Early Supplier Involvement in e-Product Configuration for Mass Customization

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Abstract

In terms of transforming supply chain into integrated value systems, the benefits of Early Supplier Involvement (ESI) in product development have been widely accepted. Despite past advancements in ESI, some unique issues have not been addressed for ESI in e-product configuration for mass customization. As far as variety management and online configuration are concerned, the difficulties of ESI in online mass customization manifest themselves through two main aspects: (1) Support the seamless information integration with respect to its high variety and large volume not only among internal functions but also with external suppliers; (2) Support real-time online configuration for product configuration generation and optimization based on customer requirements and supplier capabilities. Accordingly, this work proposes two potential solutions. PFA-based integrated information model is established to synchronize the PFA generic structure and supplier product information. Meanwhile, the mechanism of real-time bidding is explored to back up online configuration with the rapid RFQ requirements.

1. Introduction

e-commerce and mass customization have been foreseen as a primary style of manufacturing in the coming decade and beyond . With respect to 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. With the advent of information technology, electronic product configuration (ePC) for mass customization is being recognized as a potential dimension to enhance company profitability through a synergy of increasing customer-perceived value while reducing customization cost and improving product realization efficiency.

The implementation of ePC for mass customization mainly involves two critical issues: (1) Electronic catalogs have to be properly constructed to organize unstructured product information, achieve effective variety management, and enable reengineering companies' supply chain relationships. (2) The basic mechanism of online configuration needs to be explored through modeling product configuration process, formulating intelligent configuration systems, and developing approaches to the rapid request-to-quotations (RFQs) processing

In terms of transforming supply chain into integrated value systems, the benefits of Early Supplier Involvement (ESI) in product development have been widely accepted. As stated by [1], ESI is advocated as a means of integrating suppliers' capabilities in the buying firm's supply chain system and operation. Partnerships are formed with suppliers to take advantage of their technological expertise in design and manufacturing. A number of empirical studies reveal both strategic and tactical benefits of ESI. Dowlatshahi [2] develops a most comprehensive ESI framework. It is an initial conceptual ESI framework and can be used by companies. Bidault et al. [3] report the results of an empirical study that explores the drivers of the adoption of ESI in the product development process. Hartley et al. [4] conduct a study that empirically tests whether management of the buyer-supplier interface affects supplier-related delays. LaBahn et al. [5] develop a contingency model of component supplier intentions. Wynstra et al. [6] propose a coherent framework of specific activities across a number of different management areas within purchasing involvement in product development. Dowst [7] outlines nine areas in which suppliers can be involved in the buyer's design process. Huang et al. [8]~[9] identify that major ESI issues include make or buy decisions and supplier selection. Research literature on ESI in online mass customization is relatively scarce. Ghiassi et al. [10] describe a software system that supports electronic business operations in mass customized markets with synchronized supply chain required.

In spite of past progress in ESI, some unique issues have not been addressed for ESI in ePC for mass customization. As far as variety management and online configuration are concerned for ePC, the difficulties of ESI in online mass customization manifest themselves through two aspects.

Firstly, mass customization is facing a variety dilemma resulting from the continuous generation of product variants to meet diverse customer needs. To achieve effective variety management, a promising strategy is to shift the practice from designing and managing individual product instances to establishing product families. Although many research efforts have been put on supply chain management issues such as improving the process efficiency and integrating manufactures' systems with suppliers', there is a remarkable lack of clarifying the underlying mechanism of such integration in mass customization context, where product information is normally organized as product family architectures (PFA).

Furthermore, online configuration is another crucial factor to a success of ePC. Since mass customization involves understanding accurately customer needs and subsequently creating a complete description of a product variant that meets those needs, this is typically a sales order configuration process. Such a configure-to-order process assumes that a valid design is assembled from instances of a fixed set of well-defined component types (e.g., part catalogs), in which components are interconnected in a predefined way to meet a set of customer requirements and certain design constraints. ESI in online configuration is mainly embodied on supply development based on competitive bidding among suppliers. The bidding process is time consuming and often conducted offline. Thus, the traditional bidding is not applicable for real-time product configuration design with the rapid RFQ processing.

To overcome the two key hindrances of implementing ESI in ePC, this work emphasizes two potential solutions accordingly. PFA-based information integration between various business entities across a supply chain enables incorporation of ESI in online mass customization. Meanwhile, real-time bidding is proposed to accommodate the demands of online configuration.

2. Framework of ePC for mass customization

With the utmost concerns on the fundamental issues of ePC, an ePC system is characterized by two basic properties: (1) Supporting the information management and integration in terms of its high variety and large volume not only within internal functions but also with external suppliers. (2) Supporting real-time online configuration for product configuration generation and optimization based on customer requirements and supplier capabilities.

