.

2. Literature review

Smartphones are the most demanded electronic devices in the world. Every year, lots of new smartphones come out from different companies with different features [36]. For this reason, choosing a suitable model or brand from among the types and brands presented is very complicated [37]. In the literature, there are many studies on choosing a smartphone that has used different methods and criteria.

Goswami and Behera [36] selected the best smartphone with the help of the preference ranking organization method for enrichment of evaluations (PROMETHEE). Also, the fuzzy Analytic hierarchy process (FAHP) based on trapezoidal fuzzy numbers was used to evaluate the criteria weights.

In other research, Goswami and Mitra [33] used two MCDM tools i.e. Complex Proportional Assessment (COPRAS) and Additive Ratio Assessment (ARAS) to choose the fine mobile version among numerous options available on the market.

In research by S. Kumar et al [38], the Integrated Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Multi-Objective Optimization based on of Ratio Analysis (MOORA) approach is proposed for prioritizing five smartphone brands.

R. Kumar et al [39], evaluated twelve mobiles using the Simple Additive Weighting (SAW) and Weighted Product Method (WPM) techniques.

Kumar & Parimala [32], evaluated and recommended the best smartphones by combining Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods.

IVIF-ARAS and IVIF-TOPSIS were used by Rani et al [40] to evaluate different smartphone alternatives based on customer benefits.

Aggarwal et al [35], evaluated smartphones using the MCDM approach with the EDAS (Evaluation Based on Distance from Average Solution) technique. In this article, hardware, economic, and physical features are used to choose the most suitable phone.

In research by Srivastava et al [41] Analytic Hierarchy Process (AHP) method was used to compare 4 smartphones of a company.

Büyüközkan and Güleryüz [42], used Intuitionistic Fuzzy TOPSIS with Group decision-making (GDM) to discover the most appropriate smartphone in a Turkish company.

The purpose of Belbag et al [43] was to measure consumers' evaluation of purchasing smartphones by applying the Fuzzy ELECTRE I method.

To determine the best smartphone, Yildiz and Ergul [34] applied Analytic Network Process (ANP) and Generalized Choquet Integral (GCI).

Trivedi et al [44], evaluated the smartphone using the fuzzy Analytic hierarchy process (FAHP) and fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS).

Akyene [31], used Entropy and TOPSIS to help the customer to buy the best mobile phone. He evaluated 10 mobile phones with 12 criteria.

The aim of Işıklar and Büyüközkan [45] was to propose AHP and TOPSIS to evaluate the mobile phone options according to the users' preferences order. These studies are given in Table 1.

Table 1. (MCDM) techniques and criteria used in mobile phone selection research

	Author	MCDM Method	criteria
1	[36]	integrating fuzzy-AHP and PROMETHEE	Price/ Storage capacity /RAM /Battery Screen size/ Camera/ Clock speed
2	[33]	AHP-COPRAS and AHP-ARAS	Price/ Internal Storage/ RAM/ Brand
3	[38]	TOPSIS and MOORA	Cost/ Performance/ Camera/ Screen Size/ Battery
4	[39]	SAW and WPM	Cost/ Weight/ RAM/ Screen pixels/ Screen size/ Storage capacity

5	[32]	hybrid MCDM/AHP and TOPSIS	Battery/ Speed/ Display/ Camera
6	[40]	IVIF-ARAS and IVIF-TOPSIS	Price/ Battery Life/ Operating System/ Storage/ Network
7	[35]	EDAS	Camera Quality/ Internal storage/ Battery backup/ Ram/ Processor/ Screen Performance/ Non-favorable/ Weight/ cost
8	[41]	AHP	Operating System/ Memory/ Display/ Touchscreen/ Data Speed/ Battery Life/ Camera/ Processor/ Speaker
9	[42]	Intuitionistic Fuzzy TOPSIS	Durability/ Battery life/ Changeable parts/Dimensions/ Memory capacity/ Processor speed/ Internet connection speed (4G/5G)/ Camera specifications/ Operation system easiness/ Variety of applications/ Brand choice/ Prestige/ Fashionable style, Aesthetics/ Personal information and media security/ Price/ Warranty /Service Availability
10	[43]	Fuzzy ELECTRE I Method	Price/ Screen size/ Weight/ Ease of use/ Resolution/ Design/ Durability
11	[34]	two-phased MCDM/ANP/GCI	Durability/ Screen size/ Thickness/ Weight/ Battery power/ Built-in memory/ Camera/ Operating system/ Pixel density/ Processor type/ RAM/ Standby time/ Talk time/ Aesthetic/ Brand/ Cost/ Ease of use
12	[44]	hybrid MCDM/ AHP/ TOPSIS	Brand value/ Camera quality/ Battery life/ Price/ User friendliness of operating system/ Sensitivity of touch panel
13	[31]	Entropy and TOPSIS	Dimensions/ Weight/ Screen Size/ Memory/ RAM/ Speed/ Blue Tooth/ Camera/ OS operating system/ CPU/ Battery/ Price
14	[45]	AHP and TOPSIS	Basic requirements/ Physical characteristics/ Technical features /Functionality/ Brand choice/ Customer excitement

