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A Distributed Cognition Framework to Compare E-Commerce Websites Using Data Envelopment Analysis

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***Abstract*—**This paper presents an approach based on the adoption of a distributed cognition framework and a non parametric multicriteria evaluation methodology (DEA) designed specifically to compare e-commerce websites from the consumer/user viewpoint. In particular, the framework considers a website relative efficiency as a measure of its quality and usability. A website is modelled as a black box capable to provide the consumer/user with a set of functionalities. When the consumer/user interacts with the website to perform a task, he/she is involved in a cognitive activity, sustaining a cognitive cost to search, interpret and process information, and experiencing a sense of satisfaction. The degree of ambiguity and uncertainty he/she perceives and the needed search time determine the effort size – and, henceforth, the cognitive cost amount – he/she has to sustain to perform his/her task. On the contrary, task performing and result achievement induce a sense of gratification, satisfaction and usefulness. In total, 9 variables are measured, classified in a set of 3 website macro-dimensions (user experience, site navigability and structure). The framework is implemented to compare 40 websites of businesses performing electronic commerce in the information technology market. A questionnaire to collect subjective judgements for the websites in the sample was purposely designed and administered to 85 university students enrolled in computer science and information systems engineering undergraduate courses.

***Keywords*—**Website, e-commerce, DEA, distributed cognition, evaluation, comparison.

I. Background

In the literature, several approaches to the websites evaluation have been proposed. They differ as to the goal of the evaluation (usability measurement, web site effectiveness evaluation, interface feature definition, web site quality) and collected information useful to the evaluation (observations and log activity, heuristics, focus group, questionnaires, brainstorming, web site features enumeration) [5], [10], [11], [17], [19], [22], [32], [42], [52], [53], [55], [61], [62], [64], [83]. Researchers that focused on a website usability and effectiveness evaluation, moving from their personal experience in the field, provided guidelines and criteria to evaluate the usability of websites design.

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The concept of usability was firstly introduced and defined by scholars in the early 1980s. Usability was considered a critical factor to achieve the success of interactive products and systems [25]. From the 1990s, with the fast growing usage of the Internet, the usability concept has been often associated to website design, so that for many people the two terms are inextricably linked. According to the International Standards Organization (ISO), usability is the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" [43, p. 34]. Both scholars in the human-computer interaction (HCI) and the information-systems (IS) domains have stressed the importance of usability assessment in the study of online purchasing behavior as a measure of website quality and use [1], [63], [64]. In the opinion of these scholars, every website design project should be subjected to usability testing, usability understanding and other validation methods [61], [62], [81], even though websites resulting with a good usability cannot guarantee users' preference [84]. Researchers that adopted a website quality measurement conceptualization driven from the quality of product or service framework usually privileged the Kano's Model of Quality as a theoretical framework to evaluate a website quality [23].

However, even though in the last years many researchers have provided frameworks and a number of ways to evaluate e-commerce websites specifically [12], [54], there is a lack of theoretical justification of the framework and evaluation criteria they adopt. Moreover, these approaches also neglect or do not effectively model the cognitive process of online consumers that determines their website quality perception during his/her usage experience. Important concepts in the usability evaluation are the ease of navigation, information structure understanding and search for useful information. Consumers expect to find the information they want, find it quickly, and to do so with little effort and greater efficiency [41]. Poor navigability, lack of navigation support, orphan pages, looping animation, slow download times, and confusing content make to search for desired information and develop useful knowledge to make a decision exhausting and frustrating. Literature addresses these issues by suggesting that an e-commerce website should be considered a sort of "decision support system" supporting all the stages of the online consumer purchasing problem-solving and decision-making process [56]. Thus the cognitive process addressing online purchasing is a process of distributed cognition between the consumer and the website interface.

This paper presents a framework based on the adoption of a distributed cognition perspective [38], [39], [49], [70], and a multicriteria evaluation methodology (DEA) to measure and compare website efficiency as a measure of website usability and quality. In particular, a model is proposed which is implemented to compare 40 e-commerce websites of companies selling goods in the information technology market. The paper has the following structure. First, the distributed cognition framework is introduced and discussed. Next, the evaluation approach is presented. Finally, the methodology used to evaluate and compare e-commerce website is illustrated and the results of the approach implementation are reported and discussed.