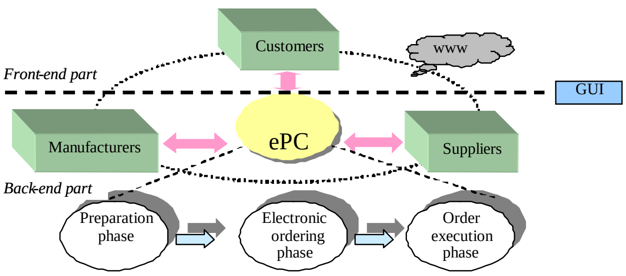

Figure 1. A simplified framework of ePC for mass customization

Electronic linkages enable better communication and coordination among distinctive entities across a supply chain and necessitate the redesign of the traditional supply chain relationships. A framework of ePC can be constructed to introduce the concept of integrated "value chains" into the online mass customization process. The whole ePC process is separated into three major phases including the preparation phase, the electronic ordering phase and the order execution phase. Once the management adopts online mass customization as its business strategy, the general procedure will start. Figure 1 illustrates the simplified framework.

Along the overall procedure, the task of the preparation phase is the construction of product family architecture (PFA), which represents product knowledge needed in the online configuration process. It defines the generic product model and classification (assortment) of products and component parts by means of modules, variety parameters, and constraints. During the electronic ordering phase, PFA is applied to product configuration. It creates a specific product instance or variant based on the generic model. This configuration solution can be represented as a product specification, a sales order, or a part list or a BOM. In this sense, PFA-based product configuration becomes the derivation of product variants through instantiating the generic product structure according to customer-specified variety parameters [11]. The order execution phase encompasses a number of sub-activities such as order entry, production scheduling, material planning, capacity planning, shop floor control, and so on. Research and applications in this area have been under their relatively strong status.

3. ESI in ePC for mass customization

Online mass customization implies an advantage over traditional supply chain intermediaries, that is, the direct interaction among customers, manufacturers and suppliers for every single transaction, which involves coordination about the customer-specific product design. The costs rising from customization consist largely of information costs resulting from the transfer of individual configurations to manufacturing, the increased complexity in production planning and control, the coordination of external suppliers involved in individual assembly, and individual distributions of customer-specific products. Electronic linkages enable companies to reengineer supply chain relationships fundamentally in reducing transaction costs through electronic handling of orders, invoices, and payments. These will facilitate reduced inventory requirements and vendor managed inventory programs. In particular, online product configuration results in an increasing number of supplier-customer relationships and an increasing use of supplier parts. Design-stage sourcing, if accomplished properly, is particularly effective at the downstream assembly-to-order stage of order fulfillment. Therefore, the involvement of suppliers in online product configuration becomes an important issue for web-based sales support. Furthermore, suppliers should be involved earlier than they must be actually involved. During online configuration, decisions regarding supplier parts, such as make or buy decisions, bid preparation, and supplier selection, must be determined with real-time interactions with customers, marketing personnel, and designers. Traditionally, however, suppliers are often involved offline after design is over.

3.1 PFA-based integrated information model

As the front-end of the company's interactive interface to online customers, electronic catalogs work as a virtual gateway by providing customers with an immediate access for obtaining product information, ordering goods, making payment, providing feedback and participating in other corporate activities. Good electronic catalogs should be built upon a thorough understanding of the coherence of product information. This research extends our previous work on the product family architecture (PFA) for mass customization [11] [12]. PFA is the conceptual structure and overall logical organization of generating a family of products, which provide a generic umbrella to capture and utilize commonality, within which each new product is instantiated and extended so as to anchor future designs to a common product line structure. The rationale of such a PFA lies in not only unburdening the knowledge base from keeping variant forms of the same solution, but also with modeling the design process of a class of products that can widely variegate designs based on individual customization requirements within a coherent framework. For each view of PFA, such as functional features (FFs), technical parameters (TPs) and components / assemblies (CAs), a generic structure can be established to understand variety and its impact on product differentiation [13]. There are basically three aspects underlying a genetic variety structure (GVS), which are product structure, variety parameters and configuration constraints.

(1) Product structure: All product variants of a family share a common structure. It can be described as a hierarchy comprising parts (P_i) at different levels of abstraction, where $\{P_i\}$ can be either abstract or physical items. Such a breakdown structure (AND tree) of $\{P_i\}$reveals the topology for end-product configuration.

(2) Variety parameters: Usually, there is a set of attributes (characteristics variables), A_i, associated with each P_i. Among them, some variables are relevant to variety and thus are defined as variety parameters, $\{V_{ij}\} \subset A_i$. Like attribute variables, parameters can be inherited by child node(s) from a parent node. The instances, $\{P_{ijk}\}$, of a particular P_i in relation to a certain V_{ij} embody the difference among product variants.

