Designing An Integrated Order Fulfillment System for Configure-to-Order Production

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Abstract – Due to the complexities resulting from the large number of customized products, an increased attention has been paid to the order fulfillment process in configure-to-order production. However, most of the solutions reported either focus on own interested areas without considering the impacts from/on the others or approach order fulfillment processes from a strategic level. In view of the limitations of existing solutions and the significance of order fulfillment activity automation and integration, this study considers the entire spectrum of order fulfillment process at an operational level and, proposes an integrated order fulfillment system (IOFS). The IOFS is designed to automatically execute order processing, configure products and process plans based on product and process family models. It assists companies to quickly respond to diverse customer requirements and deliver the expected products at low costs. An industrial example of turn unit assemblies is presented to demonstrate the feasibility and potential of the IOFS.

Keywords – Configure-to-order, order fulfillment process, product configuration

I. INTRODUCTION

In recent several decades, product customization has attracted much attention. To implement product customization, many companies have changed their business models from make-to-stock to X-to-order, where X stands for design, engineer, configure, etc. [1]. Configure-to-order (CTO) has been recognized as an ideal model that provides a right amount of product variety and a rapid response to customer orders.

In CTO, final products are configured from a set of predefined modules and components subject to the constraints among them [2]; and order fulfillment starts from order processing. In general, the activities in fulfilling a customer order can be grouped into four stages, namely order processing, planning, execution and delivery. Each succeeding stage interacts with its proceeding stage by utilizing the output of the latter and sending feedback to the latter. For example, order planning uses product specifications (i.e., the results of order processing) to configure products and require order processing to clarify or modify specifications so as to better meet customer requirements.

While each stage has its own focus, on receiving of customers’ inquiries or request for quotations (RFQs), they collaboratively work together, in attempting to achieve customer satisfaction. Order processing includes such activities that the communication among people is to articulate the particular customer needs, to obtain the corresponding product specifications and to estimate the possible cost and delivery time for answering RFQs. Order planning covers two parts regarding product configuration and process plan generation. It includes a wide range of activities from configuring products through generating the corresponding process plan to schedule production. Order execution is responsible for the realization of products. It contains such activities as the preparation of materials and manufacturing resources and the setup of production lines. It also includes production and control related activities. Finally, order delivery concerns the activities, such as delivering goods to customers. It also addresses the inventory management activities.

Although multiple solution frameworks, methodologies and methods have been proposed to improve order fulfillment processes, articles that explicitly discuss the entire spectrum of order fulfillment processes are relatively limited [3]. Moreover, the reported studies have their own functional focuses, e.g., quotation process reengineering [4], cost and delivery time estimation [5], product configuration [6], process plan generation [7]. Along with the advancements in Information technologies, a number of configuration prototypes and systems have been developed to support product customization. However, without considering other activities and the impacts associated with them, these systems only deal with partial information along the chain of order fulfillment (e.g., quotation, order quantity, delivery time). Essentially, they address order planning with an attempt to obtain product configuration.

The diverse customer requirements, large variety of possible configurations, various constraints among modules and components together with the resulting complexities in downstream planning and production demand an increased automation in order fulfillment processes for CTO production [8, 9]. In addition, the characteristics of order fulfillment processes (e.g., the dependency among activities within and between stages, the involvement of personnel from different disciplines) and the adoption of other processing systems in a company raise the importance in integrating the activities of different stages, in attempting to achieve a rapid and effective response to customer orders.

Recognizing the limitations of existing solutions to order fulfillment processes and the significance of integrating and automating activities to fulfill a customer order, this paper proposes an integrated order fulfillment system (IOFS) to provide companies with an integrated
solution to CTO production. The IOFS coordinates the activities in the entire process of order fulfillment in one platform. It handles customer order acquisition, product specification generation, production process plan configuration, production monitoring and customer order delivery. Therefore, the single platform and activity integration make order tracking easier. This in turn allows companies to be aware of the progress and problems in fulfilling a customer order at any time, thus taking the corresponding actions. The automatic order processing and product, process configuration help eliminate the errors in traditional approaches to obtaining customer orders, product configuration and process plans. Ultimately, the IOFS not only enables companies to quickly fulfill customer orders but also helps gain more potential orders through the online order acquisition.

