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Multicriteria TOPSIS Method Applied to the Satisfaction of Smartphone Users with the Android, iOS and Windows Phone Operating Systems

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***Abstract*—Smartphone users' satisfaction is related to several factors of interaction that represent criteria evaluated in the choice of the operating system. This paper investigates the usage satisfaction of Android, iOS and Windows Phone mobile operating systems users' and deals with multicriteria decision making. A survey was applied and 314 answers were obtained. The evaluated criteria and the scores obtained through the survey were the initial parameters for the TOPSIS multicriteria decision-making method. The method classified the three alternatives based on preferences over screen, terminology, learning and system capabilities. The iOS was the best classified in the proposed evaluations. Android got the second place in the Screen factors. In the others, Windows Phone was second and Android was third. A small variation in the weights did not change the order of classification found. Although ranking should reflect the decision makers preference, further investigations can be carried out using the TOPSIS method and its relationship to mobile devices interface.**

***Index Terms*—Mobile Operating Systems, Smartphones, Decision Making, TOPSIS.**

I. Introduction

NEW technologies have attracted more users to smartphones. According to Anatel, Brazilian regulatory agency for telecommunications, the number of smartphones in Brazil in 2017 has surpassed 240 million units, which corresponds to more than 1 device per inhabitant [1].

Mobile operating systems (OS) are each day more robust and seek to attract the attention of users and offer a satisfying experience. The choice of an operating system is complex and many factors may be considered in the decision process.

The progress of the technologies throughout the years offered complex applications and more interaction options [2]. There was an increase on the number of facts associated with user satisfaction. The relationship between the number of functions available in the devices and the users' expectations increased considerably [3]–[6]. These authors highlight the expectations with use of smartphone are high and equivalent to use these devices as personal computers, with the added advantage of mobility and high speed internet.

Many of researches have focused on the development of improvement for the existing operating systems [7], but also frequently focused on development and evaluating the usability of apps or new languages [4], [8]–[10]. In addition, many factors, some of them conflicting among themselves, may be involved with the satisfaction and users' expectations. Multicriteria decision making deals with this field. Among the many multicriteria methods available [11], the TOPSIS method [12] has become popular because of its implementation simplicity and of its versatility as concerned to problems that involve decision theory.

Multicriteria decision making methods offer a solid mathematical support in which the expert preferences are reflected into the decision process. These methods have been extensively used in the literature and applied to many different research fields [11], [12]. All methods start from a decomposition of the problem into a decision matrix. Alternative and criteria are made explicit and each method seeks to offer a ranking of the alternatives in a different way.

This research aimed to apply the TOPSIS multicriteria method to rank the preference among the Android, iOS and Windows Phone operating systems based on criteria of users' satisfaction. These systems were selected because they are the most known and used in the market [13]. This paper is divided into two parts: the first one was the adaptation and application of a reliable questionnaire to a group, in order to measure their expectations with several interaction criteria. The second part was to employ the multicriteria method in the database which we gathered previously in order to classify the alternatives according to the users' evaluation of those systems.

This paper studies the users' satisfaction with the Android, iOS and Windows Phone mobile operating systems and multicriteria decision making. We present the comfort and acceptation of 314 users in 23 usability criteria divided into the following categories: Screen, Terminology, Learning and System Capabilities. Afterwards, we proposed the application of a multicriteria method in order to rank the alternatives (operating systems) to the users based on their answers. The data gathered and the classification of each alternative is presented in this paper. The approach we used shows the possibility of combining data gathered from the users and the options classification, offering more clarity and assertiveness for the decision making process. Despite the importance of this research problem and the wide use of TOPSIS, we did not find in the academic literature studies that apply this method to classify mobile operating systems based on the preference of the decision makers on usability criteria.

This paper is organized as follows: section II describes the related works and presents briefly the multicriteria decision making method used in this research; section III describes the data gathering methodology and how the decision making process occurred; section IV presents the final results found according to user satisfaction and options ordering; finally section V presents our final considerations and ideas for future works.

II. Contextualization and Related Works

THIS section describes some related works that motivate this research on smartphone users satisfaction. Next, the topic of multicriteria decision making is also briefly described and we discuss the TOPSIS method, which is used in this research.

