Usability Evaluation of Mp3/CD Players: A Multi-Criteria Decision Making Approach

Ergün Eraslan

Department of Industrial Engineering, Baskent University,
06590 Ankara, Turkey
eraslan@baskent.edu.tr

Abstract. Globalization and the competition obliged the user-oriented design today. In the last years, usability has become a highly important research subject. Usability, considering user satisfaction along with the user performance, is one of the key factors in determining the success of a product in today's competitive market. Product usability is a prerequisite for high customer satisfaction and future sales of companies. Mp3 players and portable CD players are selected for this study since usability is highly important for them. Designing a usable mp3 or CD player is extremely important for users who have close interaction with them. In this study, 14 different mp3/CD players are selected and their usability is analyzed. The usability criteria used in the mp3/CD players' evaluation are divided into two major categories: performance and emotional expectations. The best alternative is determined with three different multi-criteria decision making methods which are TOPSIS, Analytic Hierarchy Process (AHP), and Fuzzy Axiomatic Design Theory (FADT). Although the same data obtained from semantic differential experiment are used for all multi-criteria decision making methods, different rankings are obtained from each method.

Keywords: Usability, TOPSIS, Analytic Hierarchy Process (AHP), Fuzzy Axiomatic Design Theory (FADT), Semantic Differential Scale.

1 Introduction

User-oriented manufacturing and design became a must because of the competition among the firms. Customer profile has significantly changed. Customers who can buy every product have disappeared. Instead, customers know what they want and choose the products which satisfy their senses and needs in terms of price and design. Consumers want to buy "usable" products which will satisfy their needs and be easy to use.

Usability of a product is a very valuable prerequisite for future sales and high customer satisfaction. Understanding the product features which are significant for the customers and reflecting the feedbacks of the customers to the design and development processes of the product are important. Designers have to evaluate vital points of usability and the satisfaction and delight rose by these vital points carefully.

Usability concept includes a few concepts such as effectiveness, efficiency, and user satisfaction. In its broadest sense, usability is the expression of whether the

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product is good enough to meet all needs of the user [1]. User evaluates the product according to the usability measures and decides whether it is usable or not. This decision affects purchasing of the product.

Han et al. (2001) stated that image/ impression and performance dimensions should be considered together to evaluate usability of electronic consumer goods. To be able to model the effects of product interface factors on the product performance and image, performance and image/impression dimensions are detailed [2].

In this study, usability of mp3 (Motion Pictures Experts Group 1 Audio Layer 3) and CD players, used very commonly in last years, are investigated. Mp3/CD players are selected for this study because of the increasing user crowd, high variability of the product and lack of studies about this subject in the literature. 14 mp3/CD players with different dimension and features are determined and usability criteria for these products are determined by a focus group study. These criteria are evaluated by three Multi-Criteria Decision Making (MCDM) Methods to determine the most usable product.

Three MCDM methods are explained in section 2, the products are evaluated and compared by the chosen methods in section 3, and the study is finalized in section 4 with the evaluation of the results.

2 Multi-Criteria Decision Making Methods (MCDMs)

In this study, TOPSIS, Analytic Hierarchy Process (AHP) and Fuzzy Axiomatic Design Theory (FADT) methods are used and they are briefly explained as follows.

2.1 TOPSIS Method

TOPSIS (The Technique for Order Preference by Similarity to Ideal Solution) method is based on that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the longest distance from the negative ideal solution (NIS). TOPSIS simultaneously considers distances to not only the positive ideal solution but also the negative ideal solution, and the alternatives are ranked according their relative closeness coefficients. The method begins with the construction of the decision matrix for n alternatives ($a_1,a_2,\ldots,a_n$) and k criteria ($y_1,y_2,\ldots,y_k$), and follows 5 steps [3,4]:

Step 1: Normalization of decision matrix y where x_{ij} is the evaluation of alternative i with respect to criterion j.
Step 2: Construct the weighted normalized decision matrix. The weighted values X_{ij} are calculated multiplying with the weights (w_{ij}).
Step 3: Determine the ideal (a^*) and negative-ideal solutions (a^-).