In the literature, it has been found that certain criteria such as appearance criteria and hardware capabilities are effective in choosing a mobile phone. No study focuses extensively on the qualitative dimensions of smartphone evaluation. In this research; the qualitative dimensions mentioned by Garvin [17] were used as criteria for choosing a mobile phone. In the following, Garvin's quality dimensions are presented according to what is stated in the academic literature.

2.1. Quality of dimensions

Quality is a complex and multidimensional concept. In general, product quality is the capacity of a product to meet or exceed customer expectations. Customer perception of product and service excellence is an operational definition of quality. [46].

Various definitions and dimensions have been stated for quality. One of the most reliable definitions of quality was provided by David Garvin of Harvard Business School (1984) [47]. According to Garvin's theory, there are eight critical dimensions of quality: Performance, Features, Reliability, Conformance, Durability, Serviceability, Aesthetics, and Perceived Quality [17].

2.1.1. Performance

Performance refers to the operational characteristics of a product [48]. This dimension includes measurable characteristics, for example, speed, ease, and convenience of use. Since they contain quantifiable properties, brands can be ranked based on their Performance [49].

2.1.2. Features

Another part of the Performance is Features. Features are like “bells and whistles” of products and services. Features are like extra things that come with products and services. These features are placed next to the main benefits and complement them. These features complement the main benefits and improve performance and quality [17,48].

2.1.3. Reliability

Reliability means how likely the product is to work perfectly for a while [50]. When we talk about reliability, we look at a few things: how long it takes for it to break down the first time, how long it lasts before breaking down again, and how often it breaks down in a set amount of time [51].

2.1.4. Conformance

The degree of compliance of the product's performance characteristics with the predetermined standards is called Conformance [51]. This is a kind of "promise" that the product must keep. The products that have this dimension of quality are under the standard [48].

2.1.5. Durability

Durability means how long a product lasts. Durability has two technical and economic dimensions. How well it works technically and how much it costs. From a technical point of view, Durability means how much you can use a product before it stops working. From an economic point of view, when deciding whether to buy a new product, people should consider how much money it will cost to fix old products versus how much it would cost to buy a newer, more reliable one [17,49].

2.1.6. Serviceability

Serviceability means how easy it is to fix something. In addition to how easy it is to fix something, it's also important that the person doing the repairs is fast, kind, and skilled. Things that can be fixed easily are better quality than things that can't be fixed [48].

2.1.7. Aesthetics

Aesthetics means how something looks, feels, sounds, tastes, or smells. It varies from person to person and depends on their preferences. The aesthetics dimension is about how something looks and helps a business be recognized [17].

2.1.8. Perceived Quality

Buyers may not know everything about a product or service. So, they use different methods to compare. When customers are trying to decide if something is good or not, they often rely on the name of the brand, the ads they have seen, and the pictures they have looked at. These things are really important for making people think something is high-quality [17]. The Perceived Quality of a product is mostly based on things like advertisements, the brand name, and past experiences, rather than the product itself [51].

3. Methodology

Biswas and Kumar [52] investigated an integrated TOPSIS method to solve decision-making problems with IVIFS information. In this study, this method has been used to choose a mobile phone.

This section provides an overview of the methodology to be employed in the research for solving the mobile phone selection problem. To begin with, fundamental information around IVIFS and the possibility degree measures for comparing two IVIF numbers (IVIFNs) are displayed, and after that, the computational steps of IVIF TOPSIS are clarified.

3.1. Preliminaries

Definition 1. *An IVIF set* $\tilde{A}$ *is defined by K.Atanassov [23] as:*

$$\tilde{A} = \{\langle x_i, [\mu_{\tilde{A}}^L(x_i), \mu_{\tilde{A}}^U(x_i)], [v_{\tilde{A}}^L(x_i), v_{\tilde{A}}^U(x_i)]\rangle | x_i \in X\}$$

Where $[\mu_{\tilde{A}}^L(x_i), \mu_{\tilde{A}}^U(x_i)]$ *and* $[v_{\tilde{A}}^L(x_i), v_{\tilde{A}}^U(x_i)]$ *denote the intervals of membership and nonmember ship degrees of an element* $x_i \in \tilde{A}$ *satisfying:*
$0 \leq \mu_{\tilde{A}}^U(x_i) + v_{\tilde{A}}^U(x_i) \leq 1, 0 \leq v_{\tilde{A}}^L(x_i) \leq v_{\tilde{A}}^U(x_i) \leq 1$ *and* $\mu_{\tilde{A}}^L(x_i) \leq \mu_{\tilde{A}}^U(x_i)$.