II. The Distributed Cognition Framework

In the traditional view, cognition is a localised phenomenon that is best explained in terms of information processing at the level of the individual [30]. Cognition refers to the way individuals process information and develop useful knowledge related to the interpretation of facts. It involves a number of cognitive processes, such as [16], [30], [58], [65], [76], [82]: short-term memory, long-tem memory and learning, problem solving, decision making, attention and scope of concern, search and scanning, time perception, perceptual or mental load, anxiety and fear. The distributed cognition approach claims that cognition is better understood as a distributed phenomenon in which cognitive activities are embodied and situated within the work setting in which they occur [33], [38], [40]. A general assumption of the distributed cognition approach is that cognitive systems consisting of one or more than one individual and artifacts have cognitive properties that differ from those of the individual or individuals alone that participate in those systems. It does not focus on human activity in terms of processes acting upon representations inside an individual mind, but it focuses on the interactions between the distributed structures of the phenomenon that is under scrutiny, i.e. the interactions among an individual or a number of individuals and some technological devices to perform a task [69], [78], [83]. The distributed cognition approach distinguishes between internal and external representations of knowledge. Internal representations are in the individual mind, as propositions, productions, schemas, mental images, connectionist networks, or other forms. External representations are in the world, as physical symbols or as external rules, constraints, or relations embedded in physical configurations [77], [89]. The representations of information and knowledge external to individuals by means of an electronic interface have a number of properties that affect user cognitive effort when performing his/her task [13], [88]: a) they can provide memory aids, and because information resides in front of the user, it has not to be remembered; b) they can anchor and structure user cognitive behavior, as the physical structures in external representations constrain the range of possible cognitive behaviors, allowing some of them and prohibiting others; c) they change the nature of the task, making its performance easier; d) they provide information that can be directly perceived and used without being interpreted and formulated explicitly, as it emerges from the physical constraints. The environment supports cognition not just passively by merely representing itself, but actively by registering and storing user activities for future use, and thus functioning like an external memory [15], [44], [45].

III. The Evaluation Approach

Individuals are information processors [51] who have, however, a limited capability to process information as a consequence of the cognitive limitation of their structure of storing memory and attention [4], [59], [73], [74]. E-commerce websites allow the consumer to perform problem-solving and decision-making more efficiently along all the stages of online purchasing, providing the consumer with an aid capable to reduce his/her cognitive effort and increase his/her ability to process information.

The proposed framework assumes that: a) the cognitive process has a central role in addressing the purchasing behavior – and in particular decision-making – of the consumer; b) cognition is distributed between individual and electronic interface; c) the website as an electronic interface provides structures to represent and store information and knowledge through the use of symbols, constraints and working rules which are complementary to those of the consumer. The behavioral models of the consumer (i.e., the Nicosia, Howard-Sheth, Engel-Blackwell, Bettman, Andreasen) emphasize that [2], [7], [28], [37], [60], [72]: information processing has a central role in the problem-solving and decision-making process of the consumer; information processing has a task-oriented nature; information processing capability of consumer is limited; information search useful to decision-making needs to resort both to the consumer internal memory and to external sources; decision-making and evaluation processes are influenced by the consumer cognitive style; information acquisition, evaluation and useful knowledge generation proceed parallel; motivation affects the effort devoted by the consumer to information search.

In this study, an e-commerce website is modelled as a black box capable to provide the consumer with a set of functionalities. When the consumer interacts with the website in order to achieve a precise goal performing the corresponding task, he/she is involved in a cognitive activity [78]. The performance of this cognitive activity during human-computer interaction is the outcome of a number of factors, both objective and subjective [66]. The objective factors that have an effect on the performance are related to the technical features of the technological system used (connection speed, monitor quality, browser version, computer performance, etc.). The subjective factors are generally related to the user capabilities, characters, attitudes and motivation (capability to use computer effectively, interest for the site content, emotional state, concentration capacity, capability to work under ambiguity and uncertainty, etc.). For instance, some individuals do not like computers, do not feel familiar with Internet navigation, or are made anxious by them [75]. Other individuals, vice versa, are strongly attracted by computers and have acquired a great capability to use Internet. Even these latter group of individuals may have different preferences for interaction styles, colours, graphic presentations, data presentations, information structure, character type, etc. A clear understanding of personality and cognitive styles can be helpful in designing a website for a specific group of users.