$$a^* = \{x_1^*, x_2^*, \ldots, x_k^*\}. \quad (1)$$

$$a^- = \{x_1^-, x_2^-, \ldots, x_k^-\}. \quad (2)$$

Step 4: Calculate the separation measures from the ideal (S_i^*) and the negative-ideal solutions (S_i^-), respectively, using the n dimensional Euclidean distance. The separation of each alternative from the ideal solutions are given as

$$S_i^* = \sqrt{\sum_{j=1}^{k} (x_{ij} - x_j^*)^2} \ . \tag{3}$$

$$S_i^- = \sqrt{\sum_{j=1}^{k} (x_{ij} - x_j^-)^2} \ . \tag{4}$$

Step 5: Calculate the relative closeness index (C_i^*) to the ideal solution. Rank the preference order. Using this index, alternatives are ranked in decreasing order.

$$C_i^* = S_i^- / (S_i^+ + S_i^-) \qquad 0 \le C_i^* \le 1 \, . \tag{5}$$

2.2 Analytic Hierarchy Process (AHP)

AHP, developed by Saaty, determines the relative importance of a set of factors in a MCDM problem [5]. The process depends on judgments on intangible qualitative criteria alongside tangible quantitative criteria. The AHP method is based on three principles: first, structure of the model; second, comparative judgment of the alternatives and the criteria; third, synthesis of the priorities.

In the first step, the problem is structured in a hierarchy which includes objective, criteria and decision alternatives. The second step is the comparison of the alternatives and the criteria with pairwise comparison matrices. The prioritization procedure starts in order to determine the relative importance of the criteria within each level. The Saaty's 1-9 scale is used for this process. At the last step, the mathematical process commences to normalize and find the relative weights for each matrix.

It should be noted that the quality of the output of the AHP is strictly related to the consistency of the pairwise comparison judgments. The final consistency ratio (*CR*), using which one can conclude whether the evaluations are sufficiently consistent, is calculated as the ratio of the *CI* and the random index (*RI*). The number 0.1 is the accepted upper limit for *CR*. If the final consistency ratio exceeds this value, the evaluation procedure has to be repeated to improve consistency [5].

This method is a common one and is used in several studies from different areas especially in the last two decades.

2.3 Fuzzy Axiomatic Design Theory (FADT)

Axiomatic Design (*AD*) forms a scientific basis to design and improves designing activities by providing the designer with a theoretical foundation based on logical and traditional thought process and tools. *AD* provides a systematic search process through the design space to minimize the random search process and determine best design solution among many alternatives considering all product development decisions.

In the literature, *AD* theory and principles are used to design products, systems, organizations and software [6]. Lo and Helander (2004) proposed axiomatic design as a formal method for usability analysis for consumer products [7]. Karwowski (2005)

also emphasized the applicability of axiomatic design for solving complex ergonomics design problems [8].

Design axioms, namely independence axiom and information axiom, are two key stones of *AD*. Independence axiom is related to maintaining the independence of functional requirements (*FR*s), i.e., design solution must be such that each one of *FR*s can be satisfied without affecting the other *FR*s. Therefore, a correct set of design parameters have to be chosen to be able to satisfy the *FRs* and maintain their independences. Information axiom, the second axiom of AD, states that the design with the smallest information content must be chosen among the design solutions which satisfy independence axiom. Information axiom of *AD* is recently used as a Multi Attribute Decision Making (MADM) method [9]. Information content of overall system, I_{sys}, is defined in terms of the probabilities (p_i) of satisfying FR_i below.

$$I_{sys} = \sum_{i=1}^{n} I_i = \sum_{i=1}^{n} \log_2\left(\frac{1}{p_i}\right) = -\sum_{i=1}^{n} \log_2(p_i) \cdot \tag{6}$$

Design with the smallest "*I* " is the best design as it requires the least amount of information to achieve design goals. If all probabilities are large enough, near to one, then information content is minimum. Probability of satisfying a *FR* is specified by design range defined by designer and generating ability of the systems range [9, 10].

Many decision making and problem solving tasks are too complicate to be understood quantitatively. Fuzzy set theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions. If system cannot be defined by using traditional quantitative terms, it is more plausible to use fuzzy linguistic terms. Linguistic terms can be transformed into fuzzy numbers. Fuzzy case of information axiom (FIA) is used herein. In fuzzy case, the intersection area of fuzzy numbers which are ranges of system and design is considered.