Definition 2. *The hesitation degree of an interval-valued intuitionistic fuzzy number* x_i *to set* $\tilde{A}$ *is defined as:*

$$\pi_{\tilde{A}} = [1 - \mu_{\tilde{A}}^U(x_i) - v_{\tilde{A}}^U(x_i), 1 - \mu_{\tilde{A}}^L(x_i) - v_{\tilde{A}}^L(x_i)]$$

If $\mu_{\tilde{A}}^L(x_i) = \mu_{\tilde{A}}^U(x_i)$ *and* $v_{\tilde{A}}^L(x_i) = v_{\tilde{A}}^U(x_i)$ *then* $\tilde{A}$ *is reduced to an IFS.*

Definition 3. *Assume that* $A = \{\langle x, \mu_A(x), v_A(x)\rangle : x \in X\}$ *be an IVIFS. Then, the ordered pair* $\langle x, \mu_A(x), v_A(x)\rangle$*, for each* $x \in X$ *is called an IVIFN.*
For ease of computation, let $a_j = \langle [a_j^l, a_j^u], [b_j^l, b_j^u]\rangle$ *denote an IVIFN. The basic operations for combining the two IVIFNs are provided in this definition.*

Definition 4. *Suppose that* $\alpha_i = \langle [a_i^l, a_i^u], [b_i^l, b_i^u]\rangle = \langle a_i, b_i\rangle$ $(i = 1,2)$ *be two IVIFNs and* $\lambda > 0$*. Then,*

$$\alpha_1 + \alpha_2 = \langle [a_1^l + a_2^l - a_1^l a_2^l, a_1^u + a_2^u - a_1^u a_2^u], [b_1^l b_2^l, b_1^u b_2^u]\rangle$$

$$\lambda\alpha_1 = \langle [1 - (1 - a_1^l)^\lambda, 1 - (1 - a_1^u)^\lambda], [(b_1^l)^\lambda, (b_1^u)^\lambda]\rangle$$

Definition 5. *For two interval numbers* $a = [a^l, a^u]$ *and* $b = [b^l, b^u]$ *having interval lengths* $L(a) = a^u - a^l$ *and* $L(b) = b^u - b^l$ *respectively, the possibility degree of* $a \geq b$ *is defined as* $p(a \geq b) = \min\left\{\max\left\{\frac{a^u - b^l}{L(a) + L(b)}, 0\right\}, 1\right\}$

Definition 6. *Assume that* $\alpha_i = \langle [a_i^l, a_i^u], [b_i^l, b_i^u]\rangle = \langle a_i, b_i\rangle$ $(i = 1,2)$ *be two IVIFNs and* $L(a_i) = a_i^u - a_i^l$ *,* $L(b_i) = b_i^u - b_i^l$ *be their interval lengths, then the degree of possibility* $p(\alpha_1 \geq \alpha_2)$ *of* $\alpha_1 \geq \alpha_2$ *is defined as*

$$p(\alpha_1 \geq \alpha_2) = \min\left\{\max\left\{\frac{a_1^u - a_2^l + b_2^u - b_2^l}{L(a_1) + L(a_2) + L(b_1) + L(b_2)}, 0\right\}, 1\right\}$$

3.2. TOPSIS method to solve MCDM problems with IVIFS information

TOPSIS technique for solving the MCDM problems in IVIF settings follows several steps and these steps are described below:

Step 1: By Definition 6, the additive reciprocal fuzzy preference relation
$P = \left(p(\tau_i \geq \tau_j)\right)_{n \times n} = (p_{ij})_{n \times n}$ from IVIF criteria weight vector
$\tau = (\tau_1, \tau_2, \cdots, \tau_n) = (\tau_j)_{1 \times n}$ is generated.

The crisp weight w_j for the IVIFN weight τ_j $(j = 1,2,\cdots,n)$ may be obtained by the optimal degree. [53] proposed the optimal degree formula to estimate crisp criteria weights or performance values of alternatives using the possibility degree matrix P as

$$\xi_i = \frac{1}{m(m-1)}\left(\sum_{k=1}^{n} p_{ik} + \frac{m}{2} - 1\right) \text{ for } i = 1,2,\cdots,m$$

Thus, the crisp criteria weight vector $w = (w_1, w_2, \cdots, w_n)$ with $w_j \in [0,1]$ and $\sum_{j=1}^{n} w_j = 1$.

