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PEQUAL - E-commerce websites quality evaluation methodology

Jarosław Wątróbski
West Pomeranian University of Technology in Szczecin, Żołnierska 49, 71-210 Szczecin, Poland
Email: jwatrobski@wi.zut.edu.pl

Paweł Ziemba
The Jacob of Paradyż University of Applied Science in Gorzów Wielkopolski, Chopina 52, 66-400 Gorzów Wielkopolski, Poland
Email: pziemba@pwsz.pl

Jarosław Jankowski
Department of Computational Intelligence, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland
Email: jjankowski@wi.zut.edu.pl

Waldemar Wolski
University of Szczecin, Mickiewicza 64, 71-101 Szczecin, Poland
Email: wwolski@wneiz.pl

Abstract— **Website quality evaluation is an important research task. Evolution and a growing set of available methods are observed. The article presents the authors' evaluation methodology of the quality of websites named PEQUAL. The formal foundation of the proposed methodology is the broadening of the classical EQUAL method with aspects of preference modelling and evaluation aggregation used in Multi-Criteria Decision Analysis (MCDA). Its empirical verification has been carried out for top e-commerce websites. The conducted research has revealed significant practical possibilities of analysis and interpretation of obtained final rankings.**

I. Introduction

ELECTRONIC commerce is one of the most prominent areas of e-business with increasing sales year by year and estimated 28.3 trillion dollars of worldwide retail sales in 2018 [1]. Estimation of digital buyers shows that 47.3 percent of global Internet users will purchase products online in 2018 what creates an increasing interest in this area [2]. E-commerce is dependent on the development of new technologies and with the growth of infrastructure, improvements of hardware and software accessibility and has changed its character since first applications [3]. The dynamic development of online sales platforms [4] and dedicated user interfaces [5] together with supporting technologies like personalization engines [6], recommending systems [7], online payment systems [8] and online marketing systems dedicated to electronic commerce [9] is observed.

The constant growth of a number of Internet stores intensifies competition between entities that offer goods and services online [10]. To improve results and maximize profits entrepreneurs use sophisticated analytic software [11], web mining techniques [12] or conversion maximization systems [13]. Together with the market growth more and more important is identification of factors affecting the performance of electronic commerce systems and customer loyalty [14]. Key elements of strategies are based on building trust [15], improving the quality of the systems [16], levels of security and privacy [17], their accessibility [18], development of international versions [19], solving cultural issues [20] and implementing new features towards consumer satisfaction and web usability [21].

For studying the quality and usability of e-commerce services and similarly for studying various types of Internet services, different types of methods based on the identification of key factors [76] influencing the perception of a given service by users are employed i.e. [22]. The methods differ especially in terms of assessment criteria and theoretical foundations on which they are based [74] [75]. Since evaluation of websites is a multiple-criteria problem, in the literature one can see attempts of using Multi-Criteria Decision Analysis (MCDA) methods for evaluating websites.

The objective of this article is to construct a quality assessment model of the most popular world e-commerce websites. An attempt to combine selected classical methods for evaluating the quality of websites (e.g. eQual) with a formal background used in the MCDA methodology constitutes a methodological research basis, which at the same time is the authors' contribution. However, it is assumed that additional application of the MCDA methodology will make it possible to carry out a wide analysis and verification of, obtained in the research, website rankings, and of users' preferences. This issue is of great importance and website quality evaluation methods used nowadays allow conducting this type of analyses only to a limited extent. Paper is organized as follows: Section II includes literature review, Section III presents methodological framework of proposed approach, Section IV presents results from the empirical study with conclusions within the Section V.

II. Literature review

A. Website evaluation methods

Website evaluation methods described in the literature employ different quality models, consequently, they differ in criteria used as well their quantity and structure [23]. In order to obtain an opinion on websites, they most often use questionnaires, and grades are expressed on an n-degree Likert scale [24]. Among website quality evaluation methods one can distinguish presented with references and key characteristics in the Table I : eQual, Web Portal Site Quality, Ahn method, SiteQual, Website Evaluation Questionnaire, Website Quality Model, E-S-QUAL and E-RecS-Qual,WAES.

The eQual method was constructed on the basis of Quality Function Deployment which is a structured process ensuring means of identification and providing users' opinion on the quality of a product on subsequent stages of its manufacturing process [25]. The eQual method was successfully used to evaluate: e-commerce [26], e-government [25] [27] [28], university [29] and WAP [30] websites.

Web Portal Site Quality came into existence on the basis of a Technology Acceptance Model. The TAM is to explain the influence of perceiving, by the user, information system characteristics on his or her acceptance of the given system. It is based on two quality dimensions, that is, perceived usefulness and perceived ease of use [31]. The Model of Information Systems Success by DeLone and McLean includes information quality and system quality [32][33]. The WPSQ method is used in evaluating portals delivering broadly defined information and services [34].

The Ahn method, similarly to Web Portal Site Quality, was devised with the use of Technology Acceptance Model [35]. The first version of the Ahn method was to study the influence of trust to bank websites on the acceptance by users [36]. When working on the method, the original TAM model was extended with subsequent elements which were important from the perspective of the Internet: information quality, system quality and service quality. These elements were borrowed from an extended Model of Information Systems Success of DeLone and McLean [37][38]. Also, quality characteristics regarding trade: the quality of a product and its delivery were added [39].

