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Technical Paper

Personalized product configuration framework in an adaptable open architecture product platform

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A R T I C L E I N F O

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A B S T R A C T

Product configuration system, as an effective tool to bridge the gap between customer requirements and product offerings, enables customer-centric product development in a cost-efficient way. Despite its advantages, however, most existing product configurators are centralized, i.e. the configuration process is conducted in a single company within its own product family. It cannot fulfill the ever increasing tendency towards personalization. This is because customers no longer have to choose from the limited options within the company's solution space in a "configure-to-order" (CTO) model, they also propose or even create their individualized design in an "engineer-to-order" (ETO) model. Moreover, companies, especially large ones, are not willing to invest much into the niche market to produce the highly personalized components. To solve this problem, an open architecture product platform with adaptable interface can be adopted to integrate the original equipment manufacturer (OEM) with various vendors into a co-creation process. This paper proposes a conceptual framework of a personalized product configuration system based on the adaptable open architecture product platform. The technical configurator is enabled by a two-stage process (i.e. modular design and scalable design) to ensure the adaptability and scalability of product variety, while the sales configurator is established by considering each customer's preferences and conducting the configuration process in an ETO manner. The technical details of the prototype system implementation are described and an illustrative example of a personalized bicycle configuration process is given to validate the overall framework.

1. Introduction

With an increased tendency towards mass customization and personalization [1–3], companies strive to provide highly customized products to satisfy individual customer requirements (CRs) in a cost-efficient way. To achieve this customer-centric product development process, both information technologies (e.g. Web 2.0, Internet of Things, and Virtual Reality) and manufacturing techniques (e.g. adaptable design, reconfigurable production system, and Additive Manufacturing) are deemed to be the enabling tools. Among them, product configuration system, also referred to as product configurator or mass customization toolkits [4], is a knowledge-based system to tailor a product according to the specific needs of a customer [5] with a shorter lead time to market [6]. It consists of a set of predefined attributes with constraints (rules) for customer to select within the product family scope [7]. In the configuration process, the input is the customer's selection of existing attributes and the output is the recommended or target product derived from the system to fulfill CRs. In such a way, it bridges the gap between CRs and the end-product by only a series of attribute selection processes in a "configure-to-order" (CTO) model [8]. Also, it benefits the company by reusing existing design elements to provide customer-perceived product variety in the product family [9,10].

Though product configuration systems have many advantages and been talked about for a long time, most of them operate in a centralized way, i.e. the configuration process is conducted in a single company within its pre-defined product family scope [11]. They cannot fulfill the ever increasing personalized CRs in an "engineer-to-order" (ETO) model [12], nor can they allow a single company flourish or survive in today's competitive global market [13]. Moreover, the configuration process is generally carried out in a fixed sequence of queries and obtains inputs passively without distinguishing different customer's preferences [9], which is not adaptable or intelligent for the human-computer interaction pro-

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cess. It is time-consuming and tedious especially for configuring the complicated products.

Aiming to satisfy individual CRs more effectively, this paper proposes a conceptual framework of the personalized distributed product configuration process based on an adaptable open architecture product platform (OAPP). It is based on two assumptions: 1) OAPP is adaptable enough with modular interfaces [13,14]; 2) customers prefer to develop new designs from the existing products in a tangible or visualized way other than design from scratch, which is the fundamental of utilizing a product configuration system in an ETO model. This paper is organized as follows: Section 2 gives a literature review of related works. The conceptual framework of the proposed product configuration system is proposed in Section 3. Both the front-end personalized sales configuration process and the back-end development of the adaptable technical product configurator are described. The prototype system implementation is given in Section 4, with an illustrative example of personalized road bike configuration process described in Section 5. The main contributions and future work are concluded in Section 6.

2. Literature review

According to the summary of Trentin et al. [15], the fundamental functions of a product configuration system are: 1) communicating company's product offerings to the customer; 2) providing real-time information, such as quotation, delivery time and product specification; 3) checking the completeness and validity of product variant; and 4) generating bill-of-materials (BOM) based on customer's selection. The first two functions are fulfilled by a sales configurator, and the latter two by a technical configurator [16], which both rely on the logic structures that model the product configuration knowledge. To achieve a personalized configuration process in an adaptable OAPP, this section reviews the related work on the interactions between customers and a sales configurator, and the adaptable design of a technical configurator is also considered.