3 Usability Evaluation of the Mp3/CD Players with MCDM Methods

In this section, the studies to evaluate the usability of mp3/CD players are provided. In this context firstly the focus group study and semantic differential scale (SDS) used in assessment are given and reliabilities of the evaluations are discussed. Then, the usability of the selected 14 products are evaluated and compared with the results of MCDMs.

3.1 Data Collection and System Reliability

Focus group is an application widely used in areas such as human factors, social sciences and market researches. Focus group is composed of people who come together to discuss a specific subject or problem. The information obtained from the group is qualitative and consists of experience, ideas, thoughts and behaviors rather that figures and facts. Synergy among the group members distinguishes the focus group study from other applications [11].

Han et al. (2001) developed a model for the effects of product interface factors of electronic devices on the product performance and image. These dimensions are valid

for all electronic consumer devices [2]. When usability study is to be performed for different products, criteria appropriate for the goods should be selected. Focus group study is used to determine the criteria for usability of mp3/CD players. For this purpose, 6 subjects who attended the meetings are selected among people who are either potential user of mp3/CD players. There were 14 mp3/CD players in the meetings and the participants examined them. In addition, all conversations are recorded during the meetings and printed afterwards.

According to the results obtained, the usability criteria specific to mp3/CD players are determined and it is decided to take technical properties into account under performance dimension. It is anticipated that some technical properties such as memory property, quality of the sound, battery life and data processing speed, play an important role in the usability of mp3/CD players. The criteria are given in Figure 1 for the mp3/CD players which are determined in focus group study formed a basis for SDS.

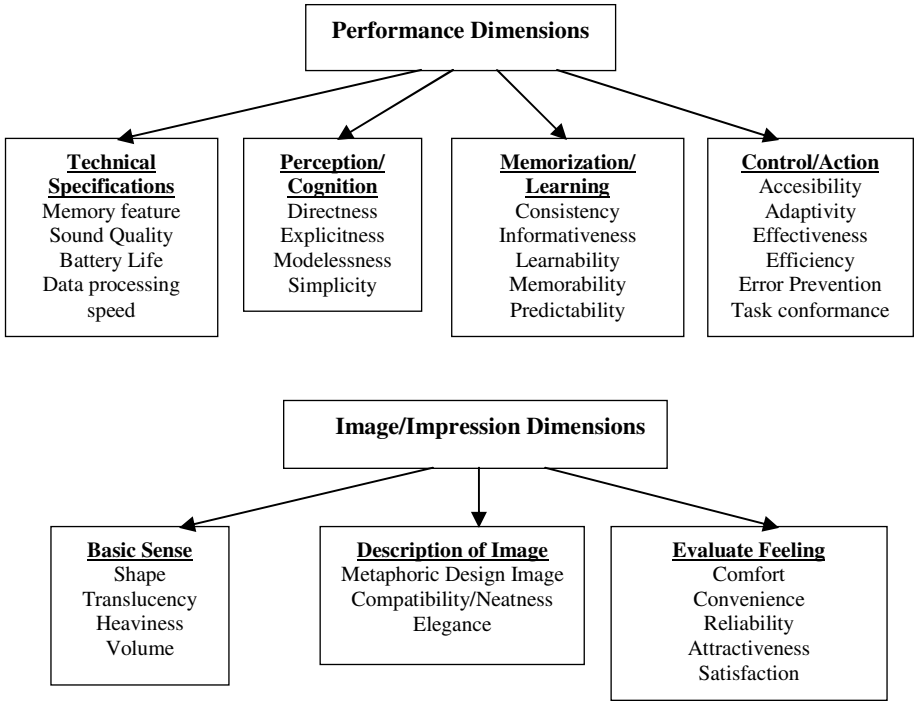

Fig. 1. Criteria Determined for Mp3/CD Players by Focus Group Study

A catalog including the details of each mp3/CD player is prepared. Technical properties which cannot be understood by visual examination such as sound quality, battery life and memory are added to this catalog. There were 22 subjects in SDS and allocated time for each subject is about 50 minutes. A reliability test is performed to confirm appropriateness of SDS results. Internal consistency among the questions is analyzed by computing Cronbach Alpha. Cronbach alpha is 0.94 meaning that the study is reliable according to these results. Confirming that results are appropriate we passed to evaluation stage by multi criteria decision making methods.