A. Smartphone Users Satisfaction

The smartphone users satisfaction has been investigated in the literature in all its facets. França et al. [4] investigated the acceptance of mobile apps by students in an education institution. The authors used the Technology Acceptance Model (TAM) and they gathered 251 answers. The authors deemed as important for the interviewees factors such as perceived utility, intention to use and ease of usage . Even though it uses another approach (TAM model) to evaluate technology acceptance, the authors do not mention decision making in their research.

Alves [3] used a questionnaire adapted from the Questionnaire For User Interaction Satisfaction (QUIS) [14] to investigate criteria associated with the usability of smartphones with Android and iOS mobile systems. Among the evaluated points, the iOS achieved a higher score in most items among the 188 answers gathered. Through the association with Pareto diagrams, which indicated that most of the problems found have few causes, the author listed 7 factors in Android and 6 in iOS that concentrate most of the grades between 1 and 5 found in the questionnaire. Hence, the proposed approach was in accordance with the Pareto principle and the author concluded that the improvement of these few items would increase the satisfaction with these systems. In this research there were no users of the Windows Phone operating system and the author could have applied some multicriteria method to present to the reader the preferred alternative.

Moumane, Idri e Abran [5] proposed an empirical study based on a set of measurements to evaluate the usability of mobile apps which worked in different operating systems. For this work, they gathered the opinions of 32 users that used the Android, iOS and Symbian operating systems. The authors used QUIS to measure satisfaction and the ISO 9241 and ISO 25062 norms to evaluate usability. The results revealed a set of actions that should be observed as to the usability of the devices, like the positive correlation between screen size and the ease to use the smartphone. The smartphone choice should be based on QUIS criteria related to Screen, Learning and System Capabilities which were used to evaluate the app quality and to indicate possible limitations of the mobile devices.

Choi e Lee [2] investigated interface simplicity factors. The fusion between visual aesthetics, information design and task complexity composed the conceptual model proposed. The model pointed out interesting results such as the relationship between the task complexity an the crucial measurement of simplicity, given that this factor is related to the user action assertiveness in any task. The authors pointed out also that the simplified interface design contributes to better satisfaction evaluations. This study is too focused on usability evaluation, more specifically on interaction simplicity, and the authors do not mention multicriteria analysis to help users.

Finally, according to previous research [1], [3], [5], [13], the Android, iOS and Windows Phone operating systems composed almost the whole smartphone market. These numbers explain many research in the field, even though it is known that developing companies may ignore the conclusions of those studies. The competition for market share and the client loyalty justify the continuation of those studies. The researches focus on many aspects in this field such as usability evaluation, user interaction, application evaluation and new tools, among others. It should be noticed that many factors are associated with users satisfaction and different forms of evaluation may be applied or proposed to measure the aspects of this interaction.

B. Multicriteria Decision Making

Multicriteria Decision Making (MCDM) is essentially used at management level [11]. MCDM methods seek to classify available options according to established criteria. Several methods are described in the literature [11], [12], [15], [16]. Their applications are many and in several research fields, because they aid to solve real-life problems where the decision maker is faced with more than one alternative and conflicting criteria

Usually the MCDM method decomposes the problem into a decision matrix with criteria and alternatives. Given that it is quite unusual for an alternative to maximize all criteria simultaneously, it is necessary to use an approach that points to the decision maker a solution that might be sub-optimal in several criteria. The importance of each criterion is decided by the decision maker before calling the multicriteria method. From there, using different mathematical functions, each method proposes a classification of each alternative to the decision maker.

At that point, it is up to the decision maker to accept or not the presented ranking and to implement the best alternative.

C. The TOPSIS Multicriteria Method

The TOPSIS method, Technique for Order of Preference by Similarity to Ideal Solution, was proposed by Hwang [12] and seeks to choose an alternative that is closest to the ideal positive solution and farthest to the ideal negative solution. The former consists in maximizing benefits while minimizing the cost, while the latter is the opposite, a maximization of cost and minimization of benefits.