(3) Configuration constraints: Configuration constraints manifest themselves through restrictions on the combinations variety parameter values, $\{P_{ijk}\}$. For the player example in Figure 2, there is a color compatible constraint among $\{P_{33k}\}$ and $\{P_{51k}\}$. The instantiation of a part, P_i is achieved by specifying one and only one value for each variety parameter related to P_i that is,

$$P_i \xrightarrow{\{V_{ij} \to V^*_{ij}\}} \{P^*_{ijk}\}, \forall k \in [1, N].$$

This can be expressed as a XOR (i.e., exclusive OR) relationship in Figure 2, meaning only one of $\{P_{ijk}\}$ can be selected for a product variant. For example,

$$P_3 \xrightarrow[V_{34} \to V^*_{34}]{\substack{V_{31} \to V^*_{31} \\ V_{32} \to V^*_{32} \\ V_{33} \to V^*_{33}}} \{P^*_{31k}, P^*_{32k}, P^*_{33k}, P^*_{34k}\} \forall k \in [1, N]$$

As far as variant handling is concerned, the rationale for the generic variety structure lies in the recognition of the origin and subsequent propagation of variety. Three levels of variations have been indicated, i.e., at the structure, variety parameter and instance levels. Different variation levels have different variety implications. Accordingly, a generic representation can be introduced to represent variety with minimum data redundancy. There are two basic concepts as described below.

