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TOWARDS CUSTOMIZATION: EVALUATION OF INTEGRATED SALES, PRODUCT, AND PRODUCTION CONFIGURATION

ABSTRACT

Unlike most of the available configuration solutions, the integrated sales, product and production configuration is proposed to help companies realize product customization from a holistic view. It achieves this by determining the functional features (i.e., sales configuration), possible product alternatives (i.e., product configuration), and production process alternatives (i.e., production configuration). With the presence of multiple alternatives, it is necessary to determine final products and production processes based on the evaluation. This study, thus, evaluates the product alternatives and production process alternatives, which are configured in the integrated configuration. In line with the fact that in practice, cost and time are two of the most important elements in quotation preparation, we develop evaluation models to minimize the production costs and completion time. In addition, to provide companies with better decision-making support in selecting product offerings, the proposed configuration evaluation computes the differences in terms of cost and time among all the product and production process alternatives. With the differences in cost and time, companies can opt for suitable selection with respect to time or cost and/or other factors, e.g., strategic objectives. A case application of temperature controllers is utilized to demonstrate the results of the proposed evaluation of the integrated configuration.

Key words: Product customization, integrated configuration, configuration evaluation.

1. INTRODUCTION

In the past several decades, companies have been struggling to design and produce customized products at affordable costs and in a shorter lead-time (i.e., product customization), in the hope of improving market shares (Brun and Zorzini., 2009). It has been well recognized that successful product customization relies on the efficiency in both designing and producing customized products (Hong et al., 2008; Pitiot et al., 2014). For given customer requirements, configuration specifies a customized product as a combination of a set of pre-designed components. It is highlighted as one of the promising approaches to facilitate product customization (Trentin et al., 2011; Felfernig et al., 2014). As a special design activity, configuration capitalizes on the results of fundamental design, which include functional specifications, component design, and relationships between functions and components (Mittal and Frayman, 1989; Brown, 1998). For given customer requirements, it determines functional features, components, and component arrangement for the corresponding customized product. Based on earlier studies (Aldanondo et al., 2003; Haag, 1998; Forza and Salvador, 2002), configuration can be either sales configuration or product configuration. While the former determines the functional features that describe products, the latter selects components that technically define products. Some authors, such as Forza and Salvador (2007) and Shafiee et al. (2018), also call sales configuration commercial or high-level configuration and product configuration technical or low-level configuration.

By extending the concepts of sales and product configurations, researchers, such as Aldanondo and Vareilles (2008), Wang et al. (2017), Wu et al. (2013), and Zhang et al. (2012), discuss production configuration for planning production processes for customized products. Production configuration deals with the configuration of production processes by integrating the principles of product configuration and production planning. In determining production processes, it utilizes design similarity and commonality inherent in product variety offered by a company. The design similarity and commonality contribute to the configuration of such production processes that help achieve production efficiency by eliminating unnecessary production changeovers on shop floors, e.g., changes to manufacturing resources, operations precedence (Verdouw et al., 2011).

Many studies have been discussed to tackle configuration-related issues from both the perspectives of operations management and artificial intelligence. In several recent studies (Felfernig et al., 2014; Felfernig et al., 2018), from the perspective of artificial intelligence, various solutions are presented to cope with configuration formulation, configuration reasoning, configuration knowledge representation, configuration knowledge diagnosis, to name but a few. In the operations management community, efforts are made to address product modelling (Rasmussent et al., 2019), documentation in configuration systems (Shafiee et al., 2017), system design and development (Haug et al., 2012; Helo et al., 2010; Zhang et al., 2010), configuration process modeling (Zhang and Rodrigues, 2013), analysis of benefits, risks, failures and impacts (Forza and Salvador, 2002; Haug et al., 2019; Stonebrader, 1996; Trentin et al., 2012 & 2014). Essentially, the available studies focus on either sales configuration or product configuration, or sales and product configuration, or production configuration. While most of them involve sales and/or product configuration, a very few address integrated sales, product and production configuration (Verdouw et al., 2011; Zhang, 2014).

In view of the limited investigations on configuration integration, a concept of integrated sales, product and production (SPP[1]) configuration is put forward to facilitate product customization from a holistic view (Zhang et al., 2013). The SPP configuration addresses simultaneously sales, product, and production configurations in one system by capitalizing on the interdependences among them. Some recent studies (Aheleroff et al., 2019; Kaneko et al., 2018) highlighted that personalization involves new design. In this regard, the SPP configuration does not offer personalization. It offers

[1] The acronym SAP[2] is used in (Zhang et al., 2013). To avoid unnecessary confusion with practice, we use SPP in this study.

customization in the sense that it allows the selection of various components of same types. The SPP configuration explicitly deals with the evaluation of configured product and production process alternatives. Based on the evaluation results, it can help companies make suitable product offering decisions in product customization. In the earlier work (Zhang et al., 2013), the model underpinning the SPP configuration, called the Generic Bill of Functions, Materials and Operations (GBoFMO), is investigated.

Built upon the above earlier work, in this study, we address the evaluation of the SPP configuration. While we consider its application in a single facility, we envision the applicability of an enhanced version in distributed manufacturing where multiple facilities are scattered in different locations. Additionally, we consider its application to products having different complexity levels, such as cars and industrial equipment. Bearing in mind that cost and time are two important elements in quotation preparation (Kingsman et al., 1996; Chen et al., 2003; Lan et al., 2008), we develop evaluation models to minimize production costs, completion time of product and production process alternatives. Besides, we also calculate different time- and cost-related values for each pair of product and production process configured. With these cost- and time-related values and/or other factors, e.g., the relationship with the customer, companies can decide on the suitable product configurations to be offered to customers. In this regard, the SPP configuration is intended to support companies to make decisions on product customization, instead of making decisions. The contributions of this study are, thus, twofold. First, we develop models to evaluate integrated sales, product and production configuration, which is largely untouched in literature. Second, this study facilitates practitioners' decision making in product offerings by providing multiple alternatives coupled with time and cost information.

The rest of the paper is organized into the following sections. In Section 2, we present the work relevant to this study. We introduce the SPP configuration in terms of its process flow and system modules in Section 3. Section 4 presents the configuration evaluation developed in this study. In Section 5, we use an example of temperature controller configuration to demonstrate the application results of the SPP configuration evaluation. We discuss further the interrelationships between the SPP configuration and product family development, which significantly contributes to product customization, in Section 6. Also discussed is the integration between the SPP configuration and companies' legacy systems. We end the paper in Conclusions by highlighting the potential avenues for future research.

2. Framework of Relevance

Since the publication of a pioneering article (McDermott, 1982), configuration has attracted increasing attention from the academia and lasting interest from industries. As a result of countless investigations, myriads of articles have been published. We present below the related studies based on the types of configuration activities, including sales, product, and production. We also point out if the studies involve product documentation and configuration evaluation.

Table 1: Related studies

Literature	Configuration			Product documentation	Configuration evaluation
	Sales	Product	Production		
Haag, 1998; Salvador&Forza, 2007; Wang&Tseng, 2011; Ardissono et al., 2003; Trentin et al., 2013 & 2014; Felfernig et al., 2014	X				
Song&Kusiak, 2009; Tseng et al. 2005; Tang et al., 2017; Kusiak et al., 2007; Hong et al., 2008; Lee&Lee, 2005; Tseng&Chen, 2006		X			
Wang et al., 2017; Wu et al., 2013; Zhang et al., 2012; Zhang&Rodrigues, 2013; Zhang, 2007			X		
Pitiot et al., 2014&2019; Verdouw et al., 2010		X	X		
Salvador&Forza, 2002&2004; Trentin et al., 2012; Zhang et al., 2010;	X	X		X	
Zheng et al., 2017	X	X			
Shamsuzzoha&Helo, 2016; Forza&Salvador, 2008; Shamsuzzoha&Helo, 2016; Helo et al., 2010;	X	X	X	X	
Zhang et al., 2013; Aldanondo&Vareilles, 2008	X	X	X		

Using kitchen configuration, Haag (1998) shed light on the challenges and approaches of sales configuration in SAP's R/3 business software suit. Salvador and Forza (2007) proposed several principles underlying effective sales configuration processes. Wang and Tseng (2011) introduced an approach based on Shapley value to capture customer requirements in sales configuration processes. Similarly, Ardissono et al. (2003) presented an adaptive, dynamically generated user interface for better capturing customer requirements in a sales configuration process. Trentin et al. (2013)

discussed the necessary capabilities of sales configurators to help companies avoid the paradox of offering more product variety while resulting in a loss of sales. In a similar study (Trentin et al., 2014), the authors presented the sales configurators' capabilities to increase customers' perceived benefits from configuring products. Using the configuration of virtual private networks as an example, Felfernig et al. (2014) described, e.g., product model, knowledge representation and reasoning, knowledge acquisition and exchange involved in sales configuration.