Step 2:

For an IVIF decision matrix $D = (d_{ij})_{m\times n} = \langle[\alpha_{ij}^l, \alpha_{ij}^u], [\beta_{ij}^l, \beta_{ij}^u], [\gamma_{ij}^l, \gamma_{ij}^u]\rangle_{m\times n}$ the weighted IVIF decision matrix is obtained using Definition 4 as $D_w = (d_{ij}^w)_{m\times n}$, where $d_{ij}^w = w_j d_{ij}$, $(i = 1,2,\cdots,m;\ j = 1,2,\cdots,n)$.

Let $D_w = (d_{ij}^w)_{m\times n} = (\langle[\mu_{ij}^l, \mu_{ij}^u], [v_{ij}^l, v_{ij}^u], [\pi_{ij}^l, \pi_{ij}^u]\rangle)_{m\times n}$ where π_{ij}^l=1-$\mu_{ij}^u - v_{ij}^u$ and π_{ij}^u=1-$\mu_{ij}^l - v_{ij}^l$

Step 3:

The intervals of relative closeness coefficients of m alternatives $A_i = (i = 1,2,\cdots,m)$ is given by $C_i = [C_i^l, C_i^u]$.

$$C_i^u = \frac{\sum_{j=1}^{r}(1-v_{ij}^l) + \sum_{j=r+1}^{n}(1-\mu_{ij}^l)}{\sum_{j=1}^{r}(2-\mu_{ij}^u-v_{ij}^l) + \sum_{j=r+1}^{n}(2-\mu_{ij}^l-v_{ij}^u)} \quad (1)$$

$$C_i^l = \frac{\sum_{j=1}^{r}(1-v_{ij}^u) + \sum_{j=r+1}^{n}(1-\mu_{ij}^u)}{\sum_{j=1}^{r}(2-\mu_{ij}^l-v_{ij}^u) + \sum_{j=r+1}^{n}(2-\mu_{ij}^u-v_{ij}^l)} \quad (2)$$

$\{X_1, X_2, \cdots, X_r\}$ and $\{X_{r+1}, X_{r+2}, \cdots, X_n\}$ represent sets of benefit criteria and cost criteria.

Step 4:

The possibility degree matrix for pairwise comparison of intervals of relative closeness coefficients C_i of alternatives $A_i = (i = 1,2,\cdots,m)$ is obtained as $P = (p_{ik})_{m\times m}$

$$p_{ik} = p(C_i \geq C_k) = \min\left\{\max\left\{\frac{C_i^u - C_k^l}{L(C_i)+L(C_k)}, 0\right\}, 1\right\} \quad (3)$$

Where $C_i = [C_i^l, C_i^u]$ and $C_k = [C_k^l, C_k^u]$, $L(C_i) = C_i^u - C_i^l$ and $L(C_k) = C_k^u - C_k^l$.

Step 5:

The performance scores as optimal degrees ξ_i for alternatives $A_i = (i = 1,2,\cdots,m)$ are evaluated

$$\xi_i = \frac{1}{m(m-1)}\left(\sum_{k=1}^{n} p_{ik} + \frac{m}{2} - 1\right) \quad (4)$$

Step 6:

The alternatives $A_i = (i = 1,2,\cdots,m)$ are ranked in decreasing order of the optimal degrees ξ_i .

4. Case study

Nowadays, the smartphone has gotten to be a fundamental portion of cutting-edge life [54]. According to Statista, the use of smartphones in Iran in 2021 was about 57.19 million [55]. According to the statistics of smartphone penetration rates in the world by 2021, Iran ranks 8th with 67.3% [56]. It is predicted that the amount of smartphone usage in Iran will reach 78.58 million in 2025 [57].

Due to the increasing use of smartphones, a mobile store plans to offer phones that are known among people in terms of quality.

This research has been done in two phases. The first phase was a survey of experts to determine the importance of Garvin's quality dimensions in mobile phones. A committee of experts consisting of seven experts is formed with members EX1, EX2 … EX7. These experts work in companies that are responsible for the warranty of mobile phone brands. The warranty of mobile phones in Iran is different from other countries. In most countries of the world, the phone manufacturer directly guarantees its mobile phones, but in Iran, except for limited companies that have official representatives, other phone manufacturers are guaranteed by a secondary agency. These experts describe the importance of the eight criteria by following linguistic terms: Very important (VI), Important (I), Moderate important (MI), Unimportant (UI), and Very unimportant (VUI).