The SiteQual method [40] came into being as a combination of the SERVQUAL [41] and Data Quality [42] models. The SERVQUAL model was to reflect service quality, whereas Data Quality was to be responsible for information quality. This model was constructed on the basis of questionnaires concerning music e-commerce websites [43].

When preparing the Website Evaluation Questionnaire method, criteria used in the Website User Satisfaction (WUS) model were used [44]. As in WUS, in every characteristic there is one negative criterion, which is used to verify reliability evaluation [45]. This method came into existence in order to examine e-government websites, but it can also be employed to assess other types of websites which are to provide their users with knowledge and information [46].

The E-S-QUAL and E-RecS-Qual methods stem from the SERVQUAL method used for studying and evaluating service quality [47]. They are a result of adjusting the SERVQUAL scale to the needs of service quality assessment on the Internet. Here, some evaluation criteria in the SERVQUAL model were kept and new criteria essential for determining e-service quality were introduced. The E-S-QUAL method contains the core of the e-SERVQUAL scale, that is criteria perceived by customers who do not have questions and problems related to e-services. On the other hand, the E-RecS-QUAL method comprises additional criteria which are vital when the user encounters problems when using services. These methods were used to evaluate service quality on bank websites [48] as well as e-commerce [49] websites.

While preparing the Website Quality Model method [50], Kano's quality model was used, in which there are defined three levels of customers' expectations with regard to the quality of a product or a service: basic, performance, and exciting [51]. The evaluation of news websites, among other things, CNN.com [52], was carried out by means of this method.

The WAES (Website Attribute Evaluation System) method is designed for assessing office and administration websites. It consists of two groups of characteristics describing transparency and interactivity of a website. An expert's evaluation on a binary scale is employed in the method [53].

In Table I one can see characterized individual quality evaluation methods of websites. For methods using questionnaires it is assumed that the number of users evaluating a website should at least amount to 30 [54].

The most interesting method, out of all analyzed ones, seems to be eQual, which is characterized by the highest formalization level and which in many cases proved to be highly universal. The method is based on 22 criteria in the form of questionnaire questions. When evaluating, a Linkert scale, which ranges from 1 to 7, is used. Weights of individual criteria are determined in the same way. Apart from criterial evaluation, respondents also provide overall evaluation of a website. On the basis of this assessment, the reliability of partial opinions of every user is verified [27]. When a collection of questionnaire results has been gathered, an analysis of the questionnaires is conducted with regard to reliability and internal cohesion. To determine the reliability of results of a questionnaire in the eQual method, Cronbach's alpha is employed. It is assumed that the reliability of results is appropriate, if the value of coefficient alpha amounts to at least 0.6 [28]. In the method the result of evaluation is the European Quality of Government Index (EQI) calculated on the basis of the formulas (1), (2), (3) and (4):

$$EQI = \sum_{k=1}^{m} EQI_k / m \tag{1}$$

$$EQI_k = \left(Score_k / Max_k\right) \cdot 100\% \tag{2}$$

$$Score_k = \sum_{i=1}^{n} (o_i(k) \cdot w_i(k)) / n \tag{3}$$

$$Max_k = \sum_{i=1}^{n} (7 \cdot w_i(k)) / n \tag{4}$$

where: m – the number of criteria, n – the number of polled users, $o_i(k)$ – the evaluation of a website with regard to the n-th criterion, given by the i-th user, $w_i(k)$ – the weight of the k-th criterion given by the i-th user.

The problem related to a practical use of the method is to gain weights of criteria by means of questionnaires, because explicit declaration of users' preference may generate errors in the research [55]. This is also confirmed by the authors' research, in which it was demonstrated that weights of crite-

TABLE I.
CHARACTERISTICS OF SELECTED METHODS OF WEBSITE QUALITY ASSESSMENT

Method	Application	No of criteria	Method determining weights of criteria	Assessment scale	Method of examining websites	No of evaluators	Theoretical basis of method	Verification of solution	Reference
eQual	e-commerce, e-government, university websites, WAP websites	22	Questionnaires	1-7	Questionnaires	min. 30	Quality Function Deployment	Consistency reliability of questionnaires (Cronbach's Alpha)	[26], [25], [29], [27], [28], [30]
Ahn	e-banking, e-commerce	54	-	1-7	Questionnaires	min. 30	Technology Acceptance Model, Model of Information Systems Success	Consistency reliability of questionnaires (Cronbach's Alpha)	[39]
SiteQual	e-commerce	28	-	1-9	Questionnaires	min. 30	SERVQUAL, Data Quality	Consistency reliability of questionnaires (Cronbach's Alpha)	[40], [43]
WEQ	e-government	18+8 (negative)	-	1-5	Questionnaires	min. 30	Website User Satisfaction	Negative criteria	[45], [46]
WPSQ	information services	19	-	1-5	Questionnaires	min. 30	Technology Acceptance Model, Model of Information Systems Success	Complex reliability tests (i.a. convergence evaluation, discriminant analysis)	[34]
WQM	information services	32	Questionnaires	1-3	-	-	Kano quality model (levels of customers' expectations)	-	[52], [51]
E-S-QUAL/ RecS-Qual	e-banking, e-commerce	22+11	-	1-5	Questionnaires	min. 30	SERVQUAL	-	[49], [48]
WAES	e-government	40	-	0-1	Expert evaluation	min. 1	-	-	[53]

ria received by means of questionnaires lead to incorrect decision solutions [56][57].