The following steps are used for the TOPSIS method (adapted from [15], [16]):

1) Define a decision matrix D made of alternatives and criteria. A_i, $i = 1, ..., n$ represent the feasible alternatives, while C_j, $j = 1, ..., m$ represent the decision criteria, x_{ij} indicate the assessment of alternative A_i over criterion C_j. The weight vector $W = w_1, \dots, w_m$ represent the individual weight of each criterion, with the condition $w_j \geqslant 0$ and $\sum_{i=1}^{m} w_j = 1$ is mandatory for the evaluation of the criteria.

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & \dots & C_j & \dots & C_m \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1j} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2j} & \dots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots & \dots & \vdots \\ x_{n1} & x_{n2} & \dots & x_{nj} & \dots & x_{nm} \end{bmatrix} \end{array} \tag{1}$$

2) Determine the normalized decision matrix (NDM) from the matrix D that represents the score of the alternatives. The normalized value r_{ij} is calculated through the following formula:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}} \tag{2}$$

3) Determine the weighted normalized decision matrix (WNDM). The weighted normalized value v_{ij} is calculated by the multiplication of each column of the normalized decision matrix (NDM) by the weight of each criterion.

$$v_{ij} = w_j * r_{ij} \tag{3}$$

4) Determine the Positive Ideal Solution (PIS, A^+) and the Negative Ideal Solution (NIS, A^-) using the following equations:

$$A^+ = \{max_i \ v_{ij} | i \in J^{'}); \ (min_i \ v_{ij} | i \in J^{''})\} \tag{4}$$

$$A^- = \{(min_i \ v_{ij} | i \in J'); \ (max_i \ v_{ij} | i \in J^{''})\} \tag{5}$$

where $J^{'}$ is associated with a benefit criterion and $J^{''}$ is associated with a cost criterion.

5) For each evaluated alternative, calculate the distance D_i^+ between the weighted normalized performance values of matrix (3) and the PIS values and the distance D_i^- and the NIS values. .

$$D_j^+ = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^+)^2} \tag{6}$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)^2} \tag{7}$$

6) Calculate the Closeness Coefficient, CC_i according to equation (8), which corresponds to the global performance of the alternatives.

$$CCi = \frac{D_i^-}{D_i^+ + D_i^-} \tag{8}$$

7) Sort in descending order the alternatives. The alternative with the CCi closer to 1 is the best classified.

III. Research Methodology

A. About the questionnaire, the target audience and the investigated operating systems

The questionnaire used was inspire in the QUIS (Questionnaire For User Interaction Satisfaction) version 7.0. This tool was developed at the Laboratory for Automation Psychology and Decision Processes (LAPDP), at the University of Maryland. It is a reliable tool that is essentially used to measure the subjective user satisfaction with the usability of an interface [3], [14], [17].

The questionnaire used was in a 1-9 points Likert scale. We used this scale because previous works using it revealed good results [18]. Table I presents the evaluated criteria.

The worst case corresponds to grade 1 and the best one, to grade 9. This means that the qualitative values are transformed into quantitative from the evaluation made by the interviewee, varying always from the worst to the best case.

In order to gather data from a more homogeneous population [19], the questionnaire was given to students or former students in the courses of managerial areas (Business Administration, Public Management and Hospital Management), Computer Science (Information Systems and Computer Science) and Engineering. Even though we understand that limiting the research may cause us to not represent the entire population, the authors defend that applying the questionnaire to a too heterogeneous

TABELA I
CRITERIA EVALUATE IN THE QUESTIONNAIRE USED

Criterion	Description	Worst Case	Best case
C_1	The screen layouts are useful	never	always
C_2	The screen sequence is	confusing	clear
C_3	Next screen in a sequence is	unpredictable	predictable
C_4	Return to previous screen	hard	easy
C_5	System keeps you informed on what it is doing	never	always
C_6	Execution of an operation leads to a predictable result	never	always
C_7	Error messages, when showed, are	unhelpful	helpful
C_8	Error messages explain the problem	never	always
C_9	There is a significant explanation when errors occurs	useless	useful
C_{10}	Learning to use the operation is a task that is	difficult	easy
C_{11}	Learning advances results is	difficult	easy
C_{12}	Learning to operate system	slow	fast
C_{13}	Exploring new features by trial and error	discouraging	encouraging
C_{14}	Exploring device results is a task that is	risky	safe
C_{15}	Discovering new resources is a task that is	difficult	easy
C_{16}	Remembering names and use of commands	difficult	easy
C_{17}	The tasks can be performed in a simple and direct way	never	always
C_{18}	The steps needed to complete a task follow a logic sequence	never	always
C_{19}	Data backup availability	never	always
C_{20}	Operating system updates availability	never	always
C_{21}	Location service in case of theft/robbery	impossible	possible
C_{22}	Item personalization	difficult	easy
C_{23}	Information on download progress	never	always

group could cause the answer to not be to connected to the research, given that it has already been established that the socio-economic condition, among other factors, can bring about different user satisfaction levels [10].

The operating systems and the respective versions used in this study were: Android (version 4.0 or above), iOS (version 7 or above) and Windows Phone (version 7 or above). These operating systems almost represent the totality of the Brazilian Market [13]. It is known that iOS and Windows Phone are systems developed only for specific hardware, while Android can be used by several brands and models. Nevertheless, the evaluation on the most recent versions of the systems helps us understand the list of expectations from the users with this system, which is the most popular in the market [13]. It is important to point out that this research considered only usability criteria and, hence, there is no influence of the used hardware on the results found.

Given that the questionnaire scale was in the Likert format, from 1 to 9 points, we used the grade average to quantify the satisfaction levels of the interviewed users with each factor and for each operating system. In order to clarify, the average is usually criticized because it is very sensitive to outliers. Nevertheless, given that the questionnaire grades were all in the interval from 1 to 9 points, there was no margin for a interviewee to offer an outlier value that could strongly affect the average.

The data were codified and loaded into the R software. For statistical purposes, we adopted a confidence interval of 95%, implying in a significance level of $\alpha = 0.05$.

B. Decision Making

In order to implement the TOPSIS multicriteria decision making methods, we considered three different operating systems as the possible alternatives for the user choice: A_1: Android, A_2: iOS e A_3: Windows Phone. The criteria, as presented in Table I, represented the interaction factors with the operating systems in four different aspects: Screen (C_1-C_4), Terminology (C_5-C_9), Learning (C_{10}-C_{18}) and System Capabilities (C_{19}-C_{23}).

The TOPSIS method is very versatile, easy to implement computationally and can be applied to a vast array of decision making problems [11], [12], [15], [16].

The Table II represents the decision matrix for the proposed problem and contain the real grades used in this research, making it more easily repeatable. Given that the scores found through the questionnaire were in a 1-9 points Likert scale, all answers must be within those limits. We understand, therefore, that $\mu_{11} = 7.24$ represents the average of all evaluations for alternative A_1 (Android) as to criterion C_1 (the screen layouts are useful: never - always), $\mu_{12} = 7.11$, the grade average for alternative A_1 as to the criterion C_2 (The screen sequence is: confusing - clear) and so on for all 23 criteria ($j = 1, 2, \ldots, 23$) and 3 alternatives ($i = 1, 2, 3$).

Different weight judgments were calculated in order to make explicit the results and possible changes in the ranking. Some of those weights were given arbitrarily, because the goal was that each one would represent the preferences of the decision maker using a set of criteria. The following judgments were performed:

1) Judg-1: Weights that favor the criteria related to Screen (w_{c_1}-$w_{c_4} = 0.6$);
2) Judg-2: Weights that favor Terminology (w_{c_5}-$w_{c_9} = 0.6$);
3) Judg-3: Weights that favor Learning ($w_{c_{10}}$-$w_{c_{18}} = 0.6$);
4) Judg-4: Weights that favor System Capabilities ($w_{c_{19}}$-$w_{c_{23}} = 0.6$);
5) Judg-5: Weights based on standard deviation.

In the first four judgments (Judg-1 to Judg-4) we attributed arbitrarily a higher weight to the criteria that compose the evaluated aspect. For Judg-1, this means that the sum of the weights attributed to criteria C_1 to C_4 was equal to 0.6 points. The remaining 0.4 was equally distributed among the other criteria, from C_5 to C_{23}. Hence, we sought to keep the preferences on each group and investigate the classification of the alternatives. In Judg-5, the weights were based on the inverse of the standard deviation. We know that that this measure is related to the dispersion around the population average. Hence, the smaller the dispersion, the higher the weight attributed to that criteria.