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Table 2 shows linguistic variables used for the importance of criteria and their relevant IVIF numbers.

Table2. Linguistic terms for the relative importance of criteria

Linguistic terms	Interval-valued intuitionistic fuzzy numbers
Very important (VI)	$< [0.80,0.90], [0.05,0.10] >$
Important (I)	$< [0.60,0.75], [0.10,0.20] >$
Moderate Importance (MI)	$< [0.30,0.50], [0.25,0.45] >$
Unimportant (UI)	$< [0.20,0.35], [0.45,0.60] >$
Very unimportant (VUI)	$< [0.00,0.10], [0.70,0.90] >$

After collecting the opinion of the experts and converting it to interval-valued intuitionistic fuzzy numbers, the average of these opinions was calculated. The opinion of the experts and their averages are shown in Table 3.

Table3. experts' opinion of the importance of criteria and their average

	Ex1	Ex2	…	Ex7	mean
Performance	VI	VI		I	$< [0.75,0.86], [0.06,0.13] >$
Features	VI	I		VI	$< [0.68,0.82], [0.08,0.16] >$
Reliability	I	MI		I	$< [0.39,0.57], [0.22,0.38] >$
Conformance	MI	UI		VUI	$< [0.18,0.34], [0.43,0.62] >$
Durability	I	MI		MI	$< [0.42,0.60], [0.18,0.34] >$
Serviceability	VI	I		VI	$< [0.62,0.77], [0.11,0.21] >$
Aesthetics	VUI	UI		VUI	$< [0.35,0.52], [0.26,0.43] >$
Perceived Quality	I	MI		I	$< [0.52,0.69], [0.14,0.26] >$

So, in the first phase, the importance and weight of the criteria were determined.

The second phase was a survey of customers. The target community is those who can evaluate the quality of phone brands. The statistical population of this research is the students of the Shahrood University of Technology.

The second phase of the research deals with students' evaluation of the quality dimensions of 4 prominent smartphone brands in the country (Brand 1, Brand 2, Brand 3, Brand 4). Based on Cochran's formula [58], the sample size was calculated to be 350.

The questionnaire included the evaluation of the quality dimensions of the smartphone through word-of-mouth advertising. The participants expressed their evaluation of the quality dimensions of 4 smartphone brands in terms of language as follows: Extremely Bad (EB), Very Bad (VB), Bad (B), Moderate Bad (MB), Fair (F), Moderate Good (MG), Good (G), Very Good (VG), Extremely Good (EG). Table 4, shows some of these data.

Table 4. Students' evaluation of the quality dimensions of 4 mobile phone brands

	Performance				Features				Reliability				Conformance			
	B1	B2	B3	B4	B1	B2	B3	B4	B1	B2	B3	B4	B1	B2	B3	B4
Student 1	VG	VG	EG	G	EG	VG	EG	MB	VG	G	EG	MG	VG	MG	EG	MB
Student 2	G	G	VG	MG	VG	G	EG	F	VG	MG	VG	MB	VG	MB	EG	EB
Student 3	F	G	VG	F	VG	MG	VG	MB	G	F	G	B	G	B	G	VB
Student 4	MG	MG	VG	B	G	MB	MG	F	MG	B	G	EB	MG	VG	F	EB
Student 5	VG	VG	F	EB	G	EB	MG	VG	VG	MG	G	G	VG	MG	VG	VB
Student 6	EG	MG	VG	VG	G	MB	MG	MG	VG	MG	VG	MG	VG	G	EG	B
Student 7	G	F	MG	VB	VG	MG	VG	MB	MG	VG	F	EB	EG	VG	EG	MG
Student 8	VG	MB	G	MB	F	VG	F	G	G	VG	F	VG	G	G	G	MG
Student 9	VG	EG	MB	VG	G	G	VG	B	VG	VG	EG	MB	VG	B	MG	G
Student 10	VG	MG	VG	G	EG	MG	VG	VG	VG	G	EG	VB	VG	EG	MG	VG
Student 11	EG	MG	EG	MG	VG	F	VG	F	VG	MG	EG	G	VG	VG	EG	VG