(1) Generic product: A generic product represents a set

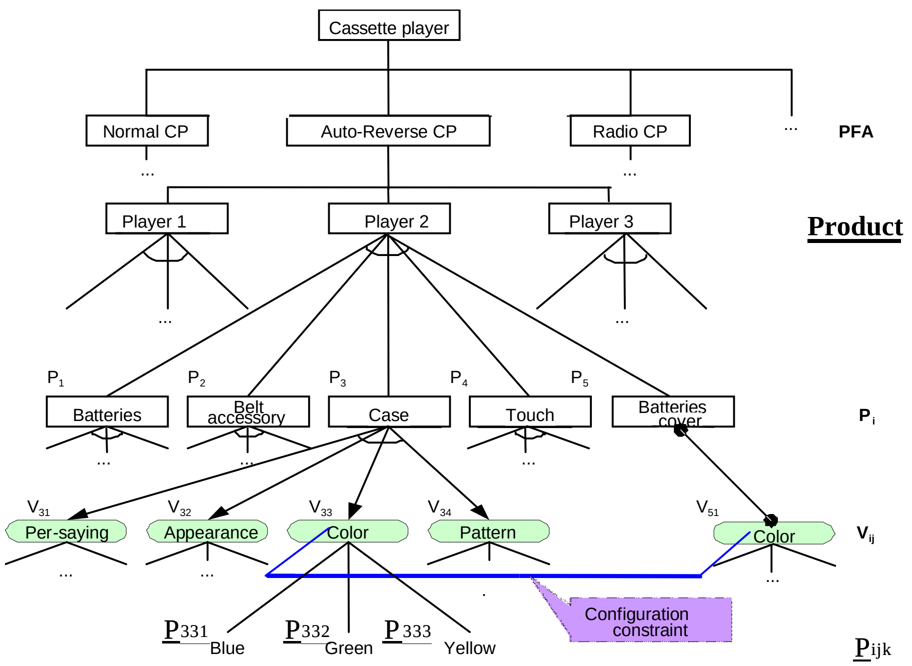

Figure 2 Generic variety representation for CP products

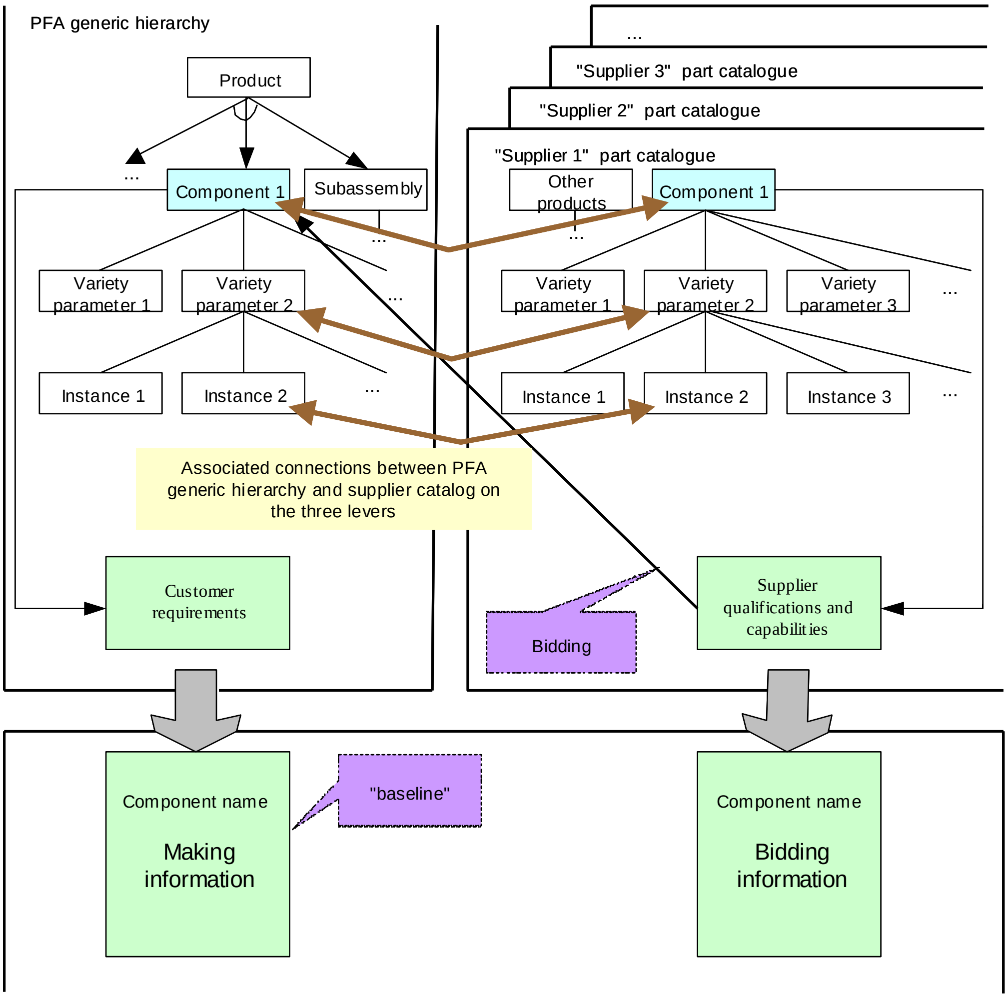

Figure 3. Integrated information model for ESI in online configuration under the umbrella of PFA

of similar products (called variants) of the same type (namely a family). A product may refer to an end product, a subassembly, an intermediate part, or a component part. For the player example in Figure 2, a blue case (P^*_{331}), a green case (P^*_{332}) and a yellow case (P^*_{333}) are three individual variants, whilst a generic product, $P_3|_{v_{33}}$, represents such a set of variants (a family of player cases), that is, $P_3|_{v_{33}} \rightarrow \{P^*_{331}, P^*_{332}, P^*_{333}\}$. Nonetheless, these variants are similar in that they share a common structure (Figure 2) in configuring a player.

(2) Indirect identification: Instead of using part numbers (referred to as direct identification), the identification of individual variants from a generic product (within a family) is based on variety parameters and their instances (a list of parameter values). Such identification is called indirect identification. In the above example, a variety parameter, color (v_{33}), and its value list, {“blue”, “green”, “yellow”}, can be used for an indirect identification of a particular variant, e.g., $P^*_{331} \sim P_3|_{v_{33}} = "blue"$. On the other hand, the identification of product family (generic product) “player case” is described as P_3.

The electronic catalog works not only as the front-end of the company’s interactive interface to on-line customers, but also integrates the back-end product operation capability of manufacturers and suppliers. The online sales order configuration coupled with supply chain planning is an important strategy in order to synchronize design and production planning functions by considering materials and capacity availability associated with suggested configurations.

Figure 3 illustrates how to incorporate ESI into online mass customization under the umbrella of PFA. Suppliers to certain component parts can be organized in a similar way to the GVS, in which attributes of the suppliers can be retrieved and evaluated according to their relevance to and satisfaction of those variety parameters required by certain component parts in a particular configuration. In this sense, variety parameters play an important role to link suppliers to the PFA.

Such issues as “Make” or “Buy” decisions and supplier selection can be dealt with according to the justification of the values of relevant variety parameters between a specific supplier and a particular instantiation of the PFA. Figure 3 shows the elaboration of the supplier product model and its information exchanges with the PFA, through which PFA information and supplier part information can be synchronized.

3.2 Real-time bidding

ESI in online mass customization differentiates itself from traditional ESI in product development through real-time bidding. Traditionally, the process of inviting and submitting bids is somehow time-consuming and often conducted off-line. With online mass customization performed, customers highly desire real-time online configuration, which aims at producing rapidly product configuration design with estimated price and delivery time subject to customer requirements and engineering or physical constraints. As such, it is really imperative to redesign the way in which a bidding process is incorporated in online configuration under mass customization environments. Real–time interactions between various entities are required as illustrated in Figure 4.

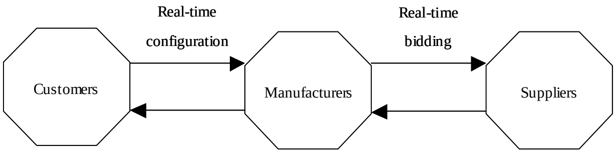

Figure 4. Real-time interactions

3.2.1 Static real-time bidding

Figure 5 shows an overview of the static real-time bidding process. A core of implementing static real-time bidding is to set up a centralized database for integration and management of supplier bidding information. The whole process starts with capturing customer functional requirements and ends at order entry. It is divided into three main stages including bidding preparation, bidding implementation as well as configuration generation and optimization.

In the bidding preparation stage, customer needs are captured as a set of functional requirements to certain components parts taking advantage of the electronic catalogs of ePC systems. As the electronic catalogs are organized based on PFA, customer requirements are actually reflected onto corresponding variety parameter instances within the generic structure of PFA. Subsequently the particular instantiation of the PFA is linked to product information systems of both manufacturers and suppliers, which are constructed in a similar way to the GVS of PFA. As a result, attributes of manufacturers and suppliers can be retrieved and evaluated according to their relevance to and satisfaction of those variety parameters in terms of customer functional requirements. In this sense, variety parameters work as a bridge to connect customers, manufacturers and suppliers together under the umbrella of PFA . While the mapping relationships among the triple entities are straightforward by using the PFA generic structure, it is critical to establish such linkages so as to enable downstream tasks such as "Make" or "Buy" decision and best supplier selection.