II. THE IOFS

A. System Overview

Fig. 1 shows an overview of the IOFS. As enabling technologies, Internet/WWW provide a means for the IOFS to integrate with companies’ legacy systems. As a result, in the iterative order fulfillment processes, the IOFS permits significant information sharing among multiple involved participants from dispersed locations. It can provide customer needs analysis, and design and manufacturing expertise through the Web-based computing environments. Moreover, the IOFS provides participants with the ability to quickly interact by accessing its built-in expertise. Starting from acquisition of customer needs (CNs), the IOFS enables requirement transformation, product configuration, process plan generation, and scheduling to be automatically performed based on the expertise.

B. System Architecture

To provide the flexibility of interoperability on a variety of operating platforms, the IOFS can be developed by employing Java as the programming language and eXtensible Markup Language as the information exchange file format. The architecture of IOFS, as shown in Fig. 3, is a three tier distributed client/server architecture. While the clients serve as a means for getting user inputs and displaying the results, the server executes all the data operations and processing. The database hosts all the data as required.

The IOFS offers an environment that allows users to access the system via any Web browser such as Netscape’s Navigator or the Microsoft’s Internet Explorer at different geographical locations. The data representation tier provides database management facilities for product, process, code, order and customer databases, respectively. Microsoft SQL Server® is used to establish such a database management system. To
facilitate communication, ActiveX Date Object (ADO) can be adopted to interface with the relational database through Open Database Connectivity (ODBC). The client tier includes a set of application clients. Via a network using Transmission Control Protocol/Internet Protocol (TCP/IP), the client computer is connected with the Web server. The only stuff needed by client users is a Web browser. Between the data representation tier and the client application, there is a server tier (or business logic tier). The Internet Information Server (IIS) can be employed as the HTTP server. It accepts all the Active Server Page (ASP) requests sent from the client’s browser. Microsoft Message Queue Server (MSMQ) can also be installed to provide the technologies that allow the transmission of messages over network connections and management of these messages.  

In the IOFS, system security is achieved through password authentication, data encryption technology and verification. In this study, password authentication involves setting up user accounts and passwords in the database.

C System Databases

The IOFS consists of 6 databases for product, process, code, customer, order, and user profile, respectively. The product database hosts such data as product IDs, assemblies, parts, their interconnections, etc. By tracing the parent-child relationships among product items, a common product structure underlying a product family (i.e., a product family model) can be identified. The database also allows users to retrieve design parameters of intermediate items and the variety parameters coupled with possible values of parts and raw materials at the lowest levels in the common product structure. To enable the system to properly work, the product database is organized into a hierarchy. The process plan related information, including operations IDs, types and sequence, machines, tools and fixtures, etc., can be extracted from the process database. Same as product data in the product database, process data in the process database is also modeled as a hierarchy. The code for design parameters, their possible values, and other product, process related data is located in the code database. The connections between product and process data are established through these codes. Therefore, the three databases contribute to integrated and automatic product configuration and process plan generation, thus being the core of the IOFS. While the customer database provides customer related information, including IDs, names, addresses, contact numbers and purchased products information such as IDs and quantities, in the order database, the data ranging from order IDs and status (open or closed) to the IDs of products to the IDs of customers, etc. are stored. At last, for the security issues, the user names and passwords are saved in the user profile database.

All the above databases can be relational databases. Foreign keys are used to establish links among databases; and primary keys are applied to identify the corresponding data tables in one database.

D System Modules

The function of the IOFS is collaboratively performed by four main system modules as follows.

Order processing: The order processing module consists of three sub-modules: the assessment, transformation and RFQ sub-modules. The assessment sub-module is to check the validity of customer inputs (i.e., CNs). The transformation sub-module automatically transfers the CNs to a set of functional requirements and further to design parameters and their feasible values; the RFQ sub-module is responsible for making an accurate estimation of product costs and delivery dates. The real-time data and latest information required in the estimation process is obtained from the legacy systems, such as, inventory management, shop floor control, financial, material and capacity requirement planning systems. As a result, the precise response to RFQ can be quickly achieved.