Student 12	F	VG	MG	VG	VB	MG	F	MG	G	B	G	B	VG	MG	VG	MB
Student 13	G	G	VG	B	MG	MG	G	VB	MG	F	MG	VB	G	VG	F	G
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Student349	VG	MG	EG	MB	G	VG	EG	MB	MG	F	MG	VB	EG	VG	EG	MB
Student350	VG	VG	EG	G	EG	VG	EG	MG	VG	G	EG	MG	EG	G	EG	MB
	Durability				Serviceability				Aesthetics				Perceived Quality			
	B1	**B2**	**B3**	**B4**	**B1**	**B2**	**B3**	**B4**	**B1**	**B2**	**B3**	**B4**	**B1**	**B2**	**B3**	**B4**
Student 1	EG	VG	EG	MG	VG	VG	EG	EB	EG	MG	EG	MG	VG	VG	EG	MB
Student 2	VG	G	EG	VB	G	VG	EG	MB	VG	MG	VG	MG	G	G	EG	MG
Student 3	G	G	VG	B	MG	G	G	EB	VG	F	VG	F	G	G	VG	B
Student 4	G	MG	VG	VB	MG	F	MG	VB	VG	MB	G	MB	MG	MG	G	VB
Student 5	G	B	G	B	VG	B	G	MB	G	MB	MG	F	G	F	G	B
Student 6	MG	B	G	EB	VG	MG	VG	G	F	G	VG	F	VG	MG	VG	MB
Student 7	VG	VB	MG	F	MG	G	VG	F	G	EG	MG	VG	G	EG	VG	EG
Student 8	EG	MG	EG	MG	F	VG	MG	VG	G	MG	EG	MG	EG	MG	VG	VG
Student 9	VG	MG	VG	F	G	MB	MG	F	MG	MG	G	VB	MG	G	EG	VG
Student 10	EG	G	EG	MB	VG	MG	VG	MB	VG	MG	EG	MB	MG	F	MG	VB
Student 11	EG	G	EG	MB	VG	G	EG	B	VG	B	MG	G	G	VG	EG	MB
Student 12	VG	MG	VG	VB	G	G	G	MG	G	G	VG	B	VG	F	VG	F
Student 13	VG	F	VG	F	VG	MG	VG	G	EG	MG	EG	MG	G	G	VG	B
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Student349	VG	G	VG	MG	VG	MB	VG	F	VG	MG	EG	G	MG	F	G	EB
Student350	EG	EG	EG	F	VG	VG	EG	VG	EG	VG	EG	VG	F	F	EG	F

This study provides a nine-point rating scale and modifies the linguistic descriptions of each term as provided in Table 5.

Table 5. Linguistic terms for the rating of alternatives.

Linguistic terms	Interval-valued intuitionistic fuzzy numbers
Extremely Bad (EB)	$<[0.02,0.05],[0.90,0.95]>$
Very Bad (VB)	$<[0.10,0.15],[0.70,0.75]>$
Bad (B)	$<[0.25,0.30],[0.55,0.60]>$
Moderately Bad (MB)	$<[0.40,0.45],[0.45,0.50]>$
Fair(F)	$<[0.50,0.55],[0.35,0.40]>$
Moderately Good (MG)	$<[0.60,0.65],[0.25,0.30]>$
Good (G)	$<[0.70,0.75],[0.15,0.20]>$
Very Good (VG)	$<[0.80,0.85],[0.05,0.10]>$
Extremely Good (EG)	$<[0.90,0.95],[0.02,0.05]>$

Using Table 5, the linguistic terms of Table 4 are converted into Interval-valued intuitionistic fuzzy numbers. The averages of all 8 criteria for 4 phone models are obtained by definition 4. Therefore, interval-valued intuitionistic fuzzy matrix (4×8) will be as follows:

IVIF decision matrix

	Performance	Features	Reliability	Conformance
Brand1	$<[0.70,0.75],[0.13,0.19]>$	$<[0.84,0.89],[0.04,0.09]>$	$<[0.75,0.80],[0.09,0.14]>$	$<[0.78,0.84],[0.07,0.12]>$
Brand2	$<[0.73,0.78],[0.11,0.16]>$	$<[0.69,0.74],[0.13,0.20]>$	$<[0.58,0.63],[0.26,0.31]>$	$<[0.60,0.65],[0.22,0.28]>$
Brand3	$<[0.85,0.90],[0.03,0.08]>$	$<[0.85,0.91],[0.04,0.08]>$	$<[0.82,0.88],[0.05,0.10]>$	$<[0.83,0.89],[0.05,0.10]>$
Brand4	$<[0.58,0.63],[0.26,0.31]>$	$<[0.49,0.54],[0.36,0.41]>$	$<[0.44,0.50],[0.38,0.44]>$	$<[0.25,0.30],[0.59,0.64]>$
	Durability	Serviceability	Aesthetics	Perceived Quality
Brand1	$<[0.82,0.88],[0.05,0.10]>$	$<[0.71,0.77],[0.12,0.18]>$	$<[0.85,0.90],[0.03,0.08]>$	$<[0.76,0.83],[0.09,0.14]>$
Brand2	$<[0.76,0.83],[0.06,0.14]>$	$<[0.74,0.79],[009,0.15]>$	$<[0.57,0.62],[0.27,0.32]>$	$<[0.76,0.83],[0.09,0.14]>$
Brand3	$<[0.78,0.92],[0.03,0.07]>$	$<[0.84,0.90],[0.05,0.09]>$	$<[0.84,0.89],[0.04,0.09]>$	$<[0.86,0.91],[0.04,0.08]>$
Brand4	$<[0.34,0.40],[0.47,0.53]>$	$<[0.38,0.44],[0.40,0.48]>$	$<[0.57,0.62],[0.27,0.32]>$	$<[0.34,0.40],[0.49,0.54]>$