2.1. CRs elicitation in product configuration process

Elicitation of CRs, as a critical step in the product planning stage, is of paramount importance to the success of product development process [17]. However, a product configuration system generally operates in between function and physical domain but not customer domain. This does not support the identification of CRs adequately and it requires customer's capability knowledge of design specifications. Customer can become frustrated with unknown specifications, or confused by the amount of product variants [18] during the configuration process.

To solve this problem, Blecker et al. [19] proposed a concept of advisory system, which was suggested to be combined with a product configuration system to better elicit CRs. Wang [20] proposed a fuzzy Kano method to incorporate customer satisfaction into the product attribute selection decision making process. Another type of work focused on the improvement of the web-based user-friendly interface in the configuration process to capture CRs effectively by taking customers' different level of product knowledge into consideration [21]. Trentin et al. [22] further validated five capabilities that sales configurators should deploy in order to avoid the "mass confusion", i.e. focused navigation, flexible navigation, easy comparison, benefit-cost communication, and user-friendly product-space description capabilities. In order to optimize the complicated configuration process, knowledge-based recommendation technique is widely used to shorten the configuration rounds, which is usually dependent on the customer's history view, purchase or transaction records to predict customers' future desires and buying intentions [23]. Tiihonen and Felfernig [24] first pointed out the application of recommendation methods in web-based product configuration. Wang and Tseng [8] proposed a game theory approach: Sharpley value to capture prospective CRs in a personalized attribute selection process. They also adopted the Gini index [9] approach in a similar way, which both optimized the configuration process by combining with Naive Bayes recommendation method.

Though existing research provides potential ways to support CRs elicitation, they still work within an existing product family in a CTO manner. A recent work by Wang and Tseng [25] proposed a Naive Bayes method to identify the probability of an emerging need which cannot be fulfilled by the existing product family. As a diagnose method, it is still within the possible product configuration space, without discussing about capturing and organizing new CRs in an ETO way.

2.2. Adaptable design

Adaptable design is first proposed by Gu et al. [14] as a design paradigm with product lifecycle sustainability concerns. It stands for the ability of a design or a product to be adapted to new requirements and reuse it when circumstance changes by adding or replacing certain modules through a pre-defined adaptable interface [26]. They further classified it into two categories: design adaptability and product adaptability.

Design adaptability is the capability of an existing design to be adapted to create a new or modified design based on the changed requirements [26]. Zhao et al. [27] proposed a new extension-clustering method approach to obtain adaptable product designs that more closely matched customers' demands. Xu et al. [28] developed a specific method in the adaptable redesign of machine tool structures, analysis and its adaptable measures to extend the utilities of a design and product. Levandowski et al. [12] utilized the design adaptability principles to develop a product platform for 'engineer-to-order' product configuration design. Product adaptability is the capability of a physical product to be adapted to satisfy the changed requirements [26]. To meet dynamic changing CRs, approaches have been proposed, to: (a) modularize and upgrade product planning [29], (b) cope with variations in users' intents, context changes and evolutions [30], (c) provide design engineers with an objective assessment of the degree to which a product can be adapted [31], (d) identify the optimal adaptable product considering changes of requirements, configurations and parameters in the whole product life-cycle [32], and to achieve robust adaptable design [33]. Due to its advantages in delivering adaptable designs or products to satisfy dynamic CRs, it can be utilized to develop the product configuration system, e.g. product platform and product family modeling.

2.3. Open architecture product

Open architecture product was first proposed by Koren et al. [13], it is defined as "one with a platform that allows the integration of modules from different sources in order to adapt product functionality exactly to the user's needs." Large companies, e.g. original equipment manufacturer (OEM), tend to develop the common platform and define the interface. Small and-medium-sized enterprises (SMEs), as third-party vendors produce add-on modules (both customized and personalized) that could be interfaced with the OAPP [13,34]. In such a case, customers can be involved in the development process by not only select from existing optional modules, but also design personalized modules with different vendors to satisfy their needs under OEM's approval. Hu [35] argued that an OAPP that allowed for product compatibility/interchangeability of its functional features or components with standard mechani-