When the user/consumer interacts with the electronic website interface, he/she sustains a cognitive cost due to the efforts to be made to search, interpret and process information. Both the information overload and redundancy arising from the interaction of the user with the website interface and the difficulty to find the requested information increases the consumer sense of uncertainty and bewilderment, which cause the search activity to become psychologically costly [79], [80], [86]. The degree of ambiguity and uncertainty he/she perceives and the needed search time determine the effort size – and, henceforth, the cognitive cost amount – he/she has to sustain to perform his/her task. Literature on cognition and organization behavior defines: a) uncertainty as the cognitive state in which an individual falls as a consequence of the lack of information [20], [34]. This lack of information increases with task complexity, and in particular, with its variety. Indeed, the increase of the number of secondary tasks increases the number of activities not strictly correlated that should be executed. Uncertainty arises both as a consequence of the increased variance of the knowledge domains that individuals have to master in the same time, and of the difficulty of planning. When a great number of activities have to be executed it is not easy to define accurately all the details before task execution is started, and new information has to be acquired during the process as the not expected events produce a gap in the knowledge; b) ambiguity as the cognitive state of an individual when he faces several different interpretations, usually contrasting, of a situation. When tasks cannot be correctly framed, their execution cannot be easily planned and has ambiguous aspects. If knowledge cannot be articulated, problems can be defined only vaguely, and individuals cannot easily address problem-solving and decision-making [20], [21], [67], [85]. By only increasing the amount of available information and knowledge it is not possible to satisfy all the needs of information and knowledge of the individuals. New data can generate confusion, and even increase uncertainty if they increase the number of possible interpretations in the same time conflictual for a certain situation [20]. Individuals can face a high level of ambiguity only by increasing the amount of rich information, capable to alleviate ambiguous situations, by resorting to mechanisms which make it possible to transfer and properly exploit tacit knowledge.

The website characteristics may seriously affect how this interaction occurs and the amount of the cognitive cost that the individual should bear. For instance, when the website includes both highlighted and non-highlighted options or differently colored options, search time for useful information depends both on the time it takes to find the target when it is a highlighted option and the time it takes to find the target when it is not a highlighted option or it is differently colored [18], [29]. Search time is strongly related to the density and complexity of the background [9], [24]. Moreover, poor web design requests to the user a greater attention to understand the logic and the way the electronic interface works. The more the user has to think about how to use the website interface, the fewer cognitive and perceptual resources he/she will have at his/her disposal to perform the main task.

On the contrary, task performing and result achievement induce a sense of gratification, satisfaction and usefulness [8]. Satisfaction, gratification and the perceived usefulness are important to the consumer as they reflect a positive outcome from the outlay of scarce resources and the fulfilment of previously unmet needs [6]. Moreover, they affect consumer's attitude and his/her intention to purchase. Several scholars have found that the quality of retailing websites is a dominant antecedent of consumer satisfaction within the online shopping environment [87]. Online shopping provides the user with a different experience from shopping in a physical retail store, and, as the web store cannot fully simulate the environment and atmosphere of a physical retailer due to the limitations of the electronic interface, the website design has to compensate for the loss of them [26], [28].

As human short-term working memory capacity is limited [57], a website should be capable to eliminate or reduce the working memory overload associated to the need to mentally retain and integrate several pieces of information and knowledge [80]. Cognitive efficiency, then, may be an effective measure of how much cognitive work the user has to perform outside of his/her working memory in a given task, given the constraining nature of the website electronic interface. The theories of cognitive efficiency suggest that, when cognitive user cognitive tasks can be performed easily and quickly, the cognitive effort can be minimized and the search performance and the user gratification can be maximized. If information is almost processed automatically with the support of the website, the user cognitive efficiency may substantially increase. Better websites thus allow the user to have a greater cognitive efficiency.