After filling in the user name and the password, the user is prompted with the corresponding Graphic User Interface (GUI) based on his profile stored in the database. If the user is a potential customer, he needs to answer the displayed questions about basic characteristics of the product that he is interested in. These questions are designed according to constraints among product items. After the answers are confirmed by the customer, the assessment sub-module is to conduct a general check to determine whether or not these input answers exceed the company’s available engineering and manufacturing capabilities. If the capabilities are violated, a warning popup window is displayed on the customer’s screen. In this case, the customer may need to re-answer the questions. After the questions are accepted by the assessment sub-module, the transformation sub-module and the RFQ sub-module begin to work on these requirements inputs. First, these needs are transformed into FRs, which are not displayed on the customer’s screen as the final result. However, designers are allowed to trace and modify them for better design. Then, these FRs are mapped to the corresponding design parameters and their
possible values resulting in a set of product specifications. Last, the results including a list of specifications, estimated product prices and delivery date ranges are displayed on the customer’s screen.

If the customer accepts the displayed information, he proceeds to online place the order by filling in and submitting the order form. In case the customer is not satisfied with either the product specifications or product price or delivery date, he can get the different results by changing the answers to questions or modifying the required delivery date.

Product Configuration and Process Plan Generation: On receiving an online customer order, a salesperson starts the evaluation module, which is to carry out a thorough examination to determine the degree to which the order can be completed within the delivery time. Differing from the requirement assessment module, it conducts the evaluation by computing current available materials and manufacturing resources, checking open orders, inventory and shop floor status, comparing the required items with the available counterparts, and performing simulation. The final result, either order acceptance or order rejection, is displayed on the salesperson’s screen. If an order is not acceptable, a prompted dialogue window with the possible reasons is popped up on the screen of customer’s computer. Such reasons can be “the product price is low” or “the delivery date is tight”.

After an order is accepted, the configuration module starts searching in the product, process and code databases for the possible features and options to fulfill the product specifications transformed. In this study, the coding system in [10] is adopted to organize the code database. Based on the selected items and the product family structure, the set of all feasible product configurations and process plans are automatically generated.

After all configuration alternatives are generated, the following step starts evaluating these alternatives to determine a preferable one. In this study, the evaluation is performed subject to multiple objectives, including the minimization of production costs and the maximization of customer perceived values. Once the evaluation is completed and product configuration and process plan are determined, the scheduling module, called scheduler, starts scheduling the production. To ensure that the schedule can be completed within the due date, the scheduler extracts the necessary data from the legacy systems. The final results including the BOM list, drawings for parts and subassemblies, routing list, flow chart, and production scheduling, etc. are displayed on the screens of different users’ computers according to their activity shown on terminals’ screens. Rather than all activities being displayed, the IOFS only allows the display of the critical activities that are shown on the terminal screen.

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Furthermore, the IOFS saves the configurations of past produced products and retrieves them for the same products ordered later. In this case, the process plans are still regenerated. However, they may not be the same as the previous ones due to the different production situations.

Production Execution: Enabled by the advancement in IT/communications, technology and manufacturing equipment, shop floor control systems are connected with other systems (e.g., inventory management systems) to share and exchange the real-time data. By connecting with these legacy systems, the IOFS displays all necessary information for production on terminals’ screens on the shop floor. The displayed BOM and routing lists, assembly plan, etc. can guide the operators to prepare materials, machines, tools, fixtures, jigs and to set up production lines accordingly. Instead of the traditional paper documents that are used to instruct and control production activities, the IOFS provides online production control. Therefore, both the operators’ training time and production engineers’ time to prepare the documents, such as Manufacturing Process Instruction, Operation Sheet and Process Flow Charts, are reduced. Meanwhile, operation accuracy can be increased and the failure rate can be reduced thanks to the visualization of operation activities shown on terminals’ screens. Rather than all information, the IOFS only allows the display of the necessary information as required at a particular work station for a particular job.