B. Evaluation of websites with the use of MCDA methods

Apart from "classical" methods, discussed in part A, in the literature there are also attempts at employing MCDA methods for evaluation. It is justified since assessment of websites is a multi-criteria problem, in which one needs to take into consideration many dimensions of quality [58]. For instance, Lee and Kozar [59] used the AHP method to evaluate e-tourist and e-commerce websites. Chmielarz widely uses his original scoring method to asses a wide range of websites, i. a. e-commerce as well as e-banking [60][61][62]. Sun and Lin [63] evaluated e-commerce websites with the use of the fuzzy TOPSIS method. Del Vasto-Terrientes et al. [64] evaluated tourist destination websites by means of a new ELECTRE-III-H method. Furthermore, in the works of Lin [65] as well as Kong and Liu [66] in the fuzzy AHP method was used to determine the significance of quality evaluation criteria of e-learning and e-commerce websites. To assess websites, hybrids of various MCDA methods are also used. In the paper by Bilsel et al. [67] determining the weights of criteria was conducted by means of the AHP method, whereas a ranking of hospital websites was constructed with the use of the fuzzy Promethee method. Similarly, Kaya [68] employed the fuzzy AHP method to define weights of criteria, and used the fuzzy TOPSIS method to construct an e-commerce website ranking. A combination of MCDA methods was also used by Huang et al. [69], where solutions were compared with the use of, among other things, Simple Additive Weighting, Multiplicative Exponent Weighting, TOPSIS, concordance and discordance analysis methods. Weights of criteria in above-mentioned were determined by means of the OWA method.

The analysis of application of MCDA methods in website evaluation indicates that most of them used questionnaires to collect assessments of websites. As for determining weights of criteria, pairwise comparison matrices and the AHP method are most often used for this purpose. Since a significant number of such comparisons might be problematic, a limited number of criteria are usually used. It should be emphasized that for constructing a model of criteria only a few papers used theoretical bases identifying the need for presenting both specific quality measures and criteria. Moreover, only in some papers the sensitivity/robustness analysis of results were carried out. However, applying MCDA methods to evaluate websites has a greater potential than just constructing a ranking. This can be proved by a model of a decision process defined by Guitouni [70] wherein critical steps are exploitation and recommendation stages. On the operation stage, one can conduct the analysis of an obtained solution, such as examining its stability [77] [78] or the analysis of decision-makers' preference.

III. PEQUAL METHODOLOGICAL FRAMEWORK

A. Selection of an MCDA method for evaluating websites

Every decision problem can be attributed to the problematics the decision problem deals with. The problematics result from the aim which is expected from the decision process [79]. In the problematics of description (P.δ), preparing a description of potential actions and the identification of a criterion or a family of criteria pose a problem. In the problematics of choice (P.α), supporting the decision-maker is concentrated on selecting a small number of "good" variants. The problematics of sorting (P.β) is concentrated on attributing a variant to one of classes available. Finally, in the problematics of ranking (P.γ), a ranking of decision variants according to defined criteria is prepared [80].

The MCDA method, which is used in evaluating websites, should especially take into consideration indifference and preference relations, which will make it possible to differentiate the quality of evaluated websites. Moreover, it should not allow an indifference relation to appear, since it is essential that the website ranking is total. Taking into account acceptable compensation criteria, it is reasonable to assume that certain website elements can convince users to use it, even though in some respects it falls short of expectations. Therefore, compensation of low-marked criteria by high-marked ones seems to be legitimate. Measuring data, on which the method will work, cannot be determined as reliable, since these are subjective users' opinions expressed in questionnaire on a quantitative scale. Nevertheless, such data unreliability may be expressed by defining a proper value of an indifference threshold. The problematics considered by individual MCDA methods is of importance, because a method ought to consider, first of all, the problematics of a ranking. It allows putting websites in order according to their synthesized quality, expressed on a quantitative scale. What is more, one can consider methods comprising also the problematics of description, what allows analyzing the obtained solution in a broader way. For the reason that quality is assessed by many users, a method should also offer a group evaluation mechanism. The analysis of characteristics and abilities of individual MCDA methods [71][72][73] with relation to the requirements discussed points out to the fact that the Promethee II [88] method along with its group development, i.e. Promethee GDSS, can be used in evaluating websites.

B. Framework of website evaluation

The authors' methodology of website quality evaluation named PEQUAL (Promethee - eQual) is based on the eQual method, which has its foundations in Quality Function Deployment. To do empirical research at first, questionnaires were collected from 41 users. In the research sample, there were computer literate users who are experienced in doing the shopping online. All of them evaluated 10 e-commerce websites: Alibaba, Amazon, Apple, BestBuy, eBay, Macy's, Rakuten, Staples, Target, and Walmart. The reason for selecting the e-commerce websites was the result of analysis of valid rankings of top e-commerce websites presented, among other things, in [81], [82], [83], [84], [85]. Thus, 410 questionnaires were collected which then were verified in terms of consistency reliability and Cronbach's alfa was determined. Questionnaire evaluation was conducted with the use of criteria and an evaluation scale of the eQual method and the results of the questionnaires were aggregated with the use of the Promethee method. Also, on the basis of this method, the broad analysis of the obtained solution was carried out. The research took into consideration two scenarios of aggregation of partial evaluations in a overall ranking. The input data had been obtained in the questionnaires. In the first scenario, partial evaluations were averaged, and next, the aggregation of mean criterial evaluations into a overall evaluation, with the use of the Promethee II method, was conducted. The second scenario consisted in determining individual rankings by means of the Promethee II meth-