With a focus on how to determine optimal product configurations, authors presented different solutions. Song and Kusiak (2009) proposed a data mining approach for companies to identify the frequently ordered subassemblies and final product configurations. Tseng et al. (2005) developed a case-based reasoning algorithm for determining product configurations. Tang et al. (2017) put forward an optimization model. In their model, they consider carbon emissions and customer satisfaction. Other authors, including Kusiak et al. (2007), Hong et al. (2008), Lee and Lee (2005), and Tseng and Chen (2006), also discussed different approaches to determine optimal product configurations. Based on principles of product configuration, some authors proposed to configure production processes for final products (Wang et al., 2017; Wu et al., 2013; Zhang et al., 2012; Zhang and Rodrigues, 2013). Unlike process planning, which deals with the planning of manufacturing processes for parts (Li et al., 2010), production configuration is to configure complete production processes, including manufacturing processes for making parts and assembly processes for producing sub-assemblies and final products (Zhang, 2007). Recognizing the importance of jointly configuring products and production processes, some authors discussed integrated product and production configuration. Pitiot et al. (2014; 2019) developed an evolutionary optimization algorithm and solution approach to optimize joint product and production configuration. Aiming to better manage demand and supply uncertainties, Verdouw et al. (2010) put forward an information architecture and configuration system development strategies for combined product and production configuration. Though the above studies focus on different configuration types, they bear a common feature: Product documentation and configuration evaluation are not considered.

Involving integrated sales and product configuration, as well as documentation, Salvador and Forza (2004) analyzed the difficulties and opportunities related to the use of product configuration systems. Forza and Salvador (2002) and Trentin et al. (2012) shed light on the benefits and contributions of product configuration systems where sales and product configurations are carried out and product documents are generated. Zhang et al. (2010) and Zheng et al. (2017) introduced their prototype systems for integrated sales and product configuration. While the former considers product documentation, the latter leaves it unaddressed.

Understanding their interdependences, authors discussed integrated sales, product and production configuration. By viewing it as a constraint satisfaction problem, Aldanondo and Vareilles (2008) extended product configuration to upstream requirement configuration and downstream production process configuration. Forza and Salvador (2008) stated that for better managing product variety, a product configuration system should be able to configure functional features, products, and production processes and to generate product documentations. Similarly, Shamsuzzoha and Helo (2016), Helo et al. (2010), and Zhang et al. (2013) discussed integrated sales, product and production configuration with different focuses. While the first two groups of authors used demo configuration systems to demonstrate their proposed integrated configuration frameworks; Zhang et al. (2013) detailed the product model underpinning the proposed integrated configuration. Addressing integrated configuration, these studies left configuration evaluation untouched.

To summarize, the available studies addressed either sales or product or production configuration or integrated configuration. While many studies involved one type of configuration activities or the integration of two types, a very few dealt with integrated sales, product and production configuration. In addition, product documentation was considered in some studies; configuration evaluation was largely ignored. In this study, we investigate the evaluation of integrated sales, product and production configuration proposed in (Zhang et al., 2013) while considering product documentation.

3. System of SPP Configuration

The SPP configuration complements the existing solutions by addressing simultaneously sales, product, and production configurations. Besides, it deals with configuration evaluation and automatic generation of important documents describing technical design of configured products and production processes. While a product's technical design is represented by bill of materials (BOM), a production process is represented by bill of operations (BOO) (Jiao et al., 2000). First introduced in (Balogun et al., 2004), a BOO includes a list of operations and precedence relationships between two operations. Also included are manufacturing resources, e.g., machines, for each operation. As stated in (Mleczko and Dulina, 2014), it is very important to automatically generate product documentation, including BOMs and BOOs, in high variety production environments. In the text below, we detail the process flows and system modules of the SPP configuration.

3.1 Process flow

Same as most reported configuration systems, a customer's answering online questions is the starting point and triggers the subsequent configuration activities, as shown in Figure 1. The SPP configuration will then assess customer inputs by checking the validity. Also assessed is the feasibility of producing functional features based on a company's available design and manufacturing capabilities. In case the negative evaluation results, it informs the customer and asks him to consider modifying the answers. The negative evaluation results might be caused by the customer's incomplete or conflicting answers (Jiao and Chen, 2006). In such cases, it is necessary to ask the customer to modify his answers. If the evaluation is positive, it generates the preliminary sales configuration. It is from this point onward that the SPP configuration works differently with the available solutions and systems. Most of the available solutions generate quotations, including prices and delivery dates, based on the historic costing and cycle time data of features. In generating quotations, the availability of manufacturing resources is ignored, leading to the current and future orders competing for the same resources. In fact, the traditional way of quotation generation assumes infinite manufacturing resources available on shop floors. As a result, quotations obtained are often inaccurate (Lan et al., 2008).

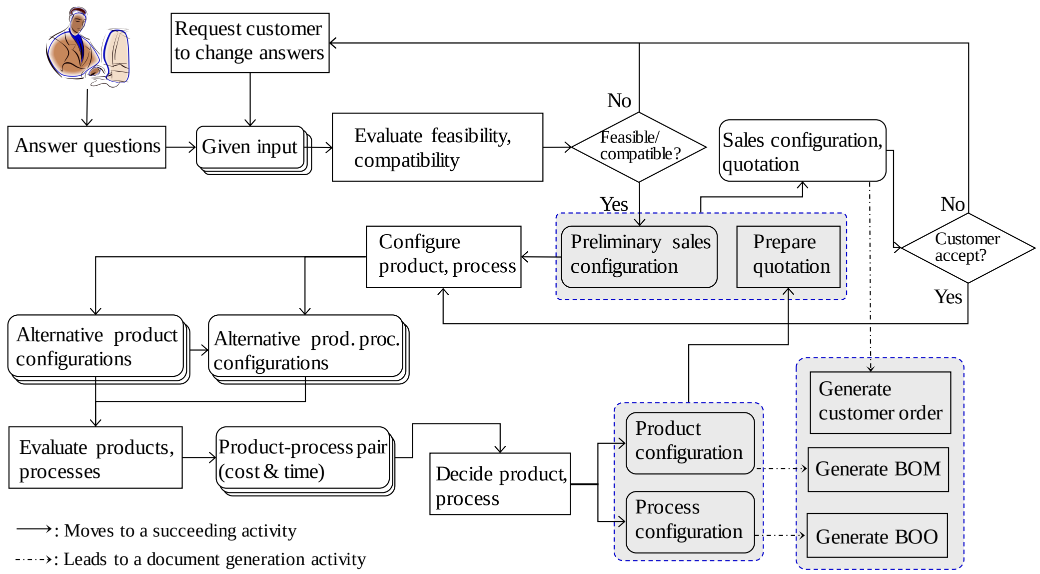


Figure 1: Process flow of SPP configuration

To prepare quotations, the SPP configuration utilizes the latest data about available manufacturing resources, leading to realistic cost calculation. Based on the preliminary sales configuration, it first configures customized products and corresponding production processes. Subsequently, the configured alternatives are evaluated in terms of production cost and completion time. The evaluation is accomplished by incorporating the real time data from companies' legacy systems, such as production planning and control systems and shop floor execution systems. The evaluation results include a list of configured product alternatives coupled with production process alternatives. (The fact that many product alternatives can be configured does not mean that a company offers all of them. These alternatives are the inputs for the company to make decisions about final product offerings.) Also included are the computed production cost and completion time for each pair. Based on the results, the company can determine suitable product configurations and production process configurations while considering the trade-offs between cost and lead time. They can also incorporate other factors, e.g., strategic objectives, relationships with customers, when making decisions. With the final decision on product and production configurations, the SPP configuration calculates the price and delivery lead time for preparing quotations. As pricing and delivery lead-time are calculated based on the latest data about manufacturing resource availabilities, the quotation is accurate. Together with the quotation obtained, it presents the preliminary sales configuration as the formal sales configuration to the customer. Upon the customer's acceptance, it generates the BOM and BOO for the configured product and production process, respectively. Also generated is the customer order. In case, the customer is not satisfied with either the price, delivery lead-time or the features included in the sales configuration, the process will start again with modified answers and/or online questions. While we summarize above the major steps involved in the SPP configuration, we elaborate the configuration details in terms of system modules below.

3.2 System modules

There are several modules in an SPP configuration system, including the user interface, input evaluation, sales/product/production configuration, configuration evaluation, quotation preparation, and order/BOM/BOO generation modules, as shown in Figure 2. These modules perform certain functions and interact with one another towards the delivery of the outputs, including customer orders, BOM and BOO of a product configured.

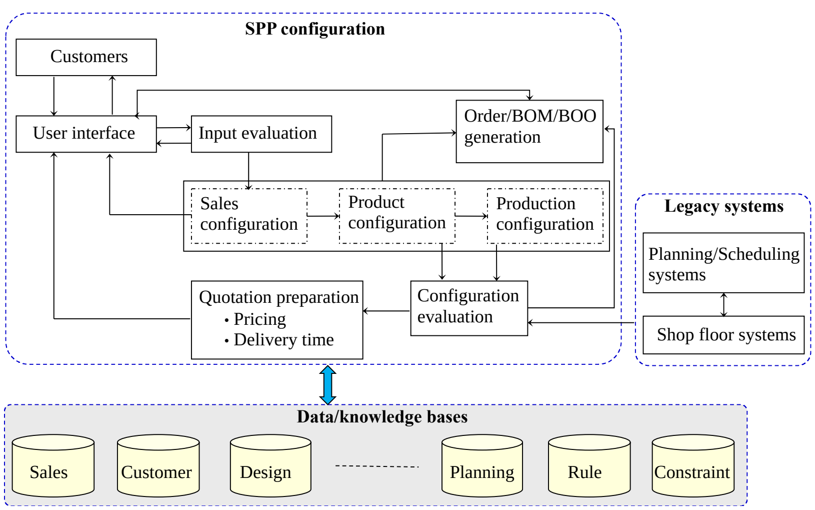


Figure 2: System modules of SPP configuration

User interface module: The SPP configuration begins with the communication of customer requirements through the user interface module. Based on the customer preference, this communication is carried out in several ways by, e.g., the customer directly answering the online questions using her web browser, a salesperson filling up the questions based on the discussions with the customer. In accordance with the different ways to obtain customer requirements, companies can develop their specific systems for either internal use or a combination of both internal and external use. When a specific configuration system is developed for a combination of both internal and external use, a customer is granted access right. With the access right, he directly answers the questions using his web browser. When a specific system is developed for internal use, the sales staff contact customers to collect their requirements and then enter the requirements in the system by answering the questions. As pointed out in several studies (Blecker et al., 2003; Randall et al., 2005; Wang and Mo., 2018), most customers do not have enough knowledge about the terminologies describing product functions and features. This is especially true for complex products or products for industrial usage (Ratchev et al., 2005). Therefore, the questions should be designed using the terms that customers are familiar with or can understand well. For example, such questions can be: What is your favorite color? In what environments do you use this product? What do you use this product for? Answering all these questions will enable the system to obtain enough customer requirements such that the customized product can be configured. In view of the negative effects of information overload on customers' decisions (Chen et al., 2009), the questions are suggested to be sequentially presented one at a time, instead of all at the same time. In addition, based on the customer's responses to preceding questions, the system dynamically determines the subsequent questions to present. To enable this, the involved knowledge, such as marketing and sales, might be organized as a decision tree. According to the answer at each node (i.e., a decision point), the system decides the branch (i.e., modeling a question) to follow. In this regard, when a customer modifies his answer to a question, the subsequent question that appears might be different with the original one.

In addition to capturing customer requirements, the SPP configuration system presents the description of a configured product, the 3D visualization of the product, the price and delivery date through the user interface module. If the customer is satisfied with the product, price and delivery date, he can also place an order through the user interface module. In case there are errors in the customer input or changes in the quoted prices and/or delivery dates (see Quotation preparation module), the dialog boxes with the explanations are also presented to the customer through the user interface module.

Input evaluation module[2]: The input evaluation module evaluates user inputs from several aspects, such as data validity and completeness, customer historic information, product manufacturability and functionality. For instance, if the module detects that the input data are incomplete or invalid, it prompts the user to make necessary additions or changes. The module also checks if the existing design and manufacturing capabilities are capable to produce a specific feature in accordance with the inputs. For example, a customer requires a 15-inched LCD monitor. The module evaluates this requirement to be unachievable as the company's design and manufacturing capabilities are not able to produce such a monitor. Furthermore, the module assesses if customer requirements conflict with one another. Similarly, if it finds incompatible or conflicting requirements, the system informs the user about the conflict and further asks modifications.

Sales/product/production configuration module: To enable sales, product, and production configurations in one system, the configuration model: GBoFMO organizes all the data and knowledge related to customers, sales, design, planning, production and process, as shown in Figure 2. Built upon the GBoFMO, three submodules, including the sales configuration, product configuration, and production configuration submodules, form the configuration module. The sales configuration submodule configures the set of compatible functional features that can meet the customer requirements evaluated. Based on the sales configuration, the product configuration submodule determines the technical specifications of the customized product. More specifically, it selects the appropriate component types, determines component attributes and their values, and finally decides the design parameters and corresponding values to define components in line with the

[2] The characteristics and work follow of this module are consistent with the available literature (Yang et al., 2005). To make the paper self-explanatory, we provide its description in the text.

attribute values. The result of product configuration includes several product alternatives, each of which consists of specific components and their parent-child relationships. For each product alternative, the production configuration submodule configures production processes, each of which is formed by operations, operations precedence, and machines along with other manufacturing resources. Thanks to manufacturing resource flexibility, usually more than one production process is feasible to produce a same product (Martinez et al., 2000). In this regard, the production configuration submodule configures multiple production process alternatives for each product alternative. Moreover, in practice, a company may possess one or more production lines. Thus, the operations and manufacturing resources configured may be relevant to one or more production lines.

Configuration evaluation module: Unlike most of the available configuration systems, the SPP configuration system not only deals with configuration but also handles the evaluation of configured alternatives. The configuration evaluation module performs this task. It takes the result of the configuration module: pairs of configured product and production process alternatives as input and evaluates each pair with respect to production cost and completion time. It outputs a list of product and process pairs along with the cost and time values. Based on such result, the company can make decision on the products to be offered by considering, e.g., the trade-off between cost and delivery time, the relationship with the customer, its strategic objectives (see details in Section 4).

To ensure the accuracy, the evaluation is based on the latest data about manufacturing resource availabilities that are obtained from the company's existing production planning and scheduling systems and shop floor execution systems, as shown Figure 2. Considering the complexity involved in the evaluation, we develop evaluation models, which are the core of this module. See the details of evaluation models in Section 4.

Quotation preparation module: As mentioned in multiple studies, the accuracy of quotation with respect to price and delivery lead time is very important in gaining customers (Chen et al., 2003; Lan et al., 2008; Zhang et al., 2010). Thus, in the SPP configuration, the quotation is prepared based on the products and production processes after configuration evaluation, instead of the features after sales configuration (as in most of the available configuration systems). The quotation preparation module calculates the prices and delivery dates based on production costs and completion times obtained from configuration evaluation. Besides, other factors might be considered for the quoted prices and delivery dates. They include the level of interest in capturing this customer order, prior pricing policies for this customer, market competition and market price for comparable products. The additional factors might be saved in customer databases or sales databases, as shown in Figure 2. As the quotation is prepared based on the latest information about manufacturing resources, if the customer does not accept it within a given period, the quotation may not be accurate due to the possible status change of manufacturing resources. In such situations, the quotation evaluation module recalculates the price and delivery date based on the re-evaluated product and production process alternatives.

Order/BOM/BOO generation module: To generate error-free BOMs, companies turn to configuration systems (Forza and Salvador, 2002). In response to the lack of studies in the generation of error-free BOOs, which together with BOMs contribute to smooth production, high product quality and reduced production lead time, the SPP configuration system is designed to automatically generate both BOMs and BOOs for the configured products and production processes. The order/BOM/BOO generation module performs this task and generates customer orders, BOMs, and BOOs. Upon receiving the customer acceptance signal from the user interface module, the generation module will generate the customer order including the basic customer information, his requirements, the sales configuration, and the price and delivery date. It then saves the customer order into relevant databases, such as the customer, sales, product and process databases, for future configuration. The module also generates BOMs and BOOs for the final selected products and production processes after configuration evaluation. Similarly, the BOMs and BOOs data will be saved in the corresponding databases for future configuration. To ensure the accuracy of BOMs and BOOs generated, the generation module gets the necessary data from the legacy systems, such as product data management systems, process planning systems, design systems. It should be noted that in many cases, customer orders, BOMs, and BOOs are companies' internal documents and are not sent to customers (Mleczko and Dulina, 2014).

4. CONFIGURATION EVALUATION

Evaluating product and production process alternatives configured attempts to help companies make decisions in product offerings. Thus, the evaluation results include a list of product and production process pairs, instead of a single pair. From this list, companies can select products to be offered and production processes to be used to produce products by taking into account some performance measures. In line with the fact that quotation preparation is based on configuration evaluation, the performance measures are production cost and completion time. Production cost includes several costs, such as material cost and machine processing cost (see details below); completion time is the calendar time[3] for completing the production of a product using a production process. The calculation of completion time, thus, considers the availability of manufacturing resources. The input of configuration evaluation is the result of product and production configurations, including a set of configured product alternatives with each having a set of production process alternatives. For these inputs, configuration evaluation first calculates production cost for a product alternative and each of its production process alternatives. It subsequently determines the production process that incurs the lowest cost. It then calculates the completion time based on the production process determined. Configuration evaluation carries out the above calculations and production process determination for each product alternative configured. With the product costs and completion time for all the product and production process pairs determined, configuration evaluation calculates the average production cost and completion time. In addition, it also calculates the differences between the average cost, time and these of each pair. Finally, configuration evaluation arranges the product and production process pairs according to either the increasing order of production costs or time or the difference of time or cost. In practice, a company

[3] The calendar time involves the calendar date where the production will be completed.

can determine the arrangement criteria based on his specific situations. The algorithm of configuration evaluation is summarized in Figure 3. Two models: cost evaluation model and completion-time evaluation model are elaborated below.

```
For a set of product alternatives configured and the production process alternative sets
   Generate a list of product and production process pairs
      Calculate production costs
         For each product alternative
            Encode components and the corresponding usage
            For each production process alternative
               Encode operations according to operations precedence
               Encode processing times for corresponding operations
               Encode machines for corresponding operations
               Encode setups for corresponding operations
               Encode tools for corresponding operations
               End
            End
          End
          For i++, do
             Call the cost evaluation model
             Remove the returned product and production process alternative from the input set
             Put the returned product and production process alternative on a list according to the increasing
             order of costs
             While i is equal to the total number of input product alternatives
             End
          End
      Calculate completion times for the generated list of product and production process pairs
         For each product and production process pair
            Call the completion time evaluation model
            Record the returned completion time for the corresponding pair
            End
         End
      Calculate the average production cost, completion time
      Calculate for each pair the difference between its production cost and the average cost
      Calculate for each pair the difference between its completion time and the average time
      Reorganize the list of product and production process pairs by adding to each pair the production cost,
      the difference between the production cost and the average cost, the completion time, the
      difference between the completion time and the average completion time
      End
   End
End
```

Figure 3: Algorithm of configuration evaluation

4.1 Cost evaluation model

Below is the notation used:

P_i : the *i*-th product alternative configured, $i = 1, \cdots, NPA$, where *NPA* is the total number of product alternatives;

C_{ic} : the *c*-th component of P_i, $c = 1, \cdots, NC_{P_i}$, where NC_{P_i} is the total number of components;

CC_{ic} : unit material cost of the *c*-th component of P_i, $c = 1, \cdots, NC_{P_i}$;

QC_{ic} : quantity usage of the *c*-th component in one P_i, $c = 1, \cdots, NC_{P_i}$;

R_{ir} : the *r*-th production process alternative configured for P_i, $r = 1, \cdots, NRA_{P_i}$, where NRA_{P_i} is the total number of production process alternatives;

O_{iro} : the *o*-th operation of R_{ir}, $o = 1, \cdots, NO_{R_{ir}}$, where $NO_{R_{ir}}$ is the total number of operations;

M_{iro} : the machine performing the *o*-th operation of R_{ir}, $o = 1, \cdots, NO_{R_{ir}}$;

T_{iro} : the tool that is used for the *o*-th operation of R_{ir}, $o = 1, \cdots, NO_{R_{ir}}$;

S_{iro} : the setup that is necessary for the *o*-th operation of R_{ir}, $o = 1, \cdots, NO_{R_{ir}}$;

PT_{iro} : the processing time incurred for performing the *o*-th operation of R_{ir}, $o = 1, \cdots, NO_{R_{ir}}$;

$CMC / CSC / CTC$: unit cost of machine/setup/tool change;

CP / CTr : unit cost of processing/transport;

TC_{P_i} : the completion-time for P_i ;

PC : total production cost; and

$$\delta(a, b) = \begin{cases} 1, & a \neq b, \\ 0, & otherwise. \end{cases}$$

Given a set of product alternatives with each having a set of production process alternatives, the cost evaluation model is to calculate the production cost for each product alternative based on a production process alternative. Due to the differences in operations, operations precedence, and manufacturing resources, for the same product alternative, different production processes incur different production costs. The cost evaluation model determines the production process with the lowest production cost as the optimal production process for the product alternative in consideration. In the classic product family design problem where multiple product variants and production processes are determined, capacities of manufacturing resources are a major influencing factor. This is because multiple products compete for the same manufacturing resources. Unlike the classic family design problem, configuration evaluation is to determine one product alternative together with one production process. In this regard, there is no competition among product alternatives for the same manufacturing resources. Thus, the capacities of manufacturing resources do not affect the development of the cost evaluation model. Accordingly, we do not restrict resource capacities in the model development. The objective function of the cost evaluation model is to minimize the total production cost. In attempting to contribute to accurate quotation preparation, we consider several cost factors, including the processing, material, machine/tool/setup change, transport, and indirect costs, as shown in Figure 4. In both practice and literature, they are considered as common factors (Alnestig and Segerstedt, 1996; Chen, 1997; Pettersson and Segerstedt, 2013).

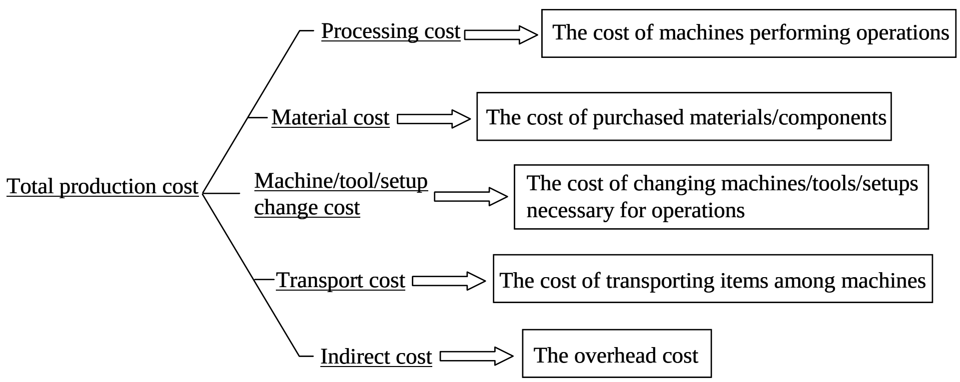


Figure 4: The structure of total production cost

Material cost (C_{Mt}): The material cost is for purchased raw materials and product components. It is determined by the usage of raw materials and components in one product based on the BOM and their unit costs. In case a component is produced in house, the usage and unit cost refer to its raw material. For the set of product alternatives, the material cost is calculated based on Eq. (1).

$$C_{Mt} = \sum_{i=1}^{NPA} \sum_{c=1}^{NC_{P_i}} QC_{ic} * CC_{ic} \tag{1}$$

Processing cost (C_{Pr}): This is the cost incurred by performing operations using manufacturing resources (e.g., machines, operators)[4]. These operations and manufacturing resources are listed on the BOO of a production process configured. This cost factor is affected by the processing time and

[4] The processing cost includes the direct labor cost because of the inclusion of operators.

the unit processing cost. In this study, the unit processing cost is the average processing cost obtained based on the historical data. It is, thus, the same for all operations. Nevertheless, it can be easily relaxed if companies prefer to use different unit processing costs. For the set of product alternatives and production process alternative sets, the processing cost is formulated below.

$$C_{\Pr} = \sum_{i=1}^{NPA} \sum_{r=1}^{NRA_{P_i}} \sum_{o=1}^{NO_{R_{ir}}} CP * T_{iro} \quad (2)$$

Transport cost (C_{Tr}): If multiple machines are involved in a production process to produce a product, transport of items among machines takes place, resulting in transport cost. The transport cost is determined by the unit transport cost and the total number of transports. The total number of transports is determined by the machines and their precedence relationships described in a BOO. Similarly, the unit transport cost is considered as the average transport cost obtained based on the historical data and is the same for the transport between any two machines. For the set of product alternatives and production process alternative sets, the transport cost is computed as follows:

$$C_{Tr} = \sum_{i=1}^{NPA} \sum_{r=1}^{NRA_{P_i}} \sum_{o=1}^{NO_{R_{ir}}} CTr * \delta\left(M_{iro}, M_{ir(o+1)}\right) \quad (3)$$

Machine/tool/setup change cost ($C_{MC} / C_{TC} / C_{SC}$): A machine change, including tool change and setup change, is required when two adjacent operations are performed by different machines. Carried out by certain manufacturing resources (e.g., operators), the change of machines takes time, thus incurring cost. This cost factor is determined by the unit machine change cost and the total number of machine changes. Similarly, the total number of machine changes can be determined based on a BOO; the unit machine change cost is considered the same. For the set of product alternatives and production process alternative sets, the machine change cost is obtained below.

$$C_{MC} = \sum_{i=1}^{NPA} \sum_{r=1}^{NRA_{P_i}} \sum_{o=1}^{NO_{R_{ir}}} CMC * \delta\left(M_{iro}, M_{ir(o+1)}\right) \quad (4)$$

A tool change is required when two adjacent operations performed by the same machine require different tools. For the set of product alternatives and production process alternative sets, the tool change cost is formulated as follows:

$$C_{TC} = \sum_{i=1}^{NPA} \sum_{r=1}^{NRA_{P_i}} \sum_{o=1}^{NO_{R_{ir}}} CTC * \left(1 - \delta\left(M_{iro}, M_{ir(o+1)}\right)\right) * \delta\left(T_{iro}, T_{ir(o+1)}\right), \quad (5)$$

where the unit tool change cost: CTC is the same for all tool changes.

A setup change is required when two adjacent operations performed by the same machine require different setups. For the set of product alternatives and production process alternative sets, the setup change cost is calculated below.

$$C_{SC} = \sum_{i=1}^{NPA} \sum_{r=1}^{NRA_{P_i}} \sum_{o=1}^{NO_{R_{ir}}} CSC * \left(1 - \delta\left(M_{iro}, M_{ir(o+1)}\right)\right) * \delta\left(S_{iro}, S_{ir(o+1)}\right), \quad (6)$$

where the unit setup change cost: CSC is the same for all setup changes.

Indirect labor cost (C_{Il}): Same with literature (Drury, 2017), the indirect cost is considered as a percentage of the processing cost, as indicated in Eq. (7).

$$C_{Il} = \alpha * \sum_{i=1}^{NPA} \sum_{r=1}^{NRA_{P_i}} \sum_{o=1}^{NO_{R_{ir}}} CP * T_{iro}, \quad (7)$$

where the coefficient α can be obtained based on the historical data.

Based on the above cost definitions, the total production cost PC for the set of product alternatives and production process alternative sets is computed below.

$$PC = C_{Mt} + C_{\Pr} + C_{Tr} + C_{MC} + C_{TC} + C_{SC} + C_{Il} \quad (8)$$

The complete integer programming cost evaluation model is formulated as follows:

$$Minimize \; PC \quad (9)$$

$$\text{s.t. } P_i = 1, \; \forall i = 1, \cdots, NPA, \quad (10)$$

$$\sum_{r=1}^{NRA_{P_i}} R_{ir} = 1, \; \forall i = 1, \cdots, NPA \quad (11)$$

$$R_{ir} \in \{0, 1\} \quad (12)$$

Constraint (10) ensures that all product alternatives are considered. Constraint (11) guarantees that one production process from the set of alternatives is selected for one product alternative.

To determine one production process for each product alternative, the above model is solved relatively easily compared with some combinatorial optimization problems. The result is a list of production processes with the lowest production costs for the set of product alternatives.

4.2 Completion-time evaluation model

For each production process obtained from the cost evaluation model, the completion-time evaluation model is to calculate the calendar time for completing the production of the corresponding product alternative. It utilizes the latest data about manufacturing resources available in the existing planning and scheduling systems, and shop floor execution systems as well. The completion-time TC_{P_i} for each product and production process pair is calculated as follows:

$$TC_{P_i} = 24 * TM_{iro} + \sum_{o=a}^{R_{ir}} T_{iro} \text{ , } \forall o = a, \cdots, R_{ir} \tag{13}$$

where TM_{iro} is the calendar time of the latest available machine performing operation O_{iro} of production process R_{ir} identified for product alternative P_i , and it is obtained from existing planning and scheduling systems. The unit of measure of the calendar time is in days, which is typically used by most planning and scheduling systems.

5. An Application Case

Case studies are often used for designing research frameworks, or analyzing a particular phenomenon, or validating a method (Teegavarapu et al., 2008). They also assist in understanding how specific problems can be addressed or resolved (Bartlett and Vavrus, 2017). In view of the potential functions or benefits of case studies, we adopt a case-based approach to demonstrate the proposed configuration evaluation.

The case company is an Electronic Manufacturing Service provider that offers manufacturing capability in both electronics and plastics parts. It has a production plant in Dongguan, China with many plastic injection machines, surface-mount technology lines, and final assembly lines. One of the products that the company produces is temperature controllers. Temperature controllers are configurable products and are widely used in warehouses, hospitals, cold chains and many other facilities. A temperature controller has many child components, such as plastic cases, surface mount components, and printed circuit board, as shown in Figure 5. The challenge that the company faces is numerous temperature controller alternatives can be specified to meet the same customer requirements, and multiple production process alternatives can be planned to produce a temperature controller. With the presence of many alternatives, the company needs to determine the most suitable one to reduce costs or delivery lead time or both.

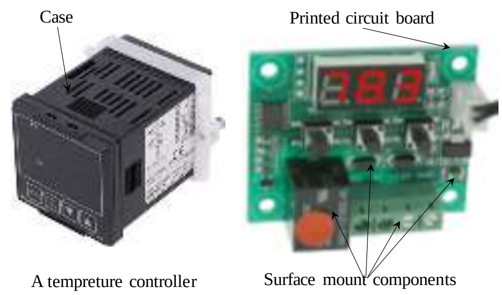


Figure 5: A temperature controller and its components

The company adopts the configuration evaluation proposed to determine customized temperature controllers to be offered and production processes to be adopted on their shop floor. The prototypical system is developed based on C#, XML, open API and JSON data format. Thanks to the use of C#, open API and JSON data format, the prototype can be easily integrated with the company's legacy systems for 3D visualization of temperature controllers and for obtaining the latest data about manufacturing resource capacities and availability. Figure 6 summarizes the information and process flow of the prototype, which is in line with the system flow introduced earlier.

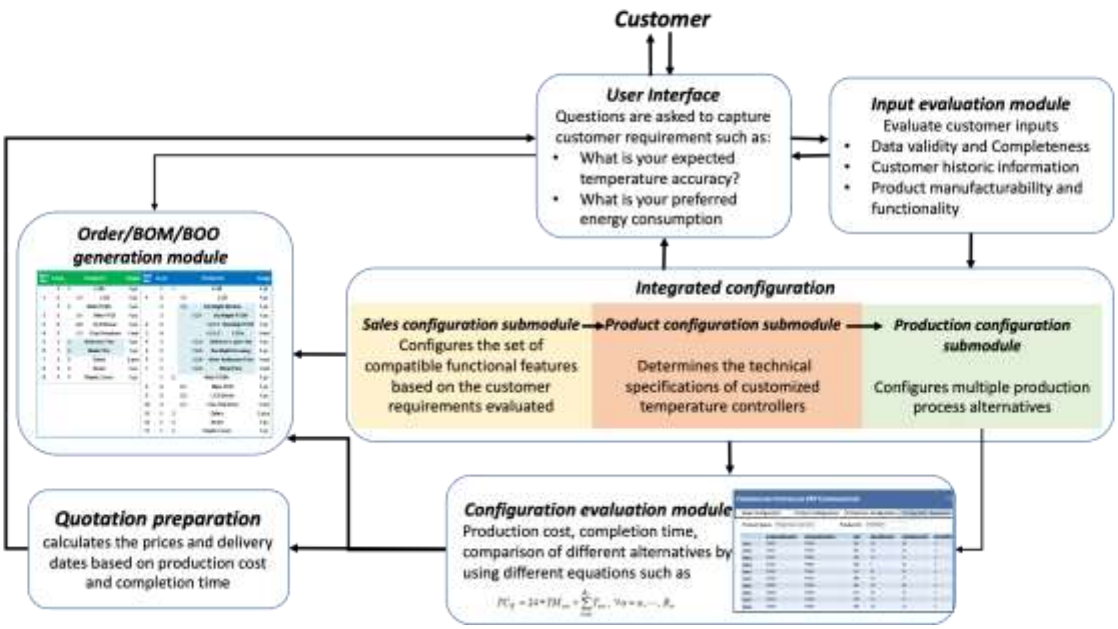


Figure 6: Information flow of the prototype

Considering the fact that most customers do not possess sufficient knowledge about the terminology describing functional features of temperature controllers, the online questions are designed to capture customer needs using the terms and concepts that customers are familiar with. Moreover, these questions are designed to present to customers in a sequential way based on their answers to the previous questions. As an example, Figure 7 provides several consecutive questions along with the input answers. The cost evaluation model is developed based on the data specific to a family of temperature controllers by referring to Eqs (1) – (12); the completion-time evaluation model is developed based on Eq. (13). To dynamically generate BOMs and BOOs, the prototype is linked with several of the company's legacy systems through open API, including product data management system, process planning system, and design system.

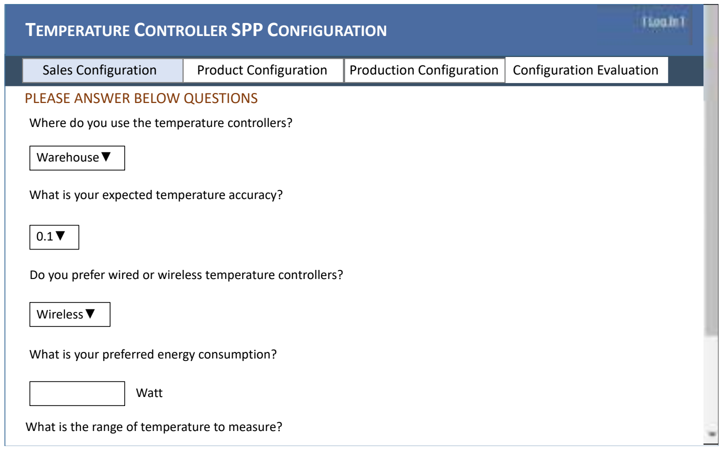
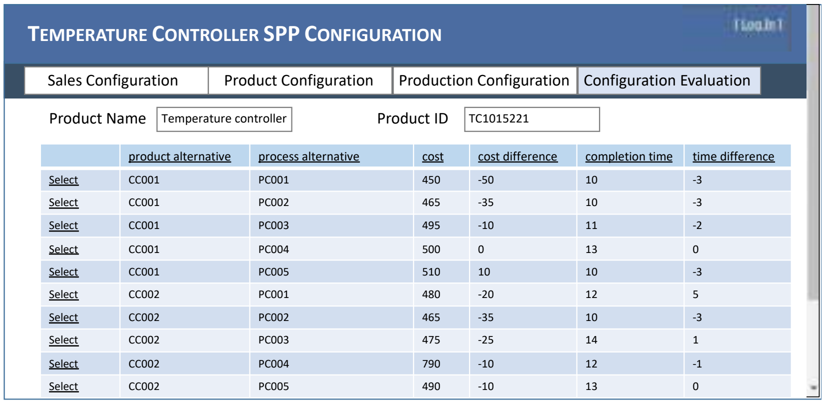


Figure 7: Example questions for capturing customer requirements

Based on all the questions including these in Figure 7, customer requirements for the customized temperature controller are evaluated. In the evaluation process, the prototype may ask a customer (or a salesperson from the company) to modify the requirements so that all the inputs can be validated and do not conflict with one another (see Input evaluation module in Section 3). The customer (or the salesperson) may abandon the configuration process because of too many requests for requirement modifications. In this case, no product and production process alternatives will be configured. The performance of the prototype is affected if too many users abandon configuration processes. With the requirements evaluated, the system configures temperature controller alternatives and production process alternatives for each temperature controller. Figure 8 shows a temperature controller alternative (as a list of design parameter value pairs of child components at different hierarchical levels) and one production process alternative (i.e., a list of operations along with necessary process elements).

Figure 8: A temperature controller alternative and its production process alternative

Thanks to the configuration evaluation module, the list of product and production process pairs are obtained. Also obtained are the production cost, completion time, time and cost differences with the average ones, as shown in Figure 9. CC and PC in the second and third columns represent temperature controller configuration alternatives and production process configuration alternatives, respectively. The production cost corresponding to each pair of product and production process is provided in the fourth column. The difference between the production cost of a pair and the average production cost is provided in the fifth column. The completion time of each pair and the differences between the average completion time and the completion time of a pair are shown in the last two columns, respectively. An excel file containing the list of temperature controller alternatives and production process alternatives can be downloaded from the prototype. Using the built-in sorting function in the excel file, the company can rearrange the list based on either an increasing order of production costs or an increasing order of completion time. With the reordered list, the company can select the final temperature controller and production process based on the factors that are the most important for them, e.g., inventory levels of some components, relationships with the customers. To reduce the excess inventory of certain components, the company can select the product alternatives, which include these components and the production process alternatives incurring shorter completion time. The prototype can, thus, be viewed as an enabler of product customization.



TEMPERATURE CONTROLLER SPP CONFIGURATION

[Log In]

Sales Configuration | Product Configuration | Production Configuration | Configuration Evaluation

Product Name: Temperature controller   Product ID: TC1015221

	product alternative	process alternative	cost	cost difference	completion time	time difference
Select	CC001	PC001	450	-50	10	-3
Select	CC001	PC002	465	-35	10	-3
Select	CC001	PC003	495	-10	11	-2
Select	CC001	PC004	500	0	13	0
Select	CC001	PC005	510	10	10	-3
Select	CC002	PC001	480	-20	12	5
Select	CC002	PC002	465	-35	10	-3
Select	CC002	PC003	475	-25	14	1
Select	CC002	PC004	790	-10	12	-1
Select	CC002	PC005	490	-10	13	0

Figure 9: The list of product and production process pairs

The configuration model underpinning the prototype is the GBoFMO of temperature controllers (see the related text in Introduction and Section 3). The GBoFMO integrates all data describing temperature controllers' functions, design, and production processes based on the relationships among them. It was very challenging to develop this integrated model in the company because all the relevant staff, such as salespersons, product experts, and production planners/process engineers needed to sit together to discuss each data point and the related information. Nevertheless, thanks to the development of this integrated model, the company staff could communicate more effectively and have obtained product knowledge beyond their expertise.

The introduction of the prototype changed many parts of the company's traditional business activities and processes, e.g., the generation of temperature controllers' BOMs and BOOs. Prototype implementation, thus, required the relevant staff to accept the changes. According to the company, it was very important to anticipate the impact of the changes on people and to plan well in advance new roles and activities for them. It was equally important to provide enough training to the employees so that they could effectively implement the prototype.

In summary, although the company encountered some difficulties in prototype development and implementation, the prototype greatly facilitates the company's decision making in the final temperature controller offerings. It achieves this by providing a list of alternative temperature controllers and production processes coupled with time- and cost-related data. Additionally, compared with the production processes, which are planned by the company's planners based on their personal experiences, those configured in the prototype lead to fewer changes to operations, operations precedence, and manufacturing resources (e.g., machines, tools).

6. FURTHER ANALYSIS AND DISCUSSIONS

6.1 SPP configuration vs. product family development

Developing product families, instead of single products, contributes significantly to product customization (Simpson et al., 2014). While most literature on product family development focuses on design by addressing design automation, it has been highlighted in several studies that planning a process family in relation to a product family (i.e., process family planning) is another pillar underpinning successful product family development (Pitiot et al., 2014; Zhang and Jiao, 2013; Zhang et al., 2012). By involving product, planning, and process knowledge and data, the SPP configuration contributes to simultaneous product family design and process family planning, as visualized in Figure 10.

With different types of data and knowledge, product developers, such as designers and process engineers, can explicitly organize data, rules and constraints resulting from product family-related design and planning activities as the GBoFMO. Thus, built on top of the GBoFMO, the SPP configuration can configure the suitable product variants and production processes for given customer requirements. These product variants and production processes, in turn, can be used as feedback for developers to fine tune design and planning activities. In this regard, as a development tool, the SPP configuration enables a company to continuously improve its product offerings while taking other factors into account, such as the manufacturing capabilities. Additionally, contemporary business operations are exponentially inundated with data and analytics. In this regard, managers can make more evidence-based configuration decisions by utilizing data-driven capabilities and resources. They can update customer orders or their requirements in a timely fashion, possible in real time. This can further improve their supply chain visibility interlocked with customer requirements and manufacturing operations, leading to a better utilization of companies' resources.

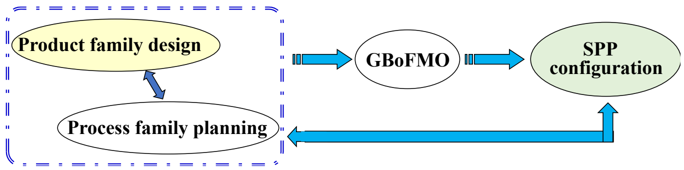


Figure 10: SPP configuration and simultaneous product/process family design/planning

6.2 Integration between SPP configuration with legacy systems

In the current family-based product development, both products and processes can be designed by adopting the similar product and process structures. Without the support of an automatic tool, designers and process engineers are troubled by a lot of time-consuming but less value-added work. For example, the process engineer may need to modify the entire set of production process only for a small change in the design. However, such trivial activities in the traditional design cannot be avoided in order to satisfy customers. The SPP configuration is, thus, proposed to automatically generate product and production process alternatives. In addition, to avoid the human-made errors in manually generated BOMs and BOOs, the SPP configuration needs to get the real-time data pertaining to manufacturing resource availabilities. In view of the above, it is imperative to integrate the SPP configuration system with all the relevant legacy systems, including product data management systems, process planning systems, design systems, shop floor execution and control systems, for getting the necessary data and information. In some companies, the legacy systems might be designed and/or developed by different software companies, thus having different compatibility issues when integrating with SPP configuration systems. In this regard, companies can explore and build suitable techniques to realize the integration, such as web service, XML integration, common gateway interface, and data replication. For details of these integration techniques, please refer to (Chowdhury and Iqbal, 2004). While integrating with the legacy systems is potentially beneficial, there might be some downsides. Some possible disadvantages might be that a company may need huge financial, human, and time investment, or that a company lacks technical expertise.

7. CONCLUSIONS

In view of the limitations of the available configuration solutions, the SPP configuration is proposed to facilitate product customization by automating the processes associated with specification, engineering, and process planning of customized products. It enables the configuration of functional features, physical components and their relationships, operations and manufacturing resources based on individual customer requirements. It also dynamically generates technical documents, such as BOMs and BOOs, and customer order documents. Since some soft factors and constraints (e.g., the relationships with customers) can be better handled by decision makers instead of computers, the SPP configuration provides companies with decision making support, rather than making decisions in product offerings. It achieves this by dealing with both configuration and configuration evaluation. In this study, we focused on configuration evaluation, i.e., the evaluation of product alternatives and production process alternatives configured. In line with the fact that time and cost are the two most important elements considered in quotation preparation, we developed the evaluation models to minimize production costs and completion time of product alternatives and production process alternatives.

We used a temperature controller example to demonstrate the application of the SPP configuration with a focus on the configuration evaluation proposed. On one hand, the results have shown that the configuration evaluation can greatly help companies make suitable product offering decisions by providing a list of products and production processes along with cost and time calculations. On the other hand, we are aware of the limitations of this study. While we discussed the company's feedback on the use of the prototypical system, we left the customers' experiences untouched. Because friendly and pleasant user experiences are very important (Randall et al., 2007), it is important to investigate integrated configuration systems from the customer's perspective with an ultimate goal to improve customer satisfaction. In this study, we targeted the SPP configuration in engineering-based industries, e.g., airplanes, home appliance, computers, automobile, where the design and manufacturing technologies are relatively stable throughout the product lifecycles. In this regard, it might not be appropriate for science-based industries, e.g., semiconductor equipment manufacturing, pharmaceutical, where the design and manufacturing technologies frequently change during the product lifecycles. Thus, future research might be directed to develop configuration solutions for science-based industries. Moreover, future efforts might be made to improve the SPP configuration so that the enhanced version can address configuration in distributed manufacturing and new component design while capitalizing on modern technologies, such as big data and block-chain technology. Many issues might deserve scrutiny in this line. They include i) criteria for evaluating the configured product alternatives and production process alternatives, ii) conflict resolution in input evaluation, and iii) types of components that can be designed. Additionally, from a practical point of view, manipulation in configuration, integrated configuration in particular, deserves much attention in the future. With a manipulation capability, configuration systems are expected to configure and recommend such products that can greatly reduce the excess inventory of components. Though these products meet customer requirements, they are not optimal in terms of production costs and time and/or product performance. Developing such manipulation capability would cause additional complexities and difficulties to a configuration project in a company, e.g., what is the new configuration model, what should be included in the database and knowledge base, how the configured products are evaluated. Therefore, future research, especially action research or longitudinal studies, should be carried out to address this interesting and relevant topic.

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REFERENCES

Aheleroff, S., Philip, R., Zhong, R.Y., and Xu, X. (2019) The degree of mass personalisation under Industry 4.0, *Procedia CIRP*, 81, 1394-1399.

Aldanondo, M., Hadj-Hamou, K., Moynard, G., and Lamothe, J. (2003) Mass customization and configuration: Requirement analysis and constraint based modeling propositions, *Integrated Computer-Aided Engineering*, 10(2), 177–189

Aldanondo, M. and Vareilles, E. (2008) Configuration for mass customization: How to extend product configuration towards requirements and process configuration, *Journal of Intelligent Manufacturing*, 19(5), 521-535.

Alnestig, P. and Segerstedt, A. (1996) Product costing in ten Swedish manufacturing companies, *International Journal of Production Economics*, 46-47, 441-457.

Ardissono, L., Felfernig, A., Fredrich, G., Jannach, D., Petrone, G., Schaefer, R., and Zanker, M. (2003) A framework for the development of personalized, distributed Web-based configuration systems, *AI Magazine*, 24(3), 93-108.

Balogun, O., Hawisa, H., and Tannock, J. (2004) Knowledge management for manufacturing: The product and process database. *Journal of Manufacturing Technology Management*, 15(7), 575-584.

Bartlett, L. and Vavrus, F. (2016) *Rethinking Case Study Research: A Comparative Approach*, ISBN: 978-1-138-93951-6, New York: Routledge.

Blecker, T., Abdelkafi, N., Kaluza, B., and Friedrich, G. (2003) Key metrics system for variety steering in mass customization. *Proceedings of the 2nd Interdisciplinary World Congress on Mass Customization and Personalization – MCPC'03*, Munich, Germany.

Brown, D. (1998) Defining configuration, *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 12(4), 301-305.

Brun, A. and Zorzini, M. (2009) Evaluation of product customization strategies through modularization and postponement. *International Journal of Production Economics*, 120(1), 205-220.

Chen, J. (1997) Achieving maximum supply chain efficiency**,** *IIE Solutions*, 29(6), 30-35

Chen, K.Z., Feng, X.A., and Zhang, B.B. (2003) Development of computer-aided quotation system for manufacturing enterprises using axiomatic design. *International Journal of Production Research*, 41(1), 171-191.

Chen, Y-C., Shang, R-A., and Kao, C-Y. (2009) The effects of information overload on consumers' subjective state towards buying decision in the internet shopping environment, *Electronic Commerce Research and Applications*, 8, 48-58.

Chowdhury, M.W. and Iqbal M.Z. (2004) Integration of legacy systems in software architecture, *Proceedings of the Workshop on Specification and Verification of Component-Based Systems (SAVCBS 2004)*, Oct 31 – November 1, 2004, Newport Beach, California, USA.

Drury, C. (2017) *Management and Cost Accounting*, Cengage Learning EMEA, UK, ISBN: 978-4737-4887-3.

Felfernig, A., Friedrich, G., Jannach, D., and Zanker, M. (2012) Web-based configuration of virtual private neetworks with multiple suppliers, *Artificial Intelligence in Design*, 41-61.

Felfernig, A., Hotz, L., Bagley, C., and Tiihonen, J. (2014) *Knowledge-Based Configuration: From Research to Business Cases*. Morgan Kaufman, ISBN 13: 978-0-12-4158177.

Felfernig, A., Tiihonen, J., Hotz, L., and Stettinger, M. (2018) *Proceedings of the 20th International Configuration Workshop (ConfWS 2018)*, http://ceur-ws.org/Vol-2220/, September 27-28, 2018, Graz, Austria.

Forza, C. and Salvador, F. (2002) Managing for variety in the order acquisition and fulfillment process: The contribution of product configuration systems. *International Journal of Production Economics*, 76(1), 87-98.

Forza, C. and Salvador, F. (2007), *Product Information Management for Mass Customization: Connecting Customer, Front-Office and Back-Office for Fast and Efficient Customization*, Palgrave Macmillan, New York.

Forza, C. and Salvador, F. (2008) application support to product variety management. *International Journal of Production Research*, 46(3), 817-836.

Haag, A. (1998), Sales configuration in business process, *IEEE Intelligent Systems and Their Applications*, 13(4), 78–85.

Haug, A., Hvam, L., and Mortensen, N.H. (2012) Definition and evaluation of product configurator development strategies, *Computers in Industry*, 63(5), 471-481.

Haug, A., Shafiee, S., and Hvam, L. (2019) The causes of product configuration project failure, *Computers in Industry*, 108, 121-131.

Helo, P.T., Xu, Q., Kyllonen, S.J., and Jiao, J. (2010) Integrated vehicle configuration system-connecting the domains of mass customization, *Computers in Industry*, 61(1), 44-52.

Hong, G., Hu, L., Xue, D., T, Y., and Xiong, Y. (2008) Identification of the optimal product configuration and parameters based on individual customer requirements on performance and costs in one-of-a-kind production. *International Journal of Production Research*, 46(12), 3297-3326.

Jiao, J. and Chen, C-H. (2006) Customer requirement management in product development: A review of research issues, *Concurrent Engineering*: *Research and Applications*, 14(3), 173-185.

Jiao, J., Tseng, M.M., Ma, Q., and Zou, Y. (2000) Generic bill-of-materials-and-operations for high-variety production management. *Concurrent Engineering*: *Research and Applications*, 8(4), 297–321.

Kaneko, K., Kishita, Y., and Umeda, Y. (2018) toward developing a design method of personalization: Proposal of a personalization procedure, *Procedia CIRP*, 69, 740-745.

Kingsman, B., Hendry, L., Mercer, A., and de Souza, A. (1996) Responding to customer enquiries in make-to-order companies: Problems and solutions, *International Journal of Production Economics*, 46-47, 219-231.

Kusiak, A., smith, M.R., and Song, Z. (2007) Planning product configurations based on sales data, *IEEE Transactions on Systems, Man and Cybernetics, Part C (Applications and Reviews)*, 37(4), 602-069.

Lan, H.B., Ding, Y.C., Hong, J., Huang, H.L., and Lu, B.H. (2008) Web-based quotation system for stereolithography parts. *Computers in Industry*, 59(8), 777-785.

Lee, H.J. and Lee, J.K. (2005) an effective customization procedure with configurable standard models, *Decision Support Systems*, 41(1), 262-278.

Li, X., Shao, X., Gao, L., and Qian, W. (2010) An effective hybrid algorithm for integrated process planning and scheduling, *International Journal of Production Economics*, 126, 289-298.

Martinez, M.T., Favrel, J., and Ghodous, P. (2000) Product family manufacturing plan generation and classification. *Concurrent Engineering: Research and Applications*, 8(1), 12–22.

McDermott, J. (1982) R1: A rule-based configurator of computer systems, *Artificial Intelligence*, 19(1), 39-88.

Mittal, S. and Frayman, F. (1989) Towards a generic model of configuration tasks, *Proceedings of International Joint Conference on Artificial Intelligence (IJCAI'89)*, 1395-1401, Detroit, USA.

Mleczko, J. and Dulina, L. (2014) Manufacturing documentation for the high-variety products, *Management and Production Engineering Review*, 5(3), 53-61.

Pettersson, A. I. and Segerstedt, A. (2013) Measuring supply chain cost, *International Journal of Production Economics*, 143, 357-363.

Pitiot, P., Aldanondo, M., and Vareilles, E. (2014) Concurrent product configuration and process planning: Some optimization experimental results. *Computers in Industry*, 65(4), 610–621.

Pitiot, P., Monge, L.G., Aldanondo, M., Vareilles, E., and Gaborit, P. (2019) Optimization of the concurrent product and process configuration: An approach to reduce computation time with an experimental evaluation. *International Journal of Production Research*, Impress.

Randall, T., Terwiesch, C., and Ulrich, K. (2005) Principles for user design of customized products, *California Management Review*, 47(4), 1-18.

Randall, T., Terwiesch, C., and Ulrich, K. (2007) User design of customized products, *Marketing Science*, 26(2), 268-280.

Rasmussen, J.B., Hvam, L., Kristjansdottir, K., and Mortensen, N.H. (2019) Guidelines for structuring object-oriented product configuration models in standard configuration software, Under review, *Journal of Universal Computer Science*.

Ratchev, S., Pawar, K.S., Urwin, E., and Mueller, D. (2005) Knowledge-enriched requirement specification for one-of-a-kind complex systems, *Concurrent Engineering*: *Research and Applications*, 13(3), 171-183.

Salvador, F. and Forza, C. (2007) Configuring products to address the customization-responsiveness squeeze: A survey of management issues and opportunities, *International Journal of Production Economics*, 9, 273-291.

Salvador, F. and Forza, C. (2007) Principles for efficient and effective sales configuration design, *International Journal of Mass Customization*, 2(1/2), 114-127.

Shafiee, S., Forza, C., Haug, A., and Hvam, L. (2018). Merging Commercial and Technical Configurators. *Proceedings of the 8th International Conference on Mass Customization and Personalization*, Novi Sad, Serbia.

Shamsuzzoha, A. and Helo, P. (2016) Fundamentals of configuration methodology: Aligning customer requirements into design philosophy. *International Journal of Electronic Customer Relationship Management*, 10(2/3/4), 103-124.

Simpson, T.W., Jiao, J.R., Siddique, Z., and Holtta-Otto, K. (2014) *Advances in Product Family and Product Platform Design: Methods and Applications*. ISBN 978-1-4614-7937-6. Springer-Verlag New York, USA.

Song, Z. and Kusiak, A. (2009) Optimizing product configurations with a data-mining approach, *International Journal of Production Research*, 47(7), 1733-1751.

Stonebraker, P.W. (1996) Restructuring the bill of material for productivity: A strategic evaluation of product configuration, *International Journal of Production Economics*, 45, 251-260.

Tang, D., Wang, Q., and Uilah, I. (2017) Optimization of product configuration in consideration of customer satisfaction and low carbon, *International Journal of Production Research*, 55(12), 3349-3373.

Teegavarapu, S, Summers, J.D., and Mocko, G. (2008) Case study method for design research: Justification. Proceedings of the ASME 2008 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (ASME - DETC 2008), New York, USA, 495-503.

Trentin, A., Perin, E., and Forza, C. (2011) Overcoming the customization-responsiveness squeeze by using product configurators: Beyond anecdotal evidence. *Computers in Industry*, 62(3), 260-268.

Trentin, A., Perin, E., and Forza, C. (2012) Product configurator impact on product qulity. *International Journal of Production Economics*, 135, 850-859.

Trentin, A., Perin, E., and Forza, C. (2013) Sales configurator capabilities to avoid the product variety paradox: Construct development and validation. *Computers in Industry*, 64, 436-447.

Trentin, A., Perin, E., and Forza, C. (2014) Increasing the consumer-perceived benefits of a mass-customization experience through sales-configurator capabilities. *Computers in Industry*, 65, 693-705.

Tseng, H-E. and Chang, C-C. (2006) Coordinating product configuration in the order fulfillment processing: An approach based on the binary tree algorithm, *International Journal of computer Integrated Manufacturing*, 19(1), 716-726.

Tseng, H-E., Chang, C-C., and Chang, S-H. (2005) Applying case-based reasoning for product configuration in mass customization environments, *Expert Systems with Applications*, 29, 913-925.

Verdouw, C.N., Beulens, A.J.M., Trienekens, J.H., and Verwaart, T. (2010) Mastering demand and supply uncertainty with combined product and process configuration, *International Journal of Computer Integrated Manufacturing*, 23(6), 515-528.

Wang, L., Zhong, S., and Zhang, Y. (2017) Process configuration based on generative constraint satisfaction problem. *Journal of Intelligent Manufacturing*, 28(4), 945-957.

Wang, Y. and Mo, D.Y.W. (2018) The effect of default options on consumer decisions in the product configuration process. *Proceedings of the 20th International Configuration Workshop (ConfWS 2018)*, Eds: Felfernig, A., Tiihonen, J., Hotz, L., and Stettinger, M., 31-36, September 27-28, 2018, Graz, Austria.

Wang, Y. and Tseng, M.M. (2011) Adaptive attribute selection for configurator design via Shapley value. *Artificial Intelligence for Engineering design, analysis and Manufacturing*, 25(2), 185-195.

Wu, D., Zhang, L., Jiao, J., and Lu, R. (2013) SysML-based design chain information modeling for variety management in production reconfiguration. *Journal of Intelligent Manufacturing*, 24(3), 575-596.

Yang, Y., Zhang, X., Liu, F., and Xie, Q. (2005) An internet-based product customization system for CIM, *Robