Web-Based Configure-to-Order Platform for Collaborative Development of Customized Products

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Abstract

To support the collaborative development of custom products in current distributed manufacturing, this paper develops a Web-based configure-to-order platform. The proposed platform enables the integration of different Web-based services across companies and various lifecycle issues of product fulfillment into a collaborative web of interactive commerce. As the kernel of the platform, a generic product family master model allows the collaboration of customization over the Internet while achieving a synergy of sales force automation, product design, manufacturing planning, and supply chain management within a coherent framework. Throughout the paper, a case of injection molded part development is used to detail the implementation of the proposal.

1. Introduction

To stay competitive in nowadays dynamic and global business markets, e-commerce along with mass customization production will be adopted by many companies as a primary style of manufacturing [1]. E-commerce has much potential to transform industries in terms of core activities such as design, resource planning, factory automation, and supply chain management. These processes can be re-engineered to utilize Internet technologies, leading to significant cost savings and reduction in lead times. In light of new capabilities implied by e-commerce, customers will be able to input and interact directly with design, manufacturing and service providers. The providers will have to respond to a high variety of requirements and orders within the constraints of cost, schedule and quality [2].

Although a number of online product customization systems have been launched, e.g., Dell.com, Idtown.com, and Cannodale.com, the proper support of information retrieval and problem solving is insufficient in product customization and navigation through complex spaces of available product information or product alternatives on the Internet [3]. Consequently, these systems have yielded few promising results [4]. However, for the business success, companies must possess the ability to identify the needs of customers and to quickly develop products that are tailored to the customer needs and can be produced at low costs and with the shortest delivery time [5]. Therefore, a collaborative product development involving all life cycle issues of product fulfillment is necessary for achieving these goals [6]. In turn, the collaborative product development calls for the integration of Web-based services and collaboration across companies and their partners, as well as among different functional departments within a company [7]. As pointed out in [8, 9], for geographically dispersed manufacturing partners, including customers, manufacturers, and suppliers, to achieve the satisfaction of the whole, it is imperative in practice to synchronize various Web-based applications within a coherent framework and to enable the unified information management of product lifecycle concerns over the Internet. In this regard, this paper develops a Web-based configure-to-order platform, with a particular application to injection molded parts, for collaborative customized product development.

2. Related work

Web-based product development and design have received world-wide attention over the last decade. A number of projects launched in America (e.g., DOME, CyberCut, AIMS) and Europe (e.g., GEN, PRODNET) have adopted the Internet and Web technologies as the common development infrastructure [10]. Web-based support to collaborative product development has its
variety, low cost, and quick delivery, the company has increasing demands from customers for product development. Facing the headquarter located in Singapore, it has several suppliers in China and Malaysia. Several fundamental issues of e-product development for mass customization are discussed in [13]. The issues in developing Web-based support to product family design have been analyzed in [14]. From a wider perspective of supply chain management, the Web technologies also possess great potential as addressed in [15]. A number of product configurators have been reported to support customer relationship management, sales force automation, and/or build-to-order production planning, e.g., [6]. Coordination strategies have been studied to avoid conflicts between design participants in collaborative design [16]. An information infrastructure architecture has been proposed for enhancing collaboration in virtual manufacturing enterprise [17].

As observed in the large number of Web-based collaborative product development frameworks that have been developed, the common setback are the narrow focus on only a limited aspects of product fulfillment and the lack of a holistic view of the entire spectrum of product development and product lifecycle issues. The importance of achieving synchronized Web applications for product development has been observed in [8]. A concept of "F2B2C" e-Commerce has been put forward in [18]. It aims to realize mass customization over the Internet through coherently integrating manufacturing production automation (F) with supply chain management (B) and sales-service support (C) into a collaborative web of interactive commerce. The authors in [19] have proposed to develop an e-manufacturing portal to facilitate business collaboration (e.g., partner selection), order process collaboration and collaborative planning, as well as engineering collaboration (e.g., collaborative product and tooling design and rapid prototyping) over the Internet.