After obtaining the IVIF decision matrix, the steps of the integrated TOPSIS method can be implemented.

Step 1

According to Table 3, the IVIF criteria weight vector is

$\tau = (\tau_1, \tau_2, \cdots, \tau_8) = (< [0.75,0.86], [0.06,0.13] >, \cdots, < [0.52,0.69], [0.14,0.26] >)$.

Using Definition 6, the possibility degree matrix obtained by pairwise comparison of criteria is

$$P = \left(p(\tau_i \geq \tau_j)\right)_{8\times 8} = \begin{pmatrix} 0.500 & 0.708 & 1.000 & 1.000 & 1.000 & 0.911 & 1.000 & 1.000 \\ 0.292 & 0.500 & 1.000 & 1.000 & 1.000 & 0.706 & 1.000 & 0.950 \\ 0.000 & 0.000 & 0.500 & 1.000 & 0.398 & 0.000 & 0.639 & 0.140 \\ 0.000 & 0.000 & 0.000 & 0.500 & 0.000 & 0.000 & 0.000 & 0.000 \\ 0.000 & 0.000 & 0.602 & 1.000 & 0.500 & 0.016 & 0.735 & 0.256 \\ 0.089 & 0.294 & 1.000 & 1.000 & 0.984 & 0.500 & 1.000 & 0.743 \\ 0.000 & 0.000 & 0.361 & 1.000 & 0.265 & 0.000 & 0.500 & 0.003 \\ 0.000 & 0.050 & 0.860 & 1.000 & 0.744 & 0.257 & 0.997 & 0.500 \end{pmatrix}$$

By $\xi_i = \frac{1}{m(m-1)}\left(\sum_{k=1}^{n} p_{ik} + \frac{m}{2} - 1\right)$ for $i = 1,2, \cdots, m$ the crisp criteria weight vector becomes

$\boldsymbol{w} = (\boldsymbol{w_1}, \boldsymbol{w_2}, \cdots, \boldsymbol{w_8}) = (\mathbf{0.181}, \mathbf{0.169}, \mathbf{0.101}, \mathbf{0.063}, \mathbf{0.109}, \mathbf{0.154}, \mathbf{0.092}, \mathbf{0.132})$

Step 2

Using Definition 4, the weighted IVIF decision matrix is obtained as

$$D_w = \left(d_{ij}^w\right)_{m\times n} = w_j d_{ij}$$

Weighted IVIF decision matrix

	Performance	Features	Reliability	Conformance
Brand1	$< [0.20,0.22], [0.69,0.74] >$	$< [0.26,0.31], [0.59,0.66] >$	$< [0.13,0.15], [0.78,0.82] >$	$< [0.09,0.11], [0.85,0.88] >$
Brand2	$< [0.21,0.24], [0.67,0.72] >$	$< [0.18,0.21], [0.71,0.76] >$	$< [0.08,0.10], [0.87,0.89] >$	$< [0.06,0.06], [0.91,0.92] >$
Brand3	$< [0.29,0.34], [0.54,0.63] >$	$< [0.27,0.33], [0.58,0.66] >$	$< [0.16,0.19], [0.74,0.79] >$	$< [0.10,0.13], [0.83,0.87] >$
Brand4	$< [0.14,0.16], [0.78,0.81] >$	$< [0.11,0.12], [0.84,0.86] >$	$< [0.06,0.07], [0.91,0.92] >$	$< [0.02,0.02], [0.97,0.97] >$
	Durability	**Serviceability**	**Aesthetics**	**Perceived Quality**
Brand1	$< [0.17,0.21], [0.73,0.78] >$	$< [0.17,0.20], [0.72,0.77] >$	$< [0.16,0.19], [0.73,0.79] >$	$< [0.17,0.21], [0.73,0.77] >$
Brand2	$< [0.15,0.17], [0.77,0.81] >$	$< [0.19,0.22], [0.69,0.75] >$	$< [0.07,0.09], [0.89,0.90] >$	$< [0.17,0.21], [0.73,0.77] >$
Brand3	$< [0.20,0.24], [0.68,0.74] >$	$< [0.24,0.30], [0.63,0.70] >$	$< [0.15,0.19], [0.75,0.80] >$	$< [0.23,0.28], [0.64,0.71] >$
Brand4	$< [0.04,0.05], [0.92,0.93] >$	$< [0.07,0.08], [0.87,0.89] >$	$< [0.07,0.09], [0.89,0.90] >$	$< [0.05,0.06], [0.91,0.92] >$