Henceforth, for every website an efficiency index can be constructed, by considering the ratio between the user perceived cognitive benefits and cognitive costs incurred during the interaction with the website:

$$\text{efficiency} = \frac{\sum \text{cognitive benefits}}{\sum \text{cognitive costs}} \tag{1}$$

IV. The Approach Implementation

A. Modeling Website Efficiency

Literature on website usability has suggested three macro-dimensions (or areas) useful to measure a website performance [11], [32], [42], [61], [62]: user experience, site navigability and structure. These dimensions were used to measure the user cognitive benefits and costs (see Fig. 1). Particularly, the "experience" dimension includes those cognitive benefits that the user receives in terms of perceived satisfaction for the website usage, usefulness and attractiveness for the website. The remaining two dimensions, "navigability" and "structure" are related to website characteristics that can originate cognitive costs for the user in the interaction with the website electronic interface. These characters can generate ambiguity and uncertainty, and determine an over-consumption of time in the search for useful information.

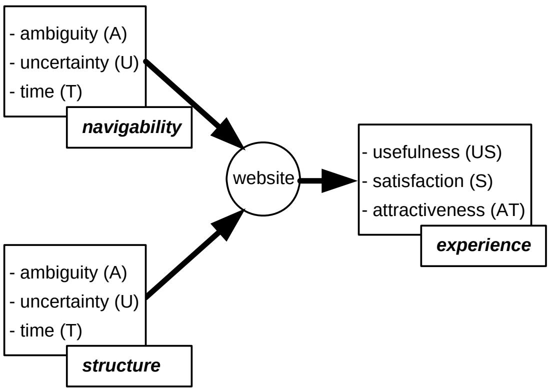

Fig. 1 The pattern for website efficiency modeling

Thus, the website efficiency index assumes the following shape:

$$\frac{\sum \text{Benefit}_{\text{Experience}}(\text{US},\text{S},\text{AT})}{\sum \text{Cost}_{\text{Structure}}(\text{A},\text{U},\text{T}) + \sum \text{Cost}_{\text{Navigability}}(\text{A},\text{U},\text{T})} \qquad (2)$$

B. Evaluating and Comparing Website Efficiency

This study adopts a non parametric multicriteria approach to measure and compare website efficiency. In the literature on efficiency measurement there has been a growing interest for non parametric methodologies [27], based on the method proposed by [14]. This method – known as DEA (Data Envelopment Analysis) – is based on a seminal idea proposed by [31] in 1957. DEA is an analytic non parametric technique that allows the extension of the efficiency analysis from a mono-dimension space to a "n" dimension space, preserving each dimension integrity, but in the same time, without making any arbitrary assumption to obtain a unique value for efficiency. Thus, it makes possible to avoid some of the critical assumptions made to measure efficiency, assessing the relative efficiency of decision-making units (DMUs) without the need to introduce any a priori minimal assumption relatively to the functional relationships between input and output factors in these units to build the efficiency frontier. Appendix illustrates how DEA works. It provides a unique efficiency measure even when there are a great number of input and output factors and does not require the assignment of predetermined weights to factors. For each unit, assuming that differences across performances of similar decision making units do exist and are measurable, the method builds an objective function as a measure of its relative efficiency against the other units. The maximization of every objective function allows to identify the relative weights assumed by each dimension of the efficiency construct.

The approach was implemented to compare 40 web sites of businesses performing electronic commerce in the information technology market. As scholars acknowledge that generally usability cannot be conceptualized independently of the context in which it is to be assessed, but it is contingent upon both the task for which the website is to be used as well as the target users [50], particular attention was addressed to define and circumscribe a task and a sample of users. Indeed, scholars found that the perceived ease of using the website and of transactional control vary with the type of task the consumer is undertaking [36], [48]. Consistently with the tradition and methods of the usability research, website evaluation needs a high user involvement. The implementation of the proposed approach was therefore conducted in an experimental environment and occurred according to the following steps:

