International Journal of Industrial Ergonomics 53 (2016) 245–256

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

An acceptability estimation and analysis methodology based on Bayesian networks

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ARTICLE INFO

Article history:
Received 27 October 2014
Received in revised form
31 December 2015
Accepted 22 February 2016
Available online 2 March 2016

Keywords:
Acceptability evaluation
Product design
Innovation
Bayesian networks
User preferences

ABSTRACT

As companies are forced to conceive innovative products to stay competitive, designers face the challenge of developing products more suited to users' needs and perceptions in order to be accepted, thus reducing project risk failure. Evaluating users' acceptability has become an important research problem. Current approaches leave the acceptance evaluation question to be answered in the last stages of product development process (NPD), when an almost finished prototype is available and when there is no time left for important modifications. Acceptability evaluation methods suitable for use from the early stages of the NPD process are thus needed. This paper proposes a method for acceptability evaluation and analysis that can be used in the early stages of the development cycle. It is based on the evaluation of the solution concept by the users. The relationships among the factors (or criteria) are made explicit, thus helping designers to identify the key factors for acceptance. As the users' tests and the maturity of the concept prototype are limited in this stage, the proposed method exploits the inference properties of Bayesian networks making it possible to make useful estimations and allowing the exploration of actions that could improve the product acceptability level. Two case studies are presented in order to illustrate the method, the first related to a technological product design for a home-health care service provider and the second to a work-related musculoskeletal disorder prevention software design.

Relevance to industry: The article describes an acceptability assessment and an analysis approach to be used by industrial engineers, designers and ergonomists in the early phases of design projects. The method can help the design team to identify the levers (key factors) for enhancing product acceptance and to identify different actions (e.g. product modification, deployment strategy, and training).

1. Introduction

Innovation in product development projects is associated with risk and uncertainty. Besides responding to users' needs and requirements, designers should anticipate consumers' acceptance of their innovation to avoid undertaking projects that will not succeed. Acceptability evaluation is one of the key problems in product development (Luo et al., 2011).

To define acceptability as treated in this article, we should consider the technology adoption process as a temporal *continuum*. Three moments of analysis could be considered: acceptability *a priori*, acceptance, and appropriation (Terrade et al., 2009). The first one refers to the subjective representations of technology use, *i.e.* trying to predict technology usage from the perspective of what is "perceived" by the individual, even before the technology has been totally developed. In this context, dimensions such as "perceived utility" and "perceived ease of use" should be taken into account. Acceptance refers to the study of the factors which had an impact on the first interactions between the technology (developed) and the user. Finally, once the system has been deployed, it is convenient to study and assess its effective appropriation and usage.

In the scientific literature several methods for acceptability evaluation have been proposed. Some of the approaches deal with the use of subjective and even unconscious feelings, about a product, to be translated into concrete product attributes (Luo et al., 2011; Camargo et al., 2014). The latter proposed an approach to integrate user's perception and identify the importance and interaction of semantic attributes, thus allowing designers to validate and adjust product concepts. Another kind of approach is related to the need assessment process. The proposed methodology based on the Kano model presented in (Ben Rejeb et al., 2008), can be used as a decision aid tool for selecting consumer needs. Other approaches are based on the theory of technology acceptance, in which the users' behavioral intention could be used as a measure of acceptability. They derive from Ajzen

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http://dx.doi.org/10.1016/j.ergon.2016.02.005
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and Fishbein's Theory of Reasoned Action (Ajzen and Fishbein, 1980). The most influential approach deriving from this trend is the Technology Acceptance Model (TAM) (Davis, 1989); the theory states that a user's behavioral intention for a new technology is influenced by its perceived usefulness (PU) and its perceived ease of use (PEOU). PU was defined by the author as "the degree to which a person believes that using a particular system would enhance his or her job performance" and PEOU as "the degree to which a person believes that using a particular system would be free from effort". The TAM model was expanded first as TAM2 (Venkatesh and Davis, 2000) to include other factors influencing the PU, and later to include factors from the organizational context of the user in the unified theory of acceptance and use of technology (UTAUT) (Venkatesh et al., 2003). Another model (mainly used in usability studies) has been proposed by Nielsen (1993). This model distinguishes the acceptability factors of a system in two categories: social acceptability and practical acceptability. The former refers to the system's compliance with social needs, whereas the latter is related to the technical environment of the proposed system (reliability, compatibility) as well as aspects related to its use (utility, usability). It evolved as the ISO 9241-210:2010 norm and could be used as a prescriptive tool in product design.