It is understood that the weights can also be based on the users evaluation, so that each criterion will receive a weight proportional to the average grade it received. Since these parameters were already used as the score for the alternatives, the evaluation of the set of criteria was adopted in this research, given that this is the most common strategy used when smartphone users decide to choose their devices.

C. Limits of the research

We believe that the simulation considering the factors concerning certain aspects of the interface represent possible decision maker choices. Nevertheless, we understand that new evaluation may be considered, such as criteria combination, different weights for the criteria deemed as important by the decision maker or considering each criterion separately.

The study was limited to studying the satisfaction of users from a specific group of users: graduates or undergraduate students in Management, Computer Science and Engineering. We understand that this research must continue, given that new groups can be included. Previous works revealed that low income people with low resolution smartphones had more errors in the application use than the other evaluated people [10]. Hence, we understand that new groups can reveal a different order than the one presented here, once we include persons with different income, that use different devices, etc. Nevertheless, there must be special care so that the research evaluates the operating system, free of prejudice caused by the hardware.

This study used the TOPSIS method because of its simple computation implementation and its versatility for the application in different fields [15]. However, there are many others methods available in the literature [11] which can be applied, even making a comparison among them, if they yield different results. Finally, this study focused on the evaluation of the smartphones interfaces and did not consider the evaluation of advanced apps, such as previous work [2], [4], [5], [7], [8].

IV. Results and Discussion

We gathered a total of 314 valid answers [1]. The answers that reflected on different operating systems and from users outside the focus group were discarded. Table III shows the data gathered through the questionnaire for each operating system among the courses of Management, Computer Science and Engineering. The larger amount of answers found for the Android operating system, followed by iOS and Windows Phone corroborates IDC previous research [13]. These three operating systems dominate the smartphones market place, and the Android alone represents a larger market share than the other two combined.

Figure 1 shows a comparison of the users' satisfaction of the three evaluated operating systems. Notice that iOS showed better evaluations with a interquartile interval between 6 and 8 points and average close to 8 points. It was superior to the other two systems. The Android OS and the Windows Phone OS presented similar interquartile intervals, close to 6 to 7 points. Nevertheless, Android has a smaller average than iOS. We conducted a variance analysis in order to make multiple comparisons among the systems. The results suggest that there is a statistically meaningful difference in the model ($p - value = 0.00143$). This difference can be seen in the Figure 2. If $A2 - A1 > 0$ it suggests that $A2 > A1$. In the same way, given that $A3 - A2 < 0$ it is suggested that $A2$ is bigger that $A3$. $A1 - A3$ shows no difference.

Decision making involved the implementation of the TOPSIS method according to the steps described in the subsection II-C. The values for each alternative were found using the average of the grades for each evaluated criterion for each operating system gathered through the questionnaire. The weights were proposed so that they would reflect the preferences of the decision maker. We judged as more important each aspect of the interface, that is Screen, Terminology, Learning or System Capabilities.

Next, we applied the TOPSIS method, considering the 3 alternatives and the 23 criteria. As described before, given

[1] www.dropbox.com/s/un5i0f61lxkfm9e/FMSI2017.txt?dl=0

TABELA II
Decision Matrix with the Average for Each Alternative Over Each Criterion

	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}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}
A_1: Android	7.24	7.11	7.05	7.03	6.40	6.76	5.41	5.06	5.37	7.63	6.60	7.29	6.56	6.65	6.73	6.60	6.88	7.05	6.46	6.36	5.65	6.46	7.65
A_2: iOS	7.78	7.75	7.60	7.57	6.88	7.31	6.61	6.16	6.40	7.46	6.78	7.25	6.84	7.58	7.18	7.10	7.43	7.43	7.45	7.81	7.93	6.40	7.49
A_3: WP	6.73	7.17	7.10	7.33	6.50	6.93	5.97	5.77	6.03	7.53	6.30	7.03	6.50	6.77	6.37	6.87	6.83	6.93	7.10	6.93	6.47	6.43	7.40

TABELA III
Answers Gathered with the Questionnaire

		Courses			
SO	N	Mgmt.	CS	Eng.	% Accumulated
Android	217	29	106	82	69.1
iOS	67	13	21	33	90.4
WP	30	2	15	13	100.0

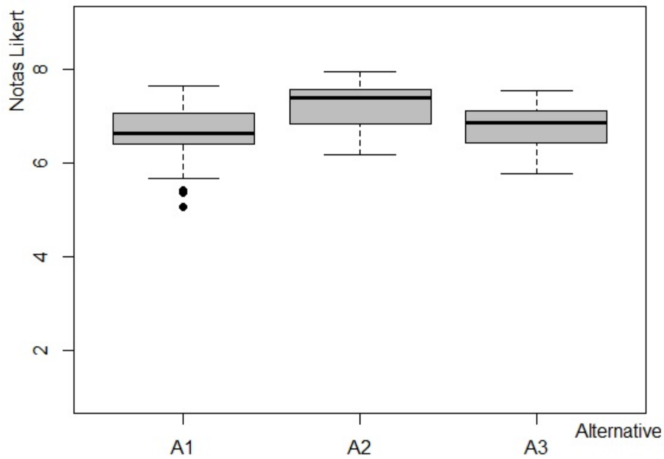

Fig. 1. Scores for the three Different Operating Systems

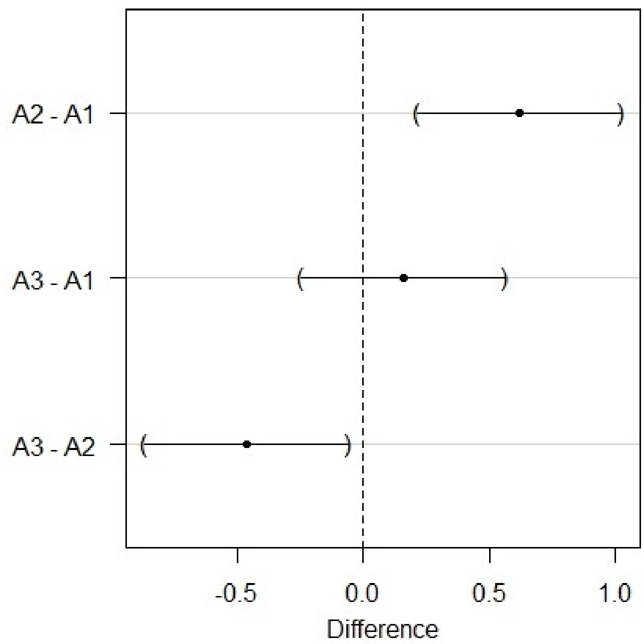

Fig. 2. Comparison of the Averages of all Operating Systems

the decision matrix D, the method normalizes the data (NDM), weighs the alternatives based of the value of the alternatives and weights of each criterion ($WNDM$), calculates the distances based on the Positive Ideal Solution (PIS, A^+) and the Negative Ideal Solution (NIS, A^-) and then the Closeness Coefficient (CC_i). The final ranking found corresponds to the decreasing order of the CC_i.

The classification of each alternative with the respective CC_i found when applying the TOPSIS multicriteria decision making method is presented in Table IV.

TABELA IV
Classification Order Considering the Preferences on the Set of Criteria

	Judg-1		Judg-2		Judg-3		Judg-4		Judg-5	
A_i	CC_i	Ord.	CC_i	Ord.	CC_i	Ord.	CC_i	Ord.	CC_i	Ord.
A_1	0.2888	2	0.0565	3	0.2256	3	0.0858	3	0.1676	3
A_2	0.9790	1	0.9833	1	0.9320	1	0.9477	1	0.9466	1
A_3	0.2291	3	0.5261	2	0.3083	2	0.4002	2	0.3874	2

The best classified alternative was A_2, iOS, with closeness coefficient CC_i (eq. (8)) equal 0.9790, 0.9833, 0.9320, 0.9477 and 0.9466 for judgements Judg-1 to Jugd-5, respectively. The good evaluation and preference for iOS can be seen in Table II. Its average was superior in all four evaluation groups.