3. Case company

The company under investigation produces custom injection molded parts for worldwide customers. With the headquarter located in Singapore, it has several branches in different countries, e.g., design offices in the US, suppliers in China and Malaysia. Facing increasing demands from customers for product variety, low cost, and quick delivery, the company has been striving to effectively offer individualized plastic parts thus delighting customers. However, there exist some hindrances that prevent the company from satisfying its customers effectively. At different stages of its product development and mold design and making process, negotiations are required so that an injection molded part and its mold can be developed in harmony to conform to various manufacturing constraints.

The difficulties in their daily operation are observed as 1) the time-consuming and low efficient negotiations among engineers in different locations for coordinated part and mold development, 2) the lack of well documentation of data and information about produced parts, and 3) the un-easy access to supporting information. As a result, the extremely long procedures of specifying parts are characterized by delays and errors. Furthermore, the same parts are often redesigned due to the loss of records and the missing of data. Realizing these problems, the company has adopted Internet enabled solutions for interactively communicating information related to product design, development, manufacturing, logistics with its partners, thus cutting down part development cost and time.

Figure 1 illustrates the injection molded part development process in the company. It involves customers, mold makers designing and producing molds, and suppliers providing materials and components for injection molding and mold making.

As shown in the figure, the sales and marketing department of the company negotiates with customers to provide request for quotation, the design department designs parts according to customer orders. While the engineering analysis department analyzes the product models to optimize design parameters, the
manufacturing department fabricates the parts using injection molding machines. For producing customer specified parts, the company chooses a mold making company considering cost and manufacturability. The selected mold maker accordingly develops the appropriate mold through intensive collaboration among part designers, CAE experts, injection molding production engineers, mold designers, and mold flow experts. The mold maker also needs to select suppliers for necessary mold parts (e.g., plates, cores, standard parts, etc.). While sample parts made by the designed mold are required for the company to validate the mold, prototypes produced by the valid mold must be sent to customers for assessment. Often, parts need to be redesigned and molds to be improved.

Since, an injection molded part is a type of highly customized products, the company has to struggle with frequent design changes and process variations. It also has to negotiate with the mold maker and supplier companies regarding tedious re-work on mold design and fabrication, as well as assessment on material and component supplies. Thus, throughout the customization process, intensive collaboration is required among multiple parties.

4. Platform-based product design

Developing product families has been well recognized as an effective means to reduce development costs and time-to-market while increasing product variety and enabling customization. Product family design is also referred to as platform-based product development—designing a product platform and the corresponding product family.

Figure 2 depicts a framework of collaborative customization based on the product platform approach. It involves two layers of collaboration, namely platform collaboration and customization collaboration.

The development of injection molded part platform involves mainly two parties: the product designer and the mold designer. They have to work coherently to specify the overall architecture of the product family and the corresponding mold assemblies. While the platform collaboration determines the interface boundaries and key architectural properties of product and mold assembly configuration design, the major concern of the customization collaboration is to customize product and mold platforms to meet individual customer needs. The achievement of the later collaboration is based on the shared product family design master model, which is the output of the former collaboration. Such a product family design master model contains all formally approved design information regarding both customer requirements and detailed design.

![Figure 2. Platform-based product development for collaborative customization](image)

4.1. Web-based configure-to-order platform

Figure 3 illustrates a Web-based framework of the configure-to-order platform. It consists of four layers: (1) the application client layer encompassing all collaborative parties, (2) the application server layer constituting the traditional design platform, (3) the knowledge repository layer encoding all necessary product and process information; and (4) middleware enabling integration and communication over the Internet.

The platform, embodying a typical client/server mechanism, separates design application systems (e.g., Pro/Engineer) from knowledge repositories and links them via middleware, so that various application systems are independent of knowledge repositories. Common repositories are designed to be open so that they can be expanded by any user according to the specifications of the knowledge definition. The knowledge in the repositories is organized around a unified generic product family (GPF) master model. Both the product designer and the mold designer may use these repositories. The structure of repositories is organized as a distributed network and thus the designers can add their knowledge into the repositories or construct their own repositories according to the structure of the master model. Furthermore, the knowledge acquisition, organization, construction and utilization can all be implemented through the Internet as integrated distributed repositories. As a result, the design of the Web-based configure-to-order platform is conducive to the achievement of two important requirements of Internet-enabled collaboration, namely the access to information, tools and collaborators [11], as well as information sharing and dissemination [20].
4.2. Generic product family master model