The models proposed in the literature lack a global vision of the influence factors that could help master its complexity. Furthermore, those models are mostly used as measure mechanisms once the technology has been deployed thus requiring a finished prototype and a huge amount of users' test. Consequently, this paper aims to present a method for acceptability evaluation that can be used to guide the design process, helping designers to identify the levers (key factors) for acceptability from the early stages of the design process. As prototypes and users' test data are scarce in the first stages of product development, some artificial intelligence techniques can help deal with those drawbacks. There have been some propositions to evaluate and predict acceptability using some of those techniques. Elazouni et al. (2005) for example, estimated the acceptability of a new formwork system for construction using neuronal networks; Luo et al. (2011) proposed a combination of techniques (Radial Basis Function Networks, Support Vector Machine Sequential Minimal Optimization and their ensembles) along with Bayesian networks to predict acceptability of products. They tested the methodology with a car evaluation; their methodology, however, requires large data-sets. Compared to other techniques (neural networks, support vector machines, decision trees) a Bayesian network allows the integration of different sources of information (experts' knowledge, and data), allows the handling of uncertainty and incomplete data and provides a visual graph of criteria. Therefore, the basis of our proposed method resides on the usage of Bayesian networks and their inference properties.

The remainder of the paper is structured as follows: in Section 2 we present and overview of the properties related to Bayesian networks. Section 3 describes the proposed methodology. Section 4 presents the case example. Results and implications for theory and practice are discussed in section 5. Finally, conclusions and perspectives for future research are presented in section 6.

2. Reminder on Bayesian networks

Bayesian networks are directed acyclic graphs that represent the probabilistic relationships between a group of variables (Pearl, 1988). They are generally composed of two parts: a quantitative part and a qualitative part. The qualitative part is the graph in which the nodes represent the states of random variables and the arrows pointing from a parent node to a child node represent the causal conditional dependency between the two nodes. As for the quantitative part, it mainly refers to the relationships between a node and its parents. The relationship can be represented by the probability that the node's state will provide different probabilities of the parent's node state. This information is consigned to the conditional probability table (CPT) of the node.

Two types of reasoning are possible with Bayesian networks: (1) diagnosis (backwards inference) which, given an observation, makes it possible to find the most probable cause among the hypotheses, and (2) prediction (top-down inference), which makes it possible to estimate the probability of an observation given the assumptions (Jensen and Nielsen, 2007).

In the framework of our research work, these properties are interesting since they will allow us to: calculate and predict the level of acceptability of a new technology (acceptability index), to identify among the criteria the key levers for acceptability improvement and to estimate the impact of different scenarios of action on the computed acceptability index. The aim is to reduce the risk of project failure by improving the product acceptability. Indeed, Bayesian networks have been shown to be successfully used in risk management. For instance, Hu et al. (2013) used them in the analysis of software projects risk; and Song et al. (2013) used them to assess the risk of service failures by focusing on ripple effects.

3. Proposed methodology

The objective of the proposed methodology is to contribute to the concept validation process by estimating the acceptability index of a solution concept and helping the designers to identify how factors contribute to this index. Once the initial estimation is made, the proposed approach helps in the analysis of different sets of actions (scenarios) that are most suited to improve the users' acceptability of the solution concept. The proposed method is composed of three main phases (Fig. 1): evaluation model construction, assessment and analysis and finally, action.

3.1. Evaluation model construction

The aim of this phase is to build the acceptability evaluation model. The first step consists in the identification of the acceptability criteria. The second step consists in collecting data about those criteria (or factors) by means of user evaluations of the solution concept. The third step uses the collected data to build a Bayesian network (BN) for the acceptability assessment. The BN is build by generating the conditional probability tables (CPT) of the network from the collected data.

3.1.1. Factors identification

We propose to use a user acceptance model like TAM or UTAUT (Davis, 1989; Venkatesh and Davis, 2000; Venkatesh et al., 2003) to define the factors that should be evaluated. To facilitate model development, factors can be divided into two groups: those related to the user (*e.g.* perception of utility, perception of ease of use) and those related to the context of usage (*e.g.* social influence, facilitating conditions). Analysts can review the literature of the domain concerned to find related factors. As an example for a new medical diagnosis application, in the TAM model two criteria explain the intention to use: perceived ease of use and perceived usefulness (utility). One can define composing factors to evaluate each one of those criteria. The utility of the medical application relies on its diagnosis and accuracy capability, and so perceived usefulness can be composed by "diagnosis is accurate" (users' perception of device diagnosis accuracy) and other factors. A group of experts should be consulted to facilitate, complete and validate the evaluation model.

3.1.2. Data collection

In this step a questionnaire is prepared, including all the criteria and their composing factors identified in the previous step.