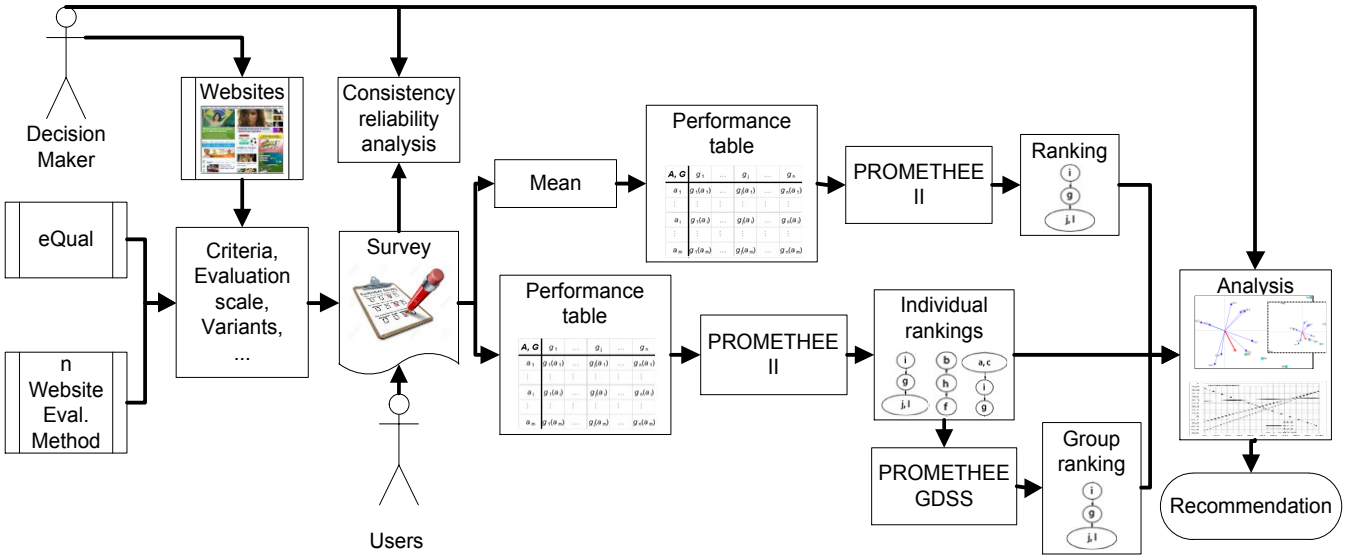

Fig. 1 PEQUAL methodological framework of website evaluation

od on the basis of partial evaluations and then aggregating individual rankings in a group ranking by means of the method Promethee GDSS. After generating rankings, the analysis of the solution obtained was carried out in every scenario with the use of the GAIA method and the analysis of ranking robustness to the changes of weights of criteria, which are an integral part of the Promethee method. On the grounds of the transparency of the conducted analysis, it was assumed that the weights of all criteria are equal. Moreover, it was assumed that the partial evaluations obtained in the questionnaires can be characterized by some degree of uncertainty. Therefore, an application of various indifference variants was considered, and consequently the influence of minor errors in partial evaluations on the obtained results was eliminated. The presented practical approach is depicted in Figure 1. What is more, at first, the aggregation of questionnaire results into a final evaluation with the use of the eQual method was carried out. This was aimed at conducting a comparative analysis of obtained results with reference to the results of eQual.

IV. Results

A. Empirical research

After gathering the results of the questionnaires, their consistency reliability analysis was carried out. The value of Cronbach's alpha obtained in the research amounted to 0.95. All scores of the consistency reliability analysis, including the value of Cronbach's alpha for individual groups of criteria, are presented in Table II. The values of Cronbach's alpha indicate high reliability of the conducted questionnaire, since it exceeds the boundary value of 0.6 [28].

Next, in accordance with the eQual method a overall value of eQual Index and values obtained for individual criteria and their groups were determined. The scores of the total value and groups of criteria are depicted in Table III.

In another research the scores of questionnaires were averaged and calculations were made with the use of the Promethee II method. Average criterion evaluations of questionnaire scores, which constitute a performance table, are depicted in Table IV (average values are in accordance with values used for the eQual method). In the Promethee II method for each criterion a preference model with a preference V-shape function, for which an indifference threshold q=0 and a preference threshold p=7, was used. A preference direction was maximized. The selected preference model was assumed in order to reflect, as accurately as possible, the model used in the eQual method. A website ranking obtained according to the Promethee II method, with the use of the given preference model, is presented in Table V. The sequence of variants in the obtained ranking is in accordance with the sequence in the eQual method.

