Integrated Vehicle Configuration System—Connecting the domains of mass customization

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ABSTRACT

Configuration design for mass customized vehicles necessitates the coordination of customer requirements, product characteristics, production processes, and logistics networks, in order to achieve rapid response to customer orders. Existing product configurators are mainly used as sales tools, and fail to account for the requirements of the entire customer order fulfillment process. In this regard, this paper proposes an Integrated Vehicle Configuration System (IVCS) to facilitate customer order processing based on information from multiple domains in a mass customization environment. An IVCS business model is proposed to incorporate the decision factors for configuration design related to different planning stages. The business model is supported by a comprehensive ontology framework, which enhances communications between different stakeholders involved in the order fulfillment process. The configuration approach is based on combinations of selective and generative rules and can be integrated with existing ERP systems. It also provides mechanisms to handle configuration rules that allow users to convert soft preferences into product specifications, bill-of-materials, and, furthermore, into logistics configurations. An example of a computerized configuration system showcases the process from customer engineering to design and production.

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1. Introduction

Mass customization has reshaped the landscape of many industries such that rapid response to individual customer needs, coupled with high production efficiency, are vital for a firm's business success [1,2]. The automobile industry is no exception, in that the mass customization of such expensive and complex products is often very time-consuming and it is a complex issue to define product option combinations, formulate an offer for the customer and secure an order from it, generate bill-of-material (BOM) of the customized product, and link it to the logistics of the manufacturing process [3,4]. Notably, there is a gap between what the customer wants and what the producer can offer in terms of product characteristics, as well as the order fulfillment process.

In such a situation, automobile companies have developed product/sales configurators to automate the order handling process according to the customer requirements. Typically, a product configurator is a tool especially for the sale of component-based products and in some cases implemented within an Enterprise Resource Planning (ERP) system [5]. Without going

into the details of the product design and manufacturing process, the product configurator signifies the producer's awareness of customer needs and the capacity to fulfill these needs with respect to its product offerings [6]. Thus, it allows for easy and quick product definition, guides the salesperson in a negotiation situation, and prevents the selection of components and option combinations that, for production or other reasons, are impossible or unprofitable.

However, viewing a product configurator as a sales tool may restrict its application in vehicle mass customization. In particular, existing configurators are inadequate to facilitate decisions in the customer order fulfillment process, mainly because of their inability to (1) capture the actual customer needs, (2) account for decision factors beyond the functional/physical domain, and (3) exchange information among different planning teams. Most legacy systems focus on the technical details of products and neglect the customer perspective [7]. However, it is unlikely that customers could make logical selections when they do not have adequate product expertise. Moreover, there seems to be an over-emphasis on the functional/physical aspect of products, e.g., engine type, automatic gearbox, ABS brakes, etc. Equally important, if not more so, is the customer's affective needs in the choice of an automobile, where the affect involves the emotional aspects of the customer requirements, such as aesthetics, prestige, and

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pleasure [8,9]. In fact, emotional aspects play an important role in forming customers' perceptions of an automobile, and thus influence their purchasing behaviors [10]. Furthermore, decisions related to the order fulfillment process do not rely solely on the product configuration. Other factors, such as logical production and logistics configurations, may also influence the performance of the order fulfillment in terms of time and cost [4,11]. Finally, a logical estimation of the cost and time for fulfilling a specific customer order may be hampered by the loose connections among different stakeholders, such as customers, sales staff, and production engineers. This can be attributed to the different terminologies and information systems used by them. It is desirable to develop a common ontology for configuration and to integrate the heterogeneous subsystems used by different stakeholders, thus achieving effective information exchange and reuse [12,13].

This paper aims to extend the scope of product configurators to the entire process of customer order fulfillment. Towards this end, an Integrated Vehicle Configuration System (IVCS) is proposed to facilitate the order fulfillment process by connecting customers with back-end product configuration options in a mass customization environment. The system can be used by customers and salespersons to demonstrate product offerings that take into account both affective and functional requirements. It can also assist the product planner to make preliminary estimations of the performance of the production based on product and manufacturing process information. A business model is proposed to incorporate the decision factors for vehicle configuration design in different domains, including customer, functional, physical and process domains (Section 3.1). The model is supported by a comprehensive ontology framework, which enhances communications between different stakeholders involved in the order fulfillment process (Section 3.2). An integrated configuration process is defined to streamline the activities of configuration design and provide decision support (Section 3.3). The configuration approach is based on combinations of selective and generative rules and can be integrated with existing ERP systems. A prototype system is presented with a case study of the configuration of truck products to demonstrate the overall configuration process (Section 4).