In respect of static real-time bidding, supplier bidding information must have already existed, that is, a number of potential suppliers are selected to put into an initial database based on last experience. In this case, ePC invites suppliers to provide the entire PFA-based product information instead of inviting bids for individual component parts. The bidding information is constantly updated in terms of suppliers' current capabilities. Towards this end, it is essential to integrate the centralized supplier database into their MRP or ERP systems. Moreover, the suppliers in the database may keep changing. New suppliers are added with new partnerships built whereas unqualified suppliers are deleted.

Based on customer requirements, supplier bidding content is primarily comprised by two parts, supplier

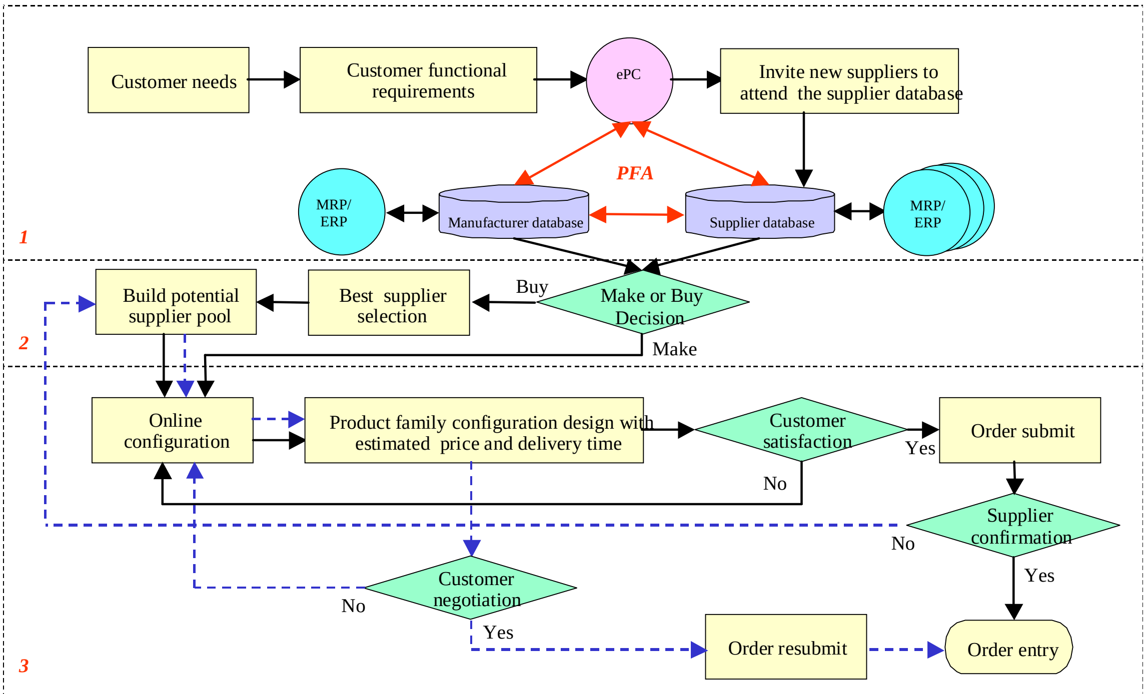

Figure 5. Static real-time bidding

qualification information and supplier production capability. Supplier qualification information is related to a set of fundamental non-technical requirements such as financial status, quality management systems and after sales customer service. On the other hand, supplier production capability is mainly concerned with technical requirements consisting of PFA-based part catalogs as well as component price and delivery time.

According to supplier bidding information, "Make" or "Buy" decision and best supplier selection can be carried out to achieve real-time bidding.

"Make" or "Buy" decision making is embedded in the ePC system. Manufacturers who are capable of providing customers with the expected functional features first publish their "Making" information of specific component parts as a baseline for all suitable suppliers who are automatically authorized to participate in the bidding process. Through comparing with supplier bidding information, ePC can draw conclusions whether or not "Buy" has advantages over "Make". Outsourcing only occurs when supplier bidding information surpasses the baseline. A Make/Buy index (MBI) is introduced to express the outcomes of comparisons between the suppliers and the baseline. Initially, MBI is 0 for both