3.2 Usability Evaluation with TOPSIS Method

5 steps of TOPSIS method are used to rank 14 mp3/CD players according to 31 usability criteria. Firstly, criteria weights are calculated. All criteria are compared pairwise and the case of a criterion is more important than another is stated with yes or no. Using the number yes values, criteria weights are determined [12].

In the next step, vector normalization is used to compute normalization ratios. The normalized values are multiplied with criteria weights and by this way normalized matrix is calculated.

Positive-Ideal and Negative-Ideal solutions (a^* and a^-) are computed by taking the weighted normal values calculated in the previous step into account. Distance between alternatives is measured to compute the similarity to PIS, the alternative with maximum C_i value is selected as the best product based on all criteria. Table 1 shows the ranking of products according to C_i values. It can be seen that product 12 has the largest C^* value, 0.9681.

Table 1. Differentiation Measures and Product Ranking

Products	S^+	Ranking	S^-	Ranking	C*	Ranking
1	0.0338	13	0.0081	12	0.1930	12
2	0.0180	7	0.0227	7	0.5571	7
3	0.0330	12	0.0071	13	0.1762	13
4	0.0346	14	0.0060	14	0.1479	14
5	0.0261	11	0.0152	11	0.3688	11
6	0.0201	8	0.0219	8	0.5220	8
7	0.0126	5	0.0274	10	0.6856	5
8	0.0204	9	0.0195	9	0.4887	9
9	0.0227	10	0.0168	5	0.4249	10
10	0.0065	2	0.0351	2	0.8433	2
11	0.0108	3	0.0285	3	0.7245	3
12	0.0013	1	0.0382	1	**0.9681**	1
13	0.0120	4	0.0275	4	0.6854	4
14	0.0158	6	0.0238	6	0.6015	6

3.3 Usability Evaluation with AHP

The criteria which are determined to be important for the usability of mp3/CD players by the focus group study are examined in a hierarchic structure via AHP method (Figure 1). It is assumed that performance and image/impression dimensions have the same effects on electronic devices. Therefore, neither dimension is superior to the other. Besides, there is no relation among their subcriteria.

After AHP hierarchy is composed, it is aimed to determine dominance of each criterion at every level to others. For this purpose, results of the SDS are used. Satisfaction criterion is used as the basis here. Superiorities of the criteria to each other are determined according to the points of the criteria against satisfaction. These superiorities are used compute the weights required for pairwise comparisons.

Consistency ratios of all matrices formed according to these scales and none of them was more than %10. After the control of consistency ratios, relative importance

vector is calculated by multiplying the weights with each other in accordance with the hierarchic structure.

The most suitable product for the objective is found when values of the relative importance vector are multiplied with the product points obtained from SDS. Analyzing Table 2, it can be seen that 8.5225 is the greatest value which belongs to product 12.

Table 2. Points of Products

# of Product	Point Values	# of Product	Point Values
1	5.5365	8	7.2623
2	6.8955	9	6.5628
3	5.1271	10	7.9827
4	5.2476	11	7.8769
5	6.2387	12	**8.5225**
6	6.9416	13	7.7513
7	7.5897	14	7.4977

3.4 Usability Evaluation with FADT

To make design analysis using fuzzy axioms first the results of semantic differential study should be converted to fuzzy data. For this purpose, we used the conversion scale which is the most commonly used tool to convert the qualitative data into triangular fuzzy numbers in the literature.

In SDS, every criterion is given a point by each user between 1 and 5 meaning that, bad, average, good, very good and excellent, respectively. Averages of the triangular fuzzy numbers corresponding to these points are computed. These values are determined as the system intervals showing the sufficiency of the current system.

After defining system intervals it is also necessary to determine design intervals to make the calculations. Design interval is determined by the designers, and it can be defined as the features which are demanded in the product or the system. For this purpose, we determined the intervals for every criterion and gave two of them as an example (Table 3). After determining the system and design intervals, information content is computed for every product and for each criterion. Summing the information contents for each product, it can be seen that Product 10 is the best one with the least information content (Table 4).