Step 3

Using Eqs. (1) and (2) The intervals of relative closeness coefficients of alternatives are obtained as

$$C_1 = [0.212,0.255]$$
$$C_2 = [0.176,0.208]$$
$$C_3 = [0.249,0.302]$$
$$C_4 = [0.096,0.111]$$

Step 4

Using Eq. (3), the possibility degree matrix for the pairwise comparison of alternatives is

$$\boldsymbol{P} = \left(\boldsymbol{p_{ij}}\right)_{4\times 4} = \begin{pmatrix} \mathbf{0.500} & \mathbf{1.000} & \mathbf{0.059} & \mathbf{1.000} \\ \mathbf{0.000} & \mathbf{0.500} & \mathbf{0.000} & \mathbf{1.000} \\ \mathbf{0.941} & \mathbf{1.000} & \mathbf{0.500} & \mathbf{1.000} \\ \mathbf{0.000} & \mathbf{0.000} & \mathbf{0.000} & \mathbf{0.500} \end{pmatrix}$$

Step 5

Using Eq. (4), the performance scores of alternatives $A_i = (i = 1,2, \cdots, m)$ as optimal degrees ξ_i are estimated as

$$\boldsymbol{\xi_1} = \mathbf{0.297}$$
$$\boldsymbol{\xi_2} = \mathbf{0.208}$$
$$\boldsymbol{\xi_3} = \mathbf{0.370}$$
$$\boldsymbol{\xi_4} = \mathbf{0.125}$$

Step 6

Thus, the ranking of alternatives becomes

$$\boldsymbol{Brand_3} > \boldsymbol{Brand_1} > \boldsymbol{Brand_2} > \boldsymbol{Brand_4}$$

5. Conclusion

Lots of people use mobile phones every day and new technology is appearing quickly. This is making lots of companies create different kinds of mobile phones to sell. Choosing the right mobile phone can be hard because there are many criteria to consider.

The goal of this work was to include Garvin's quality dimensions to identify the most suitable smartphone from the users' perspective. Since people are influenced by word-of-mouth advertising and it is effective in their decisions, this source of information was used to evaluate the quality dimensions of the smartphone and its selection.

To choose the best smartphone option, we need to use MCDM techniques because it is difficult to evaluate all options with different criteria alone.

In this research, an integrated TOPSIS method was used to solve MCDM problems with IVIF information.

According to Table 3, experts who work in smartphone warranty agencies, believe that Performance, Features, and Serviceability are very important among Garvin's quality dimensions and they assigned a high weight to them.

The students influenced by word-of-mouth advertising, have evaluated the quality dimensions of 4 brands of smartphones. According to the IVIF matrix which is the mean of students' ideas, Brand 3 is higher in all dimensions and only in Aesthetics and Durability Brand 1, has been evaluated better than Brand 3. Brand 2 is evaluated better than Brand 1 in Performance. Also, Brand 2 is equal to Brand 1 in Perceived Quality. Brand 4 is lower than other brands in all dimensions, but it is equal to Brand 2 in Aesthetics.

Considering the opinion of experts and students shown in the weighted IVIF matrix, it can be concluded that Brand 3 was superior in all aspects of quality, but the Aesthetics of Brand 1 was ranked higher than Brand 3. Brand 1 has been evaluated as higher than Brand 2 and Brand 4 in many dimensions, but in Perceived Quality Brand 2 is equal to Brand 1, and also Brand 1 in Performance and Serviceability has been evaluated as lower than Brand 2.

Brand 4 is lower than other brands in all dimensions and is equal to Brand 2 only in Aesthetics.

Finally, according to the opinion of experts and students, the mobile store can recommend brand 3 to customers because it has higher quality in many aspects. Of course, if only Aesthetics is concerned, Brand 1 is a good suggestion. After Brand 1, Brand 3 can be a good option, but in terms of Performance and Serviceability, Brand 2 has been able to attract the opinion of customers. Brand 4 was lower than other brands in all dimensions.

In general, it can be concluded that among the four smartphone brands, Brand 3 has been able to emerge as the best alternative among other smartphones in terms of quality dimensions and word-of-mouth advertising. These results can vary based on weight and customer opinion.

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