a) design of a questionnaire to collect judgements for the websites considered in the study. The questionnaire was designed in order to measure each one of the nine variables of the model respectively used to measure experience and cognitive cost sustained by the user (i.e., the cognitive cost induced by a sense of ambiguity during website navigation, the cognitive cost induced by the site structure, the cognitive cost determined by the feeling to lose too much time to navigate in search of useful information, the experience linked to site attractiveness, etc.). Each variable was built using a list of statements. The user had to express his/her agreement/disagreement for the statement content using a 9-level measurement grid. After questionnaire filling in, scales reliability was measured calculating the Cronbach alfa index. The questionnaire included also a scale based on the Kolb model to assess the consumer/user *learning style* [46].
b) the questionnaire was administered to a sample of 85 students enrolled in the second year of the course of degree in computer science and information systems engineering of the University of Naples Federico II. Each student was asked to evaluate all the 40 websites. Sixty-three questionnaires were filled in completely and were considered acceptable for the study.
c) questionnaires were classified and grouped according to the users' *learning style*. Five questionnaires were randomly chosen from the group including the largest

amount of the questionnaires filled in by students. These questionnaires were considered in the following step.

d) the mean value was calculated for every item of the scale by summing up judgment values given in the 5 questionnaires. Next, the values assumed by variables measured through the 9 constructs were calculated.

e) efficiency for the 40 websites was evaluated by adopting the CCR DEA formulation, maximizing user experience dimensions (output) while keeping cognitive costs fixed (inputs) [14].

TABLE I
RELIABILITY OF SCALES USED TO ASSESS WEBSITE COGNITIVE DIMENSIONS

website dimension evaluation	scale	# items	Cronbach alfa
website-user interaction experience	website usefulness	7	0.92
	user satisfaction for website usage	4	0.91
	website attractiveness	5	0.83
website structure	uncertainty induced by website structure	3	0.93
	ambiguity induced by website structure	9	0.89
	time consuming induced by website structure	3	0.89
website navigability	uncertainty generated during website navigation	13	0.94
	ambiguity generated during website navigation	4	0.89
	time consuming during website navigation	5	0.78

V. RESULTS

Table I reports information relatively to reliability of scales used to assess website dimensions. Cronbach alfa is higher than 0.70, a threshold value that in social sciences is considered acceptable for using the scale without any fear to lose consistency. Table II also provides the reader with information regarding the scales'size in terms of number of items. For the sake of brevity, the questionnaire used to collect data is not included in the paper.

Table II summarizes the outcome of the CCR DEA model implementation. The assumption was done that scale is influential in the benchmarking study. Websites considered inefficient have an efficiency rate lower than 100%. A website is inefficient if a reference "virtual" website can be built as a linear combination of some websites of the sample, as the virtual website produces at least the same amount of output performance consuming a lower input amount compared to the examined real website. Table II shows that 35 websites are assessed as relatively inefficient. Efficiency evaluation provided by DEA shows the inefficiency degree of a website against its reference set. However, it does not provide any ranking among the sites. Therefore, for instance, it can be inferred that the website *Compy* is inefficient at about 59% compared to the website *Primestore* which is its reference set, while the website *Eprice* is inefficient at about 70% compared to the websites *Ebest* and *Primestore* of its reference sets.

TABLE II
WEB SITE EFFICIENCY

N.	website	efficiency	reference set
1	compy	58.51%	40
2	worldcenter	60.61%	36
3	gigamatic	62.31%	40
4	mediaworld	63.04%	36
5	computerdiscount	63.04%	40
6	vobis	65.22%	40
7	mytechline	67.39%	40
8	telpc	67.75%	40
9	computerunion	67.80%	40
10	eprice	70.19%	36, 40
11	dgsystem	73.17%	40
12	strabilia	73.66%	40
13	websight	79.34%	40
14	oicom	81.44%	36, 40
15	dualpower-pc	81.71%	36, 40
16	fraelpoint	82.40%	36, 40
17	frael	84.15%	40
18	help-informatica	85.51%	40
19	zetabyte	87.47%	36, 40
20	chl	87.52%	36, 40
21	dell	88.04%	40
22	miocomputer	88.82%	36
23	wellcome	89.16%	36, 40
24	acaminformatica	89.89%	36, 40
25	eplaza	90.12%	36, 40
26	e-comp	90.50%	36, 40
27	inforeashop	90.68%	36
28	oeminformatica	91.41%	36
29	spartano	93.17%	36
30	buzville	93.17%	36
31	aroundstore	93.26%	36, 40
32	pcservicesrl	94.06%	36, 40
33	bow	94.93%	40
34	wireshop	96.27%	36
35	prime	96.85%	37, 39
36	ebest	100.00%	-
37	bitstore	100.00%	-
38	input-computer	100.00%	-
39	computerstore	100.00%	-
40	primestore	100.00%	-