TABLE II.
CRONBACH'S ALPHA SCORES

Cluster of criteria	Group of criteria	Criterion	α if item deleted	α for group of criteria
Usability	Usability	C1	0.9454	0.9379
		C2	0.9453	
		C3	0.9449	
		C4	0.9453	
	Site design	C5	0.9461	0.8722
		C6	0.9454	
		C7	0.9459	
		C8	0.9451	
Information quality	Information quality	C9	0.9455	0.8854
		C10	0.9455	
		C11	0.9521	
		C12	0.9452	
		C13	0.9450	
		C14	0.9456	
		C15	0.9449	
Service interaction	Trust	C16	0.9447	0.9038
		C17	0.9445	
		C18	0.9455	
		C22	0.9464	
	Empathy	C19	0.9465	0.767
		C20	0.9473	
		C21	0.9472	

B. Graphical analysis of Promethee solution

After determining the ranking, its analysis, based on the GAIA methodology, was done. Figures 2-4 depict the scores of this analysis separate for: clusters (Figure 4), groups (Figure 3) and individual criteria (Figure 2).

TABLE III.
ASSESSMENT RESULTS OF WEBISITES ACCORDING TO EQUAL METHOD

Website	Evaluation Quality Index									
	Alibaba	Amazon	Apple	BestBuy	eBay	Macy's	Rakuten	Staples	Target	Walmart
Usability	70.30%	78.66%	79.62%	70.56%	82.93%	71.17%	70.47%	69.08%	68.38%	72.65%
Site design	69.25%	75.09%	83.01%	62.46%	69.34%	68.21%	62.28%	65.68%	60.80%	67.16%
Information quality	71.33%	78.00%	77.15%	72.97%	78.55%	70.08%	69.34%	69.34%	71.33%	68.74%
Trust	68.12%	81.62%	85.37%	64.72%	79.88%	65.85%	61.85%	67.42%	60.54%	70.30%
Empathy	60.05%	70.85%	70.15%	55.87%	61.09%	57.26%	54.24%	55.98%	52.96%	59.23%
Overall	68.64%	77.27%	79.20%	66.79%	75.53%	67.42%	64.84%	66.46%	64.41%	68.15%
Rank	4	2	1	7	3	6	9	8	10	5

TABLE IV.
PERFORMANCE TABLE FOR PROMETHEE II BASED ON MEAN VALUES OF CRITERION EVALUATIONS

Group of criteria	Criterion	Website									
		Alibaba	**Amazon**	**Apple**	**BestBuy**	**eBay**	**Macy's**	**Rakuten**	**Staples**	**Target**	**Walmart**
Usability	C1	4.902	5.610	5.683	5.000	6.024	5.049	4.976	4.927	4.854	5.049
	C2	4.951	5.707	5.415	4.878	5.951	4.976	5.098	4.927	4.756	5.220
	C3	5.000	5.317	5.610	5.000	5.610	4.854	4.805	4.829	4.683	4.829
	C4	4.829	5.390	5.585	4.878	5.634	5.049	4.854	4.659	4.854	5.244
Site design	C5	4.829	5.024	5.976	4.341	4.683	4.707	4.268	4.512	4.220	4.927
	C6	5.098	5.488	6.024	4.561	5.341	5.049	4.707	4.927	4.707	4.805
	C7	4.829	5.366	5.829	4.537	4.878	4.756	4.439	4.732	4.415	4.805
	C8	4.634	5.146	5.415	4.049	4.512	4.585	4.024	4.220	3.683	4.268
Information quality	C9	5.000	5.537	5.049	5.073	5.634	4.780	4.805	4.780	4.756	4.537
	C10	4.902	5.537	5.902	5.098	5.683	4.902	5.024	4.805	4.902	4.805
	C11	5.585	5.268	5.488	5.122	5.415	5.512	5.488	5.146	5.561	5.317
	C12	4.951	5.463	5.341	5.268	5.537	4.902	4.732	4.854	5.049	4.610
	C13	4.732	5.537	5.561	5.244	5.512	4.878	4.756	4.707	4.902	4.976
	C14	4.854	5.488	5.171	5.098	5.220	4.634	4.659	4.854	5.024	4.488
	C15	4.927	5.390	5.293	4.854	5.488	4.732	4.512	4.829	4.756	4.951
Trust	C16	4.927	5.829	5.927	4.244	5.878	4.512	4.415	4.488	4.195	4.927
	C17	4.732	5.805	6.000	4.537	5.659	4.512	4.293	4.927	4.317	4.951
	C18	4.732	5.610	5.805	4.707	5.561	4.659	4.390	4.780	4.220	4.902
	C22	4.683	5.610	6.171	4.634	5.268	4.756	4.220	4.683	4.220	4.902
Empathy	C19	3.951	4.927	4.878	3.537	4.049	3.976	3.659	3.756	3.366	3.951
	C20	3.878	4.683	4.293	3.366	3.488	3.439	3.463	3.610	3.146	3.756
	C21	4.780	5.268	5.561	4.829	5.293	4.610	4.268	4.390	4.610	4.732