The kernel of platform-based product customization is a GPF master model embedded in the platform, as shown in Figure 4. A GPF is an information model that encodes not only the mapping relationships between product functional specifications and the corresponding design solutions, but also the design and manufacturing decision-making criteria that must be fulfilled for the applicability of each design solution. Hence, it should be constructed in such a way that not only captures the decision-making criteria within each individual design domain, but also exploits the kind of interaction and mapping mechanisms required to guide the acceptability of particular design solutions throughout the design process. The GPF model structure as a UML class diagram is illustrated in Figure 4.

The design solution class in the product domain constitutes a generic product structure (GPS). It is characterized by a set of design feature classes, possessing relationships to the product functional specifications in the functional domain, as well as to the downstream design solutions. The characteristic classes of manufacturing options and mold design solutions in the process domain are grouped as a generic manufacturing structure (GMS), which in turn is specialized as mold assembly class, costing model class, and manufacturing plan class. Both the GPS and GMS are associated, through interactions and mapping relationships, with the supply base class and the supply contract class in the supply chain domain, which are classified as a generic supply structure (GSS). The set of interaction instances, defining the decision criteria to be applied to each design solution instance, are modeled as generic planning. All primitive classes of the generic structures are linked to generic planning by defining appropriate variety parameters and configuration constraints for modeling interaction and mapping relationships. The specification of rules in the generic planning aims at the valid derivation of specific items from the generic items in the GPF, under the umbrella of which, the GPS, the GMS and the GSS are unified by employing the same set of variety parameters and the instantiations of their values in handling variety.

Based on the GPF information model, the injection molding design can be formulated as a type of parametric product family design, wherein according to the generic variety representation (i.e., the underlying mechanism of a GPF), both feature-based injection molded part design and mold assembly configuration design can be parameterized around variety parameters and their value sets. Likewise, parametric family design can be constructed for production plans and various costing models according to the associated variety parameters and their instantiations. Since the GSS is linked to the same set of variety parameters, parametric family design can be applied to manage various supply specifications as well.

5. Implementation

5.1. System architecture

Figure 5 shows a typical three-tier client-server-database system architecture for the Web-based configure-to-order platform. It is consistent with the multilayer distributed application model of Java 2 Platform, Enterprise Edition (J2EE). The client side is the Web browsers and applications that support the HTTP protocol. It supports not only the customers but also many users involved in product development like the mold designer and suppliers. While within the J2EE structure, an application server is run by the Web
container, which contains WEB components such as JSP and Servlet, the operational tier of logic servers is called Enterprise Java Beans (EJBs) and aims to realize logic services. All the configuration logics and planning rules are defined by EJBs. The two basic types of EJBs are the Session Bean and the Entity Bean. While Session Beans mainly deal with operational logics, Entity Beans represent objects, such as records in the database.

As shown in Figure 5, the system architecture consists of a number of clients, a JDBC/ODBC database server, a coordinator server, a GPF server, and a number of other application servers. The GPF server provides functions for creating projects, defining product and process structures, building component-supplier hierarchies, and assigning access privileges. The information from the GPF server is stored in the relational databases in the JDBC/ODBC server. For each Web server, the eXtensible Markup Language (XML) sockets and JDBC/ODBC proxies are adopted to maintain native formats of various data, thus making it possible to integrate those heterogeneous application platforms used among different designers and planners. In addition, the Java applet-servlet pairs and HTML/JSP techniques are used as for Web server computing. This enables shared applications to perform multiple activities in parallel. The coordinator server provides services with functionalities that allow developers to participate in and exit from a particular collaborative process. Also, it is able to provide synchronization support for carrying out multiple tasks of collaborative customization.

5.2. System implementation

To support the integration of many different application systems under the configure-to-order platform, the XML format on the Web is adopted to provide data exchange standards. Any communication between two application systems is achieved through XML sockets. The processing of an XML object in the XML document is referred to as XML parlance, which is accomplished by reading and parsing the resource. The XML parser version used in this research is the XML for C++ parser (XML4C) from IBM.