2. Related work

Product configuration planning involves a number of research and application issues. The research perspective usually focuses on such issues as formulation of the configuration tasks, representation of configuration knowledge, and configuration problem-solving. Mittal and Frayman [14] propose a generic definition of the configuration task, based on which the knowledge required in configuration design is classified, and the problem-solving process is discussed. Sabin and Weigel [15] classify existing configuration methods into rule-based reasoning, modeling-based reasoning, and case-based reasoning in accordance with the knowledge representation scheme. Franke [13] identifies three major directions in configuration research, namely common ontology, function representation and functional reasoning, and scaling configuration to large problems. Considering the importance of understanding customer needs, Blecker et al. [7] propose an advisory system that guides customers to generate product configurations according to their profiles and preferences. Wielinga and Scheiber [21] emphasize the role of knowledge in configuration design problem-solving, and compare three types of knowledge-intensive methods, namely case-based methods, propose-critique-modify methods, and hierarchical configuration methods. Siddique and Rosen [16] have developed the Product Family Reasoning System (PFRS) to formulate product platform design as a configuration design problem. Corbett and Rosen [17] extend the PFRS approach and propose a partitioning method to

reduce the size of the feasible design space. Fujita et al. [18] propose a modular design approach for product family configuration design, whereby simulated annealing is used to search for the optimal solutions [19].

While problem-solving has been extensively studied in the literature, the development of ontology for configuration is an equally important but constantly overlooked issue [12,20]. A general ontology for describing configuration information is a prerequisite for communication among different parties, including engineering, manufacturing, marketing staffs, as well as customers. Thus, the ontology framework emphasizes information exchange and reuse in vehicle customization, where ontological choices may include configuration specification, configuration result, configuration model and configuration solution techniques [13]. Gruber [20] views ontology as designed artifacts that are formulated for the purpose of being shared and reused in specific situations and evaluated against certain design criteria. Wielinga and Schreiber [21] distinguish four types of domain knowledge for configuration design (components, assembly, function, and constraint) and propose a hierarchical structure for organizing configuration knowledge. The product modeling strategy proposed by Yu and Skovgaard [3] involves four elements, namely object types, constraints, resources, and product modularization. Soininen et al. [12] present a generalized ontology of product configuration, where a detailed conceptualization of knowledge of product structures is introduced. The NIST design repository project involves the development of taxonomies and ontologies for representing product functions, artifacts and relationships, with the ultimate goal of achieving interoperability of product information [22,23].

However, the above-mentioned ontologies are inadequate for product configuration in two aspects. Firstly, they focus exclusively on the functional aspect of product configuration. For consumer products such as automobiles, the customers' affective needs play an important role in forming the value profile of the product, and thus should not be overlooked in the configuration process. Therefore, the ontology must incorporate affective needs in addition to functional ones. Secondly, the ontologies are usually limited to individual domains, i.e., they deal with the configuration knowledge used by specific stakeholders only, be they customers, salespersons, or designers. This inevitably restricts the application of ontology-driven configuration design because such decisions are made based on partial information of the whole system. Therefore, a more comprehensive ontology is needed which incorporates decision factors of multiple domains.

From the application perspective, various prototypical and commercial configuration systems have been developed with emphasis on customer relationship management and integrated solutions [24]. A number of general purpose commercial product configurators are available, such as SmartCatalog (http://www.smartcatalog.com/), Tacton (http://www.tacton.com/), Summium (http://www.summium.com/), among others. These systems aim at simplifying and expediting the configuration, pricing and quotation of complex products and services. In the automobile industry, major automobile manufactures are developing online product configuration systems that exhibit the vehicle product offerings with customizable options. These configurators are usually web-based, with the aim of rapid response to requests for quotations through enhanced customer–vendor interactions.

Yu and Skovgaard [3] have developed the salesPLUS system, which is a configuration tool used in real world configuration applications. Haag [25] enhanced the SAP's R/3 system with a sales configuration engine to support the engineer-to-order process. Regli and Cicirello [44] have developed digital libraries to facilitate collaboration in computer-aided design. Helander and Khalid [26] and Khalid and Helander [10] analyzed the customer decision-