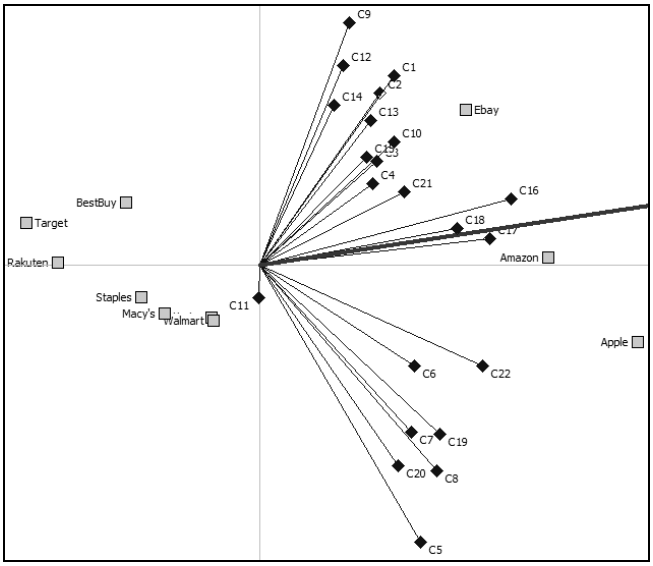

Fig. 2 GAIA analysis for criteria

The analysis of Figure 2 demonstrates that almost all criteria, except C11, support three leading variants in the ranking, i.e. Apple, Amazon and eBay. This observation is confirmed by a detailed analysis of numbers contained in Table IV. Moreover, a criterion C11 is in conflict with C9, C12, C14, C1, C2, C13 and also partially with subsequent criteria placed in the first quarter of the system of coordinates. It means that variants which are highly evaluated with regard to the criterion C11 get lower evaluation in terms of other criteria mentioned. Furthermore, the length of C11 vector points out that this criterion has the least influence on the final website ranking.

An analysis of Figure 3 allows finding out that users evaluate Usability and Information Quality of individual websites in a similar way. In other words, if an examined website gets high marks for criteria in the Usability group, it is usually highly marked with regard to criteria in the Information Quality group. However, evaluations of criteria in the Usability and Site Design groups are independent of each other. This piece of information is important, because criteria in the groups belong to one cluster of criteria, therefore, their evaluations should usually be similar to one another. Similarly, criteria evaluations of Empathy and Trust, which also belong to one cluster, are independent of each other. Moreover, one can state that the most significant influence on the final ranking have criteria belonging to the Site Design and Usability groups, since their vectors are longest. Furthermore, the final ranking of websites most strongly overlaps with the criterial evaluations of the Trust group.

The presentation of clusters of criteria (Figure 4) on the GAIA plain indicates that evaluations of variants with regard to criteria belonging to the Usability and Service Interaction clusters and they are independent of the Information Quality cluster. It may seem contradictory to the conclusion drawn

when analyzing Figure 3 which expresses the similarity of evaluations with regard to the Usability and Information Quality criteria groups. However, one needs to bear in mind that the Usability cluster contains the Usability and Site Design criteria groups. When considering the impact of individual criteria clusters on the final ranking, it should be noted that this ranking is, to the highest degree, dependent on the criteria belonging to the Information Quality and later Service Interaction clusters. The criteria belonging to the Usability cluster have the lowest influence on the ranking.

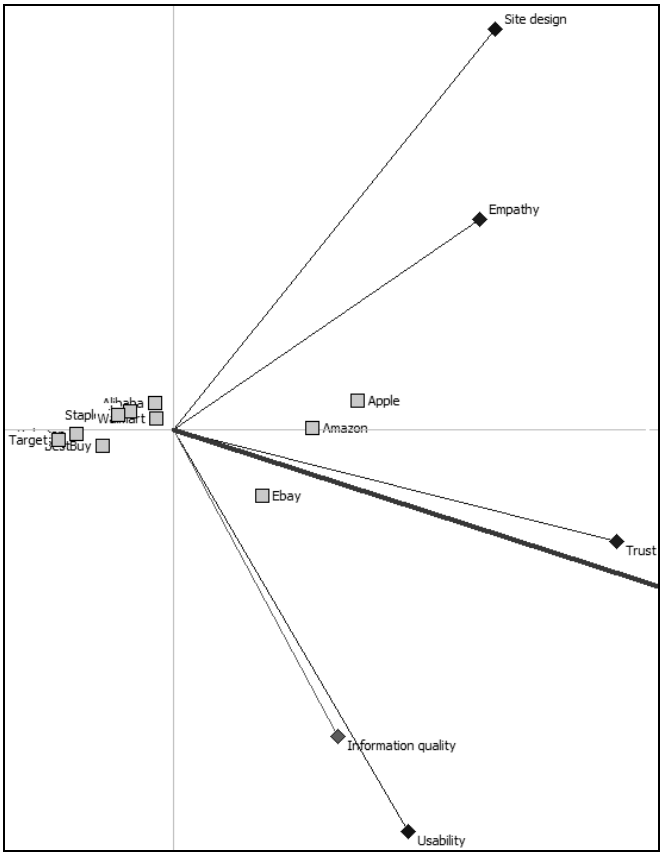

Fig. 3 GAIA analysis for groups of criteria

C. Robustness analysis of solution

Apart from the GAIA analysis, also, the robustness analysis, taking into consideration changes in weights of criteria, of the ranking was carried out. Figure 5 depicts, one by one, the scores of the analysis for weight changes of subsequent criteria clusters, i.e. Usability, Information Quality and Service Interaction. Also, Figure 5 presents the robustness analysis of the ranking for changes of weights of criteria belonging to the Usability cluster. It must be explained that the weight changes regarded all clusters, for instance, when a weight of Usability was 0, the criteria in other clusters obtained a weight of 7.14%, whereas when a weight of Usability was 100%, all of its criteria obtained a weight of 12.5%. Analogically, weights for the robustness analysis of the Information Quality and Service Interaction clusters were determined. The results of the robustness analysis indicate that three top positions in the ranking are very stable, because only increasing weights of criteria in the Information Quality cluster above 80% (that is over 11.5 for each criteria of the cluster) may cause changes on these positions. Therefore, one can assume with the high level of probability that, independent of weights of criteria, the obtained ranking is correct.