It’s important to take advantage of existing application systems, including hardware and software, by incorporating them into the Web-based collaboration process. These legacy systems may be an existing CAX system, a MRPII or ERP system, or PDM systems of the injection molding company, the mold maker, or the suppliers. Mobile agent technologies are widely used to encapsulate legacy systems and to enable plug and play configurations [21]. In this research, the Aglets Development Kit is adopted. A set of generic Aglets are developed in accordance with various legacy systems to be encapsulated. A generic Aglet performs as a template that adapts to the contents and formats of specific information exchange or the input and output relationships of the legacy systems. It can be instantiated to generate an Aglet variant such that the corresponding encapsulating interface for a remote legacy system is implemented merely at the server side, and thus the legacy system can be simply plugged into the configure-to-order platform. Implementation of the instantiation process is achieved by encoding J2EE Session Beans and Entity Beans.

The application servers are implemented as distributed object components using Java Remote Method Invocation (RMI), which supports complex interactive communications between an application server and a client so as to achieve interactive design collaboration. It also supports object serialization, which is crucial for sending object models from the server to the client. Server-side collaboration is enacted between a coordinator server and the clients. At the coordinator server side, a lookup service is designed to provide a naming mechanism to manage clients and manufacturing analysis services distributed in the configure-to-order environment. The coordinator server can dynamically generate working sessions based on a Java RMI object factory mechanism, and
provide references to these sessions for clients to request and manipulate.

5.3. Prototype demonstration

The proposed platform has been implemented for collaborative customization of pipe fitting products. Client side collaboration is realized as Java Applets that provide the interfaces for multiple parties to interact with one another and access and manipulate the product and process information. Figure 6 shows the functional view of the GPF of 45° bend products, which performs as an electronic catalog for customers to interact with the product families.

![Electronic catalog for the pipe fitting products](image)

Figure 6. Electronic catalog for the pipe fitting products

Product specifications are derived from the customer ordering process, where customers make tradeoffs through interactions with diverse product functional features. Figure 7 (a) shows the customer ordering and product specification for a customer making decisions. Figure 7 (b) gives the visualization of the designed part for customer to evaluate and refine their requirements, i.e., the virtual prototype for customer assessment.

![Customer decision making and virtual prototype for assessment](image)

Figure 7. Customer decision making and virtual prototype for assessment

In accordance with each pipe fitting product family, a configurable mold design as given in Figure 8 is developed to accommodate all the variants of 45° bend product family. Figure 9 shows a parametric collapsible core design to support this modular mold assembly. As a result, all the product variants can be fabricated using the same configurable mold assembly,
subjective to variation of features within the prescribed ranges.

Injection molding production planning is realized using MxPTACi Plastics Injection Molding from Matrikon. In the prototype system, the customization of MxPTACi planning is fulfilled by constructing generic planning within the GPF. Figure 10 gives an example of injection molding production planning in MxPTACi.

Similarly, the API is also developed to incorporate the supplier management function into the prototype system. With SoftMold Solids, the suppliers of mold bases and molding components are managed under a unified platform. Examples of mold base and mold component supplier management in SoftMold Solids are shown in Figures 11 and 12, respectively.

Based on the GPF of pipe fitting, a parametric costing model is developed by compiling such cost elements as materials, tooling, machine utilization, and so on. Within the generic structures, all cost elements are linked to product features. A specific figure of the costing model is derived according to the particular specification of variety parameter set in relation to the customer order. Figure 13 shows a screenshot of the cost estimator Applet.
6. Conclusions

Web-based configure-to-order platform supports collaborative customization by allowing customers to create customized products via the Web, enabling guided product selection and configuration, facilitating variant production planning, and integrating with enterprise business systems. The state-of-the-art Java and Web technologies can be employed to establish a seamless integration infrastructure for these functions. A generic product family master model is the kernel of collaborative product development. The configure-to-order platform provides a workspace to organize co-design activities with co-modeling and co-modification functions for designers. Web-based solutions could offer scalability, easier implementation, and compatibility across diverse information technology platforms, and thus reduce incremental infrastructure investments. In addition, configure-to-order product fulfillment over the Internet would allow companies to cut product development and manufacturing costs, and greatly increase collaboration among partners both internally and externally.

7. References