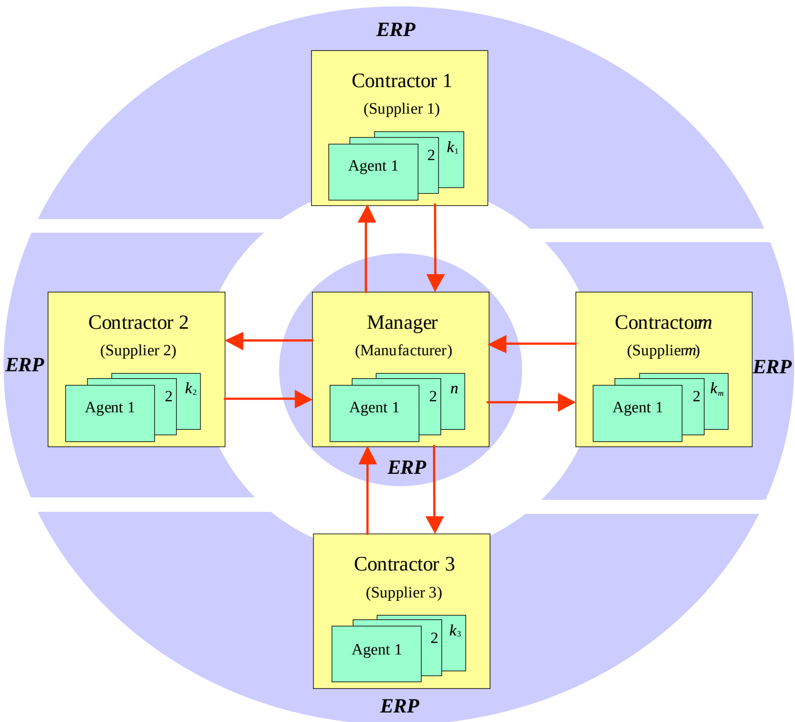

Figure 6. A multi-agent system supporting dynamic real-time bidding

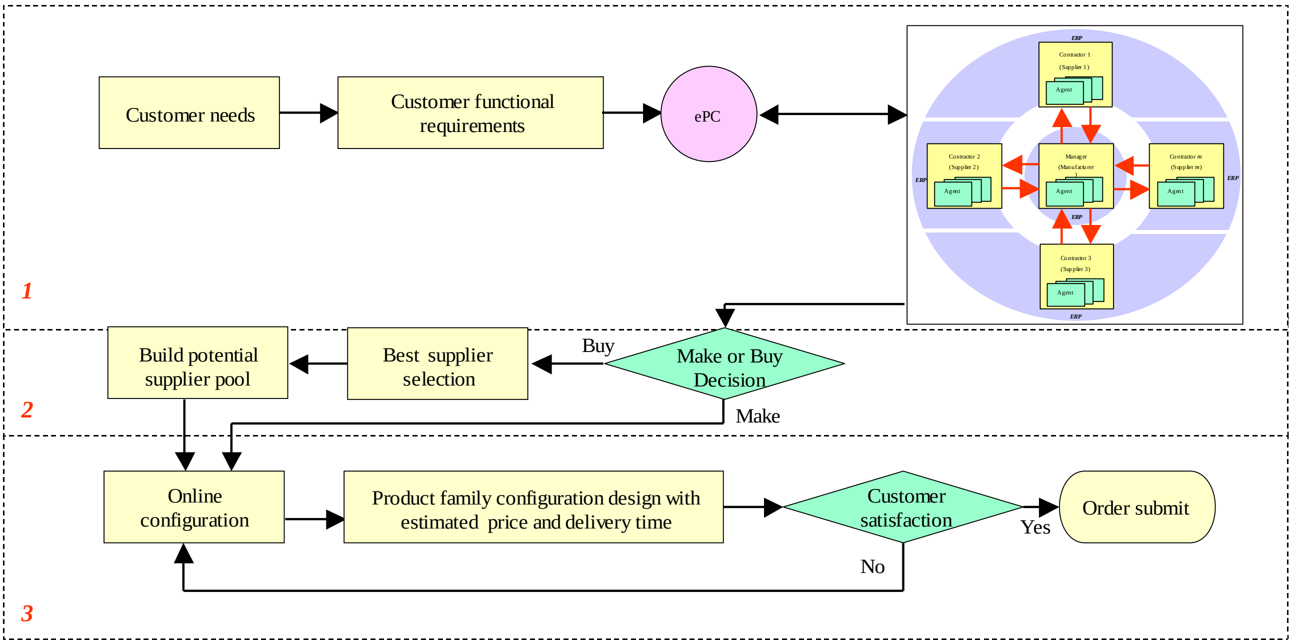

Figure 7. Dynamic real-time bidding

suppliers and manufacturers. When there is no suitable bidding supplier or there is no supplier exceeding the baseline, MBI of manufactures equals to 1. For anyone of bidding suppliers, if it surpasses overall criteria of the baseline, its MBI is set 1, which means “Buy” replaces “Make”.

Qualified suppliers with MBI equal to 1 are under further consideration for best supplier selection. Supplier selection is a multi-criteria decision making problem, which contains both qualitative and quantitative factors. In order to select the best suppliers, it is necessary to make a tradeoff between the tangible and intangible criteria, some of which may be in conflict with each other. Besides the Make/Buy index (MBI), other indices can be introduced to measure the extent to which supplier capabilities match customer requirements.

After executing supplier selection, the bidding parties with most promising indices are not directly considered for awarding the contracts. In contrast, a group of suppliers having relatively good performances are utilized to build a potential suppler pool. In other words, for a specific component part, more than one qualified suppliers will be involved as candidates for online configuration. Through carrying out product configuration design and optimization, the final selected suppliers in terms of the optimal configuration solution are not certainly the best suppliers owing to some tradeoffs made over the optimization course.

It is notable that a customer-satisfied configuration design needs to obtain the confirmation from the relative suppliers when taking into account possible variations of supplier capabilities. In other words, the selected suppliers have to make sure their bidding information once more in present scenario. Next, the contracts can be awarded to them. If the suppliers cannot offer overall production capabilities as promised in bidding information, they are referred to as unqualified suppliers, and a reconfiguration is done without the consideration of the unqualified suppliers in the potential supplier pool. The results of reconfiguration are then negotiated with customers.

3.2.2 Dynamic real-time bidding

Since supplier confirmation occurs simply after customers submit orders for static real-time bidding. This may make customers unable to obtain a configuration design which they like most. To overcome the weakness of static real-time bidding, it is essential to introduce real-time negotiation with suppliers into the bidding processes. Instead of handling fixed data, e.g. delivery time, deadlines, or prices, these information is negotiable in real world. To automate these negotiation processes, dynamic real-time bidding is conceived by building up multi-agent systems.

This research adopts Turowski’s framework of agent-based e-commence for mass customization [14]. The multi-agent systems are based on the contract net paradigm of [15]. In particular, a manager/ contractor contract net is employed.

All participants including manufacturers and suppliers in the manager/ contractor contract net are represented by agents. More specifically, the manager agents representing manufacturers invite bids by sending messages of request for quotes directly to the contractor agents. The contractor agents representing suppliers respond by submitting bids. Through negotiation, the manager agent finally informs each contractor agent whether he is under further consideration for awarding a contract based on his bidding information. Figure 6 illustrates a multi-agent system supporting dynamic real-time bidding.

Contents of negotiation include part information as well as terms and conditions associated with product price and delivery time. Agents conduct negotiation according to information from the ERP systems of both manufacturers and suppliers. Similar to static real-time bidding, the outcomes from dynamic real-time bidding will be utilized to perform the following tasks such as “Make” or “Buy” decision, best supplier selection and online configuration. A striking advantage of dynamic real-time bidding lies in the avoidance of supplier confirmation and extra customer negotiation before order entry. Consequentially, supplier capabilities are accurately embodied, and customer expectations are satisfied to the largest extent. Figure 7 shows an overview of the dynamic real-time bidding process.

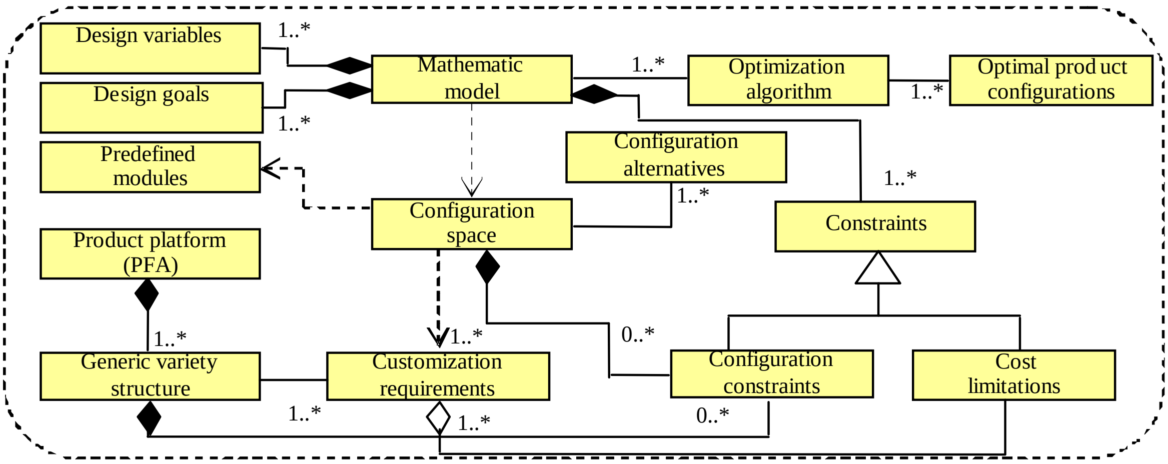

Figure 8. Underlying mechanism of product configuration design and optimization

3.3 Configuration generation and optimization

With product design practice shifted from designing an individual product to designing a product family for mass customization, product configuration design is also referred to as product family configuration design, which always contains two fundamental tasks, generation of a family of configuration design alternatives and evaluation for the optimal one. In response to them, an intelligent system is desired to achieve the following three targets simultaneously for product family configuration design: (1) Automatically produce a family of feasible configuration design alternatives according to all the requirements and constraints. (2) Subsequently select the optimal configuration design from the family in terms of multiple rational design objectives. (3) Reusable and robust to varying configuration spaces in various customization cases.

Product configuration design and optimization start with creating a PFA generic variety structure (GVS) representation. After that, customers propose functional requirements according to customizable features represented in the GVS. A configuration space is then derived from the synthesized information provided by a set of predefined modules and the customers' requirements. All configuration alternatives can be generated from the configuration space. After formulating a mathematical model with respect to the configuration space, an optimization algorithm is employed to produce the optimal configuration alternatives. A class diagram describes the underlying mechanism of product configuration deign and optimization in Figure 8.