Generally, this means that the website *Eprice* should reduce cognitive effort of the user (decrease the perceived uncertainty, ambiguity, and required time to search for useful information) approximately of 30% = 100% - 70% without reducing its output in order to increase its efficiency rate. In theory, performance (and efficiency) of inefficient websites could be improved either by increasing the output value (usefulness, satisfaction, and attractiveness) or decreasing the input values (cognitive cost to alleviate ambiguity, uncertainty and time needed to search for information). Efficiency measurements are in the range 58,51-100%. Henceforth, sample websites substantially differ as to their efficiency rate. Inefficient websites over-utilize specific inputs or they under-produce outputs. The performance of an inefficient website can be improved either by increasing experience outputs or by decreasing cognitive costs induced in the user. The extent to which cognitive costs should be reduced can be indicated by as a percentage. The same is true as to the extent to which experience dimensions should be increased to move the website to the efficient frontier. Tables III and IV respectively show two examples of that for *Aroundstore* and *Eprice*. Both tables report the relative need for reduction of every input dimension (cognitive cost), and for improvement of the output dimensions (user positive experience) to become efficient websites. For instance, *Aroundstore* could become efficient either decreasing the user cognitive cost determined by ambiguity perceived during website navigation by about 27%, or the cognitive cost determined by uncertainty due to the website structure. In the same way, website efficiency improvement can be achieved by increasing either the perceived usefulness by 8.3% or the perceived satisfaction by 7.2%.

DEA can also be used to identify efficient websites that are unique. Indeed, DEA provides the number of times each 100% efficient website appears in the inefficient website reference set. Websites that are not included in any reference set are unique. The *Input-computer* website is unique.

Finally, results can also be utilized to explore relationships between the efficiency measure and the individual variables for the overall sample of websites.

VI. Conclusion

The study has illustrated how the proposed approach based on the distributed cognition and Data Envelopment Analysis (DEA) can be fruitfully applied to carry on a benchmarking analysis to compare e-commerce websites. Similar studies can be useful to design new websites or when an existing website should be redesigned to improve the perception that the user develops about it. Moreover, the implementation of DEA offers several practical advantages: a) it provides a relative ranking of websites according to their efficiency rate; b) it identifies trajectories for potential improvements of the website against the other websites active on Internet; c) it is an objective evaluation method. The framework has several strengths. Firstly, it can be used to assess different types of e-commerce websites in different industrial sectors. Secondly, the framework does not need to retrieve specific and confidential information from the business to select evaluation criteria. Thirdly, it is easy to use and does not require that evaluators have any specific skill and knowledge when using the evaluation questionnaire.

TABLE III
Potential Improvements for *Aroundstore* Website

	factors	effective	target	potential improvement
input	ambiguity (structure)	3.289	2.649	19.5%
	uncertainty (structure)	2.133	2.049	3.9%
	time (structure)	2.133	1.716	19.5%
	ambiguity (navigability)	2.585	1.881	27.2%
	uncertainty (navigability)	2.750	1.763	35.9%
	time (navigability)	1.800	1.752	2.7%
output	usefulness	7.257	7.859	8.3%
	satisfaction	7.500	8.042	7.2%
	attractiveness	7.400	7.935	7.2%

TABLE IV
Potential Improvements for *Eprice* Website

	factors	effective	target	potential improvement
input	ambiguity (structure)	4.800	2.151	55.2%
	uncertainty (structure)	4.233	1.829	56.8%
	time (structure)	4.900	2.331	52.4%
	ambiguity (navigability)	4.977	2.113	57.5%
	uncertainty (navigability)	4.125	1.928	53.3%
	time (navigability)	5.000	2.648	47.0%
output	usefulness	5.529	7.878	42.5%
	satisfaction	5.575	7.943	42.5%
	attractiveness	4.500	8.119	80.4%