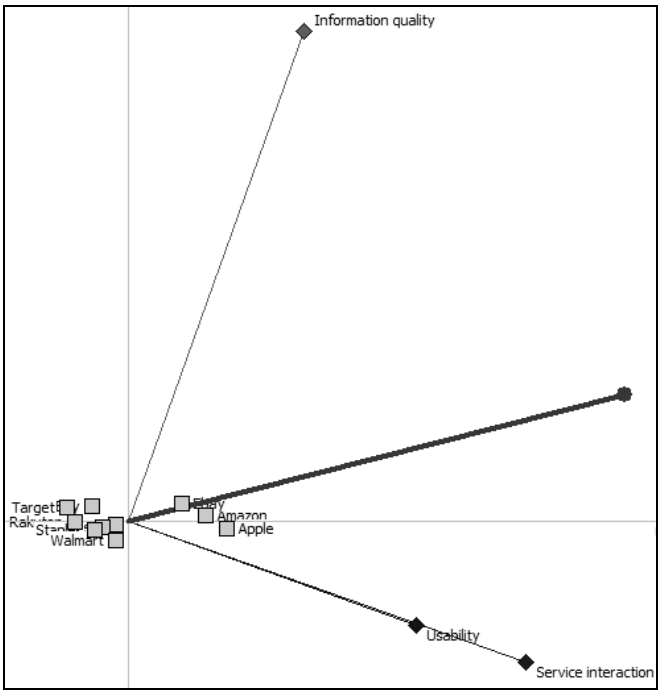

Fig. 4 GAIA analysis for clusters of criteria

D. Uncertainty analysis

The next step in the conducted analysis was to verify the influence of uncertainty of partial evaluations on the sequence of variants in the ranking. Therefore, a new ranking of variants was determined on the basis of a modified preference model, in which a preference function V-shape with an indifference area, where the indifference q=1 and preference p=7 thresholds were used, was applied. Using the indifference threshold was to eliminate the influence of potential mistakes in users' evaluation, which consists in considering one website slightly better than another one. It should be noted that the threshold q=1 for averaged values provides a

TABLE V.
RANKING OF WEBSITES BASED ON PROMETHEE II AND AVERAGED CRITERIA EVALUATIONS

Website	Alibaba	Amazon	Apple	BestBuy	eBay	Macy's	Rakuten	Staples	Target	Walmart
ϕ_{net}	-0.0137	0.0822	0.1037	-0.0343	0.0629	-0.0272	-0.0559	-0.0380	-0.0607	-0.0191
Rank	4	2	1	7	3	6	9	8	10	5

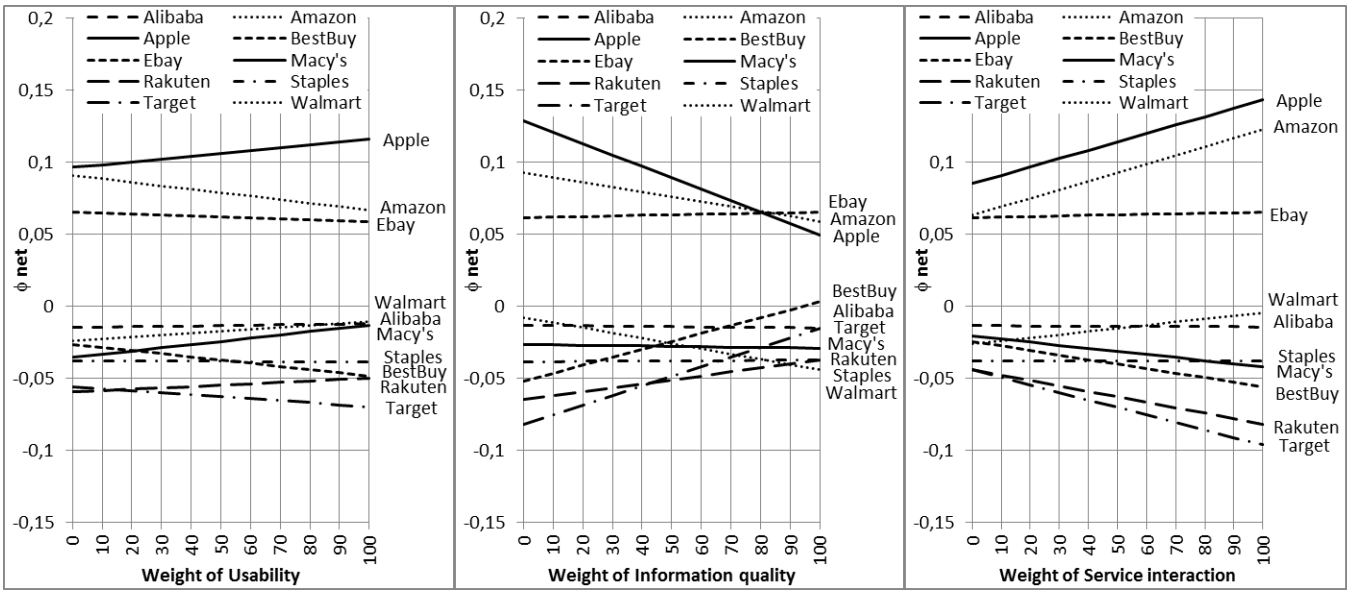

Fig. 5 Robustness analysis of criteria clusters

significant error of margin, and with regard to many criteria almost all variants are considered indifferent. However, the ranking obtained has variant shifts only on further positions. To be more specific, there was a change of websites on positions 4 and 5 (Alibaba a Walmart) as well as 7 and 8 (Staples and BestBuy). Therefore, it can be assumed that the basic ranking which was obtained with the use of the Promethee II method is reliable. The ranking obtained with the used of the described preference model is depicted in Table VI.