Customer value comes from a balance of quality, cost, and delivery time. Cost, quality, and time are three commonly used parameters in expressing customer value. To assist customers in dealing with customization options, customer-perceived quality is differentiated from engineering quality, which is not what customers really care about. In this case, utility is taken advantage of to measure customer-perceived quality. As such, Utility of quality, customization cost and delivery time are proposed as three critical performance criteria for product family configuration design optimization. Solutions resulting from such multiobejctive optimization are expected to comprehensively express customer value and desirability. In addition of consideration from customer perspectives, selection for the "best" configuration design may involve more optimization objectives from the perspectives of manufacturers, suppliers, distributors, retailers and so on. In essence, it reveals the importance of product family configuration design carried out under the umbrella of the whole supply chain. For instance, from the manufacturer or supplier perspective, customizability is recognized as a potential index to fully measure the capability of design and manufacturing in terms of the nature of product family design. This direction is under an active exploration.

4. Implementation consideration

A computer-integrated system is necessary to develop the ePC for mass customization with static real-time bidding. Figure 9 shows an example of a system architecture. Customization by customers is enabled

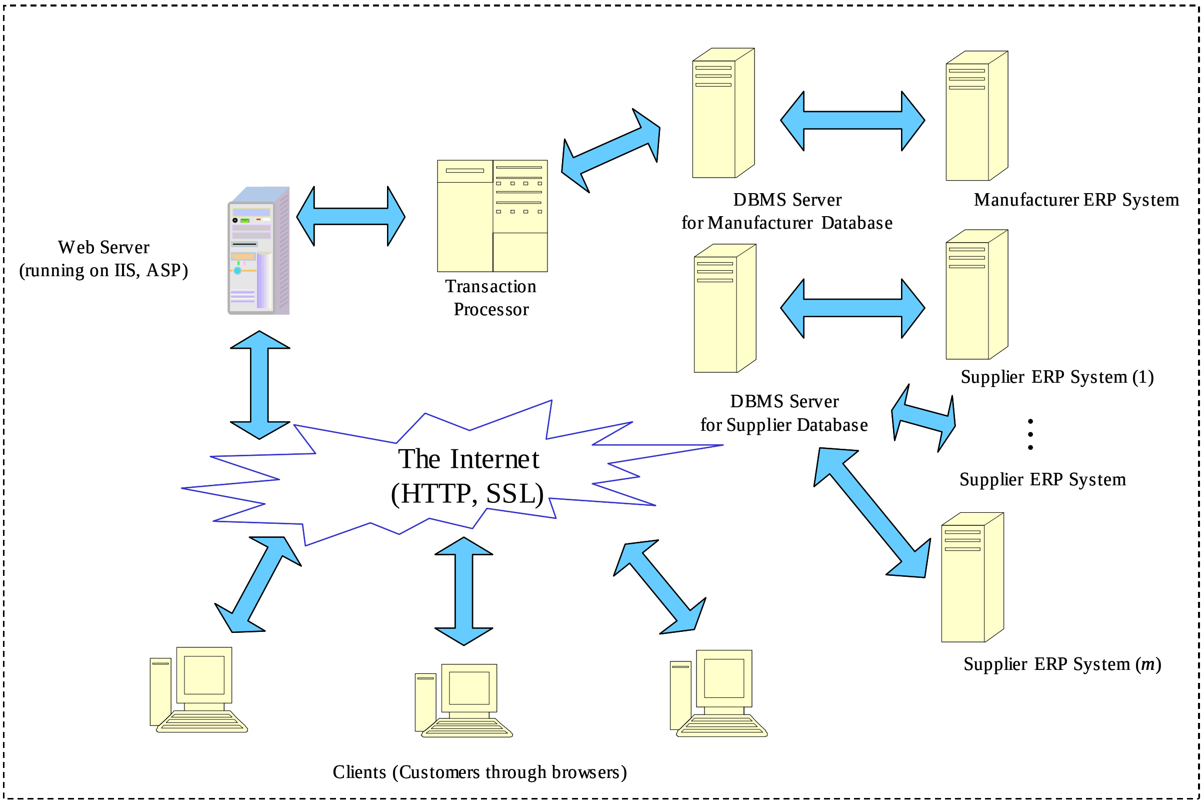

Figure 9. System architecture

through any Internet browsers. All information flow from the Internet is handled by the web server, in this case, running on an Internet Information Server (IIS) and using Active Server Pages (ASP) technology. The transaction processor acts as a connection module to process customers' data, real-time bidding and online configuration. Part of data that the transaction processor handles is retrieved from and updated into the database management system (DBMS) servers. Different DBMS servers could be assigned to deal with different tasks.

Two DBMS servers work as the manufacturer database and the supplier database respectively. Moreover, they are integrated with the ERP systems of both manufacturers and suppliers.

5. Conclusions

This research tried to investigate fundamental issues on ESI in online mass customization. PFA-based integrated information model is established across a supply chain to achieve effective variety management. Furthermore, the underlying mechanism of real-time bidding is explored to support online configuration. Two categories of methodologies are proposed as static and dynamic real-time bidding. A system architecture has been demonstrated for the ePC system with static real-time bidding.

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