For collecting the real-time data from the shop floor, the IOFS requires operators to key in the beginning and ending time of setup, operation and machine breakdown, respectively. Operators also need to select reasons for these machine stops/breakdowns from the drop-down menu, which lists all the possible causes. All information is then recorded and displayed on the screens of the corresponding engineers’ computers for them to monitor and take proper actions. At any point in time, the status of order fulfillment can be viewed online. This is coupled with the due date, time elapsed from order acceptance, time left to due date, number of products produced and the left ones to be completed. This information is then used to determine whether or not a reallocation of manufacturing resources and materials is needed or if particular bottleneck operation can be avoided.

Product Delivery: The IOFS is designed to allow the connection with existing inventory management systems, which record the types, quantities and status of finished goods. According to the information provided by online orders, the shipment department sends the right products to the right destinations, and changes orders to the closed status after the customers accept products. With the close of an order, all system databases are updated. The new product configuration, process plan, code, order, customer are added to their respective databases for problem solving in the future.

III AN INDUSTRIAL EXAMPLE

To demonstrate the potential of the proposed IOFS, a family of turn unit assemblies, which are typical CTO products, is adopted in this study. A turn unit assembly is
used at a conveyor belt to turn locomotives or other rolling stock onto one of several radically arranged tracks. It consists of several major components, such as a head module, a motion module and an enclosure module. Each module can be further decomposed into several child components. Fig. 4 shows a turn unit assembly and the common product structure and process structure of the turn unit assembly family.

A prototype IOFS is developed using ASP.Net programming, where MS Access® is used for databases management. According to the input information from a user, the relevant Web-pages are displayed; and different levels of access to the system are authorized to the user. For a customer, he needs to provide the answers to questions capturing his requirements on the turn unit assembly. Thus, the IOFS can get customer requirements which will be used to derive the technical definitions of the expected turn unit assembly. Suppose the CNs are within the coverage of company’s engineering and manufacturing capabilities, the IOFS automatically transfers these needs to FRs and product specifications. Meanwhile, the RFQ sub-module will compute the product price and possible delivery period. Then these estimated numbers and the product specifications are displayed on the customer’s screen showing information about the expected product, such as price, receiving date and technical solutions. By filling in and submitting the order form, an order is placed online by the customer in case he accepts the product outlined.

According to the product specifications transformed, the configuration module first generates a family of feasible product configurations and process plans, then evaluates and determines the optimal ones. For the turn unit assembly in Fig. 4(a), its product configuration and process plan are shown in Figs 5 & 6, respectively.

With all necessary information, such as BOM and process plan, production personnel can carry out production activities. The production information reflecting the real-time shop floor status is displayed on the screens of concerned persons’ computers and the shop floor terminals. Such updated information and production data enables the right decision to be made and the effective actions to be taken. Moreover, the IOFS can extract the real-time product data, which enabling the accurate estimation of cost and delivery time in processing orders. After completing production, the final products are delivered to the customers.

IV CONCLUSIONS

In CTO, fulfilling customer orders involves many participants from different disciplines, the interactive activities and iterative processes. The high variety of products and the resulting large volumes of product and production data make the order fulfillment process more complicated. Thus, an integrated and automated system is important for companies to efficiently articulate customer requirements, configure and produce the right products and make the final delivery. On the other hand, to some degree, the existing solutions in the order fulfillment and product configuration studies may help companies, for example, reduce the time and cost to configure a product. However, due to their inherent limitations, they cannot resolve some problems encountered in the fulfillment process (e.g., the access to the same data describing same objects). Furthermore, the claimed benefits of these solutions may be offset by the poor execution and results of other relevant activities and processes.

This study presented an integrated system to fulfill customer orders in CTO — the IOFS — along with some preliminary results from an industrial example. The IOFS allows automation and integration of activities in
fulfilling customer orders at an operational level. Thus, it enables companies to quickly react to unceasing customer requirement changes. Thanks to the connections with companies’ legacy systems, the IOFS can extract the real-time data and the latest information. Based on the predefined product and process family models, the IOFS can generate appropriate product configurations and process plans. In addition, the IOFS can retrieve the past product configurations for new orders. In this study, discussions of using the IOFS are developed based on the application to turn unit assemblies, which are not very complicated products. In this respect, future research efforts may be directed to scale up the system so that it can accommodate more complicated products.

REFERENCES