However, in the same time, this approach presents a number of limitations, due both to the adopted distributed cognition framework and DEA benchmarking methodology. As to the first type of limitations, some of them emerged in this study:

a) the approach requires preliminarily the acquisition of the knowledge of who the users are, what the key goals of those users are, what steps the users are going to take to use that site, and what type of learning style they have developed. Task type particularly may affect the need of information for the user and the way to structure it in an optimal way [35], [68]. The user cultural, ethnic, racial and linguistic background also affects the user attitudes relatively to the website and to the requirements of information. For instance, users having a more reflective cognitive style may prefer websites that differ from those preferred by users having a more action-oriented cognitive style [47]. Empirical evidence also shows that individuals systematically differ in their processing capacity. Each individual possesses a fixed capacity to process information, which is independent of the task [71]. Henceforth, the identification of the processing capacity of the typical website user could be extremely useful to design more efficient websites.

b) even though a structured questionnaire was designed for data gathering, the distributed cognition framework remains too qualitative in its nature, and concerns related to data subjectivity and context-dependence may be serious.

As to the second type of limitations, many of them have been emphasized in the literature on DEA [3]:

c) DEA assumes the linearity of the efficiency function;
d) the choice of variables and their measurement to implement the analysis are critical issues that can seriously affect the final outcome;
e) generally, DEA assumes that no differences exist between dimensions;
f) it is not always easy to interpret the outcome of the analysis.

Even though these limitations are evident, the proposed approach offers several advantages, and provides an explorative method to compare websites that can be used together with other techniques and methods. Particularly, it has the merit of: a) modelling the consumer cognitive process who interact with the electronic interface; b) allowing the comparability of the DEA outcomes to those coming from the use of other methods to assess website usability and effectiveness; c) reducing subjectivity when the assessed dimensions are weighted.

APPENDIX

Charnes et al. (1978) showed that the efficiency of a unit k can be defined as:

$$h_k = \frac{\sum_{y=1}^{s} v_{ky} O_{ky}}{\sum_{x=1}^{r} u_{kx} I_{kx}}$$

where:

I_{kx} = the quantity of input x utilized by unit k;
O_{ky} = the quantity of output y supplied by unit k;
u_{kx} = the weight associated to input x;
v_{ky} = the weight associated to input y;
r = the number of inputs;
s = the number of outputs;
h_k = the efficiency of unit k;
n = the number of units.

DEA allows to determine the values of the weights u_{kx} e v_{ky}. The weights of every unit are determined so that the efficiency of the unit is as possible close to 100%, while the efficiency of no other unit can overcome the value of 100% with the same weights.

The efficiency of unit k is evaluated determining the values of uk1, u_{k2}, ..., u_{kr} and v_{k1}, v_{k2}, ..., v_{ks} to maximize:

$$h_k = \frac{\sum_{y=1}^{s} v_{ky} O_{ky}}{\sum_{x=1}^{r} u_{kx} I_{kx}}$$

subject to:

$$h_i = \frac{\sum_{y=1}^{s} v_{ky} O_{iy}}{\sum_{x=1}^{r} u_{kx} I_{ix}} \leq 1$$

for i = 1, 2, ..., k, ..., n

This constraint imposes that no other unit can have an efficiency greater than 100% using the same weights.
Both expressions can conveniently rewrite to maximize:

$$h_k = \sum_{y=1}^{s} v_{ky} O_{ky}$$

subject to:

$$\sum_{x=1}^{r} u_{kx} I_{kx} = 1$$

and

$$\left(\sum_{y=1}^{s} v_{ky} O_{iy}\right) - \left(\sum_{x=1}^{r} u_{ky} I_{ix}\right) \leq 0$$

for i = 1, 2, ..., k, ..., n

$u_{kx} \geq 0$, $v_{ky} \geq 0$, for every value of k, x and y

The problem is thus transformed into a linear programming problem. For n units it is necessary to solve n problems of linear programming.

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