Given that multicriteria methods tend to reflect the preferences of the decision maker, we hope that when we give a higher weight to a specific set of criteria, the alternatives with the best evaluations in that criterion become highlighted. Hence, even though A_2 did not have the best evaluation in all criteria individually, it stands out with a good score when TOPSIS normalizes and weights all values of the decision matrix. The second place alternative was A_1 in respect to screen and A_3 for Terminology, Learning and System Capabilities. A_3 received low scores in criterion C_1, lower than A_1. Given that in criterion C_2 to C_4 this system received similar scores to A_1, the CC_i of both systems was slightly close in the final classification: 0.2888 for A_1 and 0.2291 for A_3. Considering that have no difference between A1 and A3, the classification difference between these two alternatives cannot be considered significant. The low evaluation in criterion C_1 may be the reason why A_3 was in third place in judgment Judg-1. In the other judgments, Judg-2 to Judg-5, A_3 was in second place and A_1 in third.

In order to understand whether small changes in weights could affect the performance of the ranking, we provided a brief sensitivity analysis. All weights were varied by 10% in both directions. This means that when specifying higher preference in relation to the criteria related to Screen (C_1-$C4$), the weight given originally, w_{c_1}-$w_{c_4} = 0.6$ was changed and for each variation the algorithm was executed again. We noticed changes in CCi values, we noticed no difference in the rankings. Although we perceived changes in the CC_i, a variation of 10% in the weights for the sets of criteria (in either direction) did not change the final ordering found in each judgment.

V. Final Considerations

SMARTPHONE users' satisfaction is related to several factors, such as: screen, terminology, learning and system capabilities. The operating system choice can be described as a multicriteria decision making process, given that it is related to several factors which are mutually conflicting.

This research investigated the smartphone users' satisfaction with the Android, iOS and Windows Phone operating systems. These three operating were chosen because they are the most used in the market [1], [3], [13]. A questionnaire based on QUIS was applied and we gathered 314 valid answers. On the 23 evaluated criteria and 3 feasible alternatives, we applied the TOPSIS multicriteria decision making method to classify these alternatives according to the scores obtained by the questionnaire. The scores for each alternative was the average obtained by each operating system in each criterion. These criteria are related to the factors Screen, Terminology, Learning and System Capabilities. Considering that the decision maker prefers one of those sets of criteria, we gave larger weights to one of them and ran the algorithm. In all compilations, alternative A_2: iOS was classified as the best one. There was a change of positions in the ranking, from second to third. When the Screen factor had the larger weight, the Android was in second place and Windows Phone in third. For all other three cases, that is, when the Terminology, Learning and System capabilities were given larger weight, Windows Phone came second and Android came third.

When analyzing the scores obtained by each operating system in each criterion, it was already possible to realize the high level of satisfaction with the iOS system, given that the evaluations were predominantly superior to the other ones. Considering each one of four sets of criteria, this alternative presented the higher average than the others. Hence, it would possibly be the best one classified by the multicriteria method. However, this order could change in case the user defined very high weights for the criteria in which this operating system did not get the higher scores, such as C_{10} and C_{22}, for instance. Another possible analysis is to judge the criteria individually or combining among them. For instance, to offer a high weigh for one or more preference criteria C_j and investigate the classification of the alternatives. Given that the method calculates the value of the normalized weighted alternative, it is possible to find changes in the final ranking.

It is known that there is a meaningful price difference between the smartphones with the evaluated operating systems. Oftentimes, the user, as consumer, acquires a device beyond or below his needs. Multicriteria analysis, as applied in this research, may help the user to chose among the feasible alternatives. He must evaluate the importance of the criteria that he considers fundamental in his daily life. Hence, based on the available information, the multicriteria method tends to help choose the most viable operating system based on those preferences.

Finally, it is known that the scores gathered through the questionnaire reflect the evaluation of graduate and undergraduate students in Management, Computer Science and Engineering. These evaluations can change immensely if we include other groups or other criteria (based on users' preference) into the analysis. Hence, this or any other multicriteria method that may be used can return interesting results. We believe that this study can be easily replicated. Hence, it allows the evaluation of other systems, applications and interfaces. We hope that this work can inspire students and researchers that are interested in usability engineering, studies about smartphones, multicriteria decision making methods or the intersection among all those themes.

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