Table 3. Design Ranges of the Some Criteria

Perception/Cognition		***Memorization/Learning***	
Directness	Very Good	Consistency	Very Good
Expicitness	Very Good	Informativeness	Very Good
Modelessness	Excellent	Learnability	Very Good
Simplicity	Excellent	Memorability	Very Good
		Predictability	Very Good

Table 4. Total Information Contents

# of Product	Information Content	# of Product	Information Content
1	Infinity	8	Infinity
2	Infinity	9	Infinity
3	Infinity	10	**54.176**
4	Infinity	11	57.562
5	Infinity	12	61.994
6	Infinity	13	60.948
7	60.518	14	Infinity

Table 5. Ranking of the products for MCDMs: Top 5 ranks include the same 5 products(*)

Ranks / Method	TOPSIS Ranking	AHP Ranking	FADT Ranking
1*	12	12	10
2*	11	10	11
3*	13	11	7
4*	10	13	13
5*	7	7	12
6	2	14	-
7	8	8	-
8	14	6	-
9	1	2	-
10	9	9	-
11	3	5	-
12	4	1	-
13	6	4	-
14	5	3	-

3.5 Comparison the Usability for MCDM Methods

The comparison of the results of the MCDMs is given in Table 5. TOPSIS and AHP methods give the ranking for all products while FADT method only gives the top five products. From the ranking it can be seen that top five products are same for all three methods although their orders are different. The orders of the other products are also different for TOPSIS and AHP.

4 Discussion and Conclusion

In this study, a decision approach for selection of usable mp3/CD players is presented. The selection process is based on the comparisons of finite alternatives according to identified usability criteria. For this purpose, 14 mp3/CD players are selected and criteria regarding the usability of mp3/CD players are determined by a focus group study. A semantic differential study is performed using these criteria and results are analyzed by MCDMs. TOPSIS, AHP and FADT methods are used in these analysis.

The data used in the three methods were obtained from the SDS performed beforehand. They were also used with minimum modifications as the methods permitted; however, some differences were observed in the results obtained. In all three methods, there were different rankings for different products. We think the reason for differences in these methods was caused by application formats. The differences are as follows:

In TOPSIS method, two distance ranges are calculated based on the idea of minimum distace to PIS and maximum distance to NIS. However, these two different distance ranges might not generate the same results. Therefore, in TOPSIS method, the result is obtained by examination to determine if there is a more suitable alternative from these two ranges utilizing a closeness index. This method is both easy to apply and is preferred.

In the AHP method, the problem is analyzed in a hierarchical structure and rankings of criteria in relation to each other at each level are determined. Criteria weights are calculated according to the pairwise comparison matrices and the best alternative which belongs to the highest weight is identified. The calculation of the criteria weights depend on the structure of the decision matrix that could alter the rankings in other methods. The ideas which can be objective and subjective can be combined in AHP in the ranking of the criteria which can be evaluated at different levels that in turn affects results when obtaining different rankings.

Using the method of design with fuzzy axioms, analysis is performed over system and design intervals. System intervals are the qualitative data obtained from the evaluations of the products by the users. Design intervals are the qualitative features of the products demanded by the designers or the people evaluating the products. This comparison might be incapable if the evaluation matrix for the alternatives cannot be formed with crisp values. Some criteria could have a qualitative structure or have an uncertain structure which cannot be measured precisely. In such cases, fuzzy numbers can be used to obtain the evaluation matrix. In analyses, the product with the minimum information content is searched for, by taking the intersections of triangular fuzzy regions of the system and design intervals. Different results can be found if design intervals change. For example, according to TOPSIS and AHP, the most usable product is product 12, while according to FADT product 10 is the most usable. It should be noted that although the methods approach the problem differently, the first five product results are the same in all methods.

It is not possible to assert that any one of the methods is better than the others. However, they all have some advantages depending on where they are utilized. When the MCDM methods are evaluated with all aspects we can say that if the given criteria in selection process are qualitative the best application method is AHP. As the AHP method includes the qualitative criteria into the decision processes better. If the criteria are quantitative, the other methods can be used for problem solving but there is no comparative degree to each other.

The fuzzy numbers can be used to obtain the evaluation matrix in all MCDM methods. Besides, the results of other MCDMs frequently using in the literature can be investigated to make a consensus. This will improve the decision making process and will give more accurate results that are the directions in the future research.

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