E. Comparison of averaged ranking with group ranking

Another part of the conducted research consisted in conducting, by means of the Promethee II method, an aggregation of partial evaluations for individual questionnaires and determining individual rankings. They were generated next to the preference model, which had been used for averaged evaluations, i.e. with the preference function V-shape and thresholds q=0, p=7. Later, the individual rankings were aggregated into a group ranking with the use of the Promethee GDSS method. The ranking is presented in Table VII and its analysis indicates that the obtained sequence of websites is the same as in the ranking obtained before, which was based on averaged evaluations, presented in Table V. The values of evaluations ϕ net are also similar.

The next step was to conduct a GAIA analysis for the group ranking. For the reason of clarity, Figure 6 depicts the GAIA plane for 10 respondents.

The projection of decision-makers' preferences on the plane shows that everybody, except DM6, supports to some extent five best websites in the ranking. However, it should be noted that evaluations of users DM7 and DM8 are contradictory, similarly to users DM4 and DM6. Moreover, the highest influence on the final ranking, out of 10 presented users, have DM8, DM9 and DM10, whose vectors are longest. As far as the respondents' individual rankings are concerned, their analysis was carried out analogically to the analysis conducted for averaged evaluations.

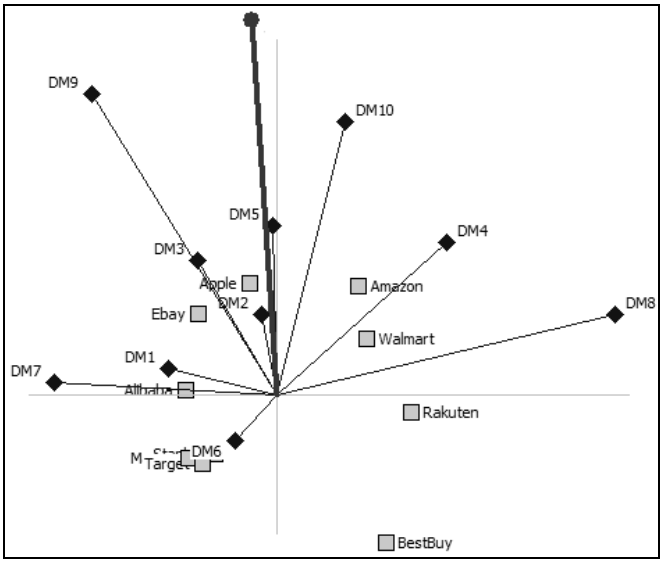

Fig. 6 GAIA analysis for clusters of criteria

TABLE VI.
RANKING OF WEBSITES BASED ON PROMETHEE II AND AVERAGED CRITERIA EVALUATIONS AND THE THRESHOLD Q=1

Website	Alibaba	Amazon	Apple	BestBuy	eBay	Macy's	Rakuten	Staples	Target	Walmart
ϕ_{net}	-0.001	0.0076	0.0175	-0.0054	0.0038	-0.0027	-0.0069	-0.0028	-0.0093	-0.0008
Rank	5	2	1	8	3	6	9	7	10	4

TABLE VII.
RANKING OF WEBSITES BASED ON PROMETHEE GDSS

Website	Alibaba	Amazon	Apple	BestBuy	eBay	Macy's	Rakuten	Staples	Target	Walmart
ϕ_{net} **GDSS**	-0.0078	0.0455	0.0574	-0.0192	0.0347	-0.0134	-0.0313	-0.0213	-0.0339	-0.0108
Rank GDSS	4	2	1	7	3	6	9	8	10	5

V. CONCLUSION

In the proposed approach the multi-stage construction of the model was realized with regard to the criteria taken from the eQual method with the use of the Promethee method (PEQUAL). It extends earlier approaches by introducing MCDA based multi stage evaluation and analyses. In the article, 10 most popular world e-commerce websites were evaluated. On the basis of the presented research, one can state that e-commerce websites most highly valued by users are: Apple, Amazon and eBay. The conclusions were confirmed by verifying the obtained ranking with the use of the analysis of robustness to changes of weights of criteria and examining the influence of evaluations on the final ranking.

Furthermore, the use of the Promethee GDSS method and the GAIA analysis, which is an integral part of the Promethee method, made it possible to indicate users' individual preferences. Also, the GAIA analysis allowed examining mutual dependences between individual groups and clusters of criteria on the basis of graphic data. The interpretation of the GAIA plane is less time-consuming and easier than the analysis of number values of evaluations, and the conclusions drawn on its basis are equally essential [86] [87].

The research framework of the quality of websites presented in the article can be the basis for their evaluation along with the correctness verification of obtained evaluations and preferences of the respondents. As it has been demonstrated in the presented research, this solution is functionally richer than classical MCDA-based methods of website evaluation methods which have been used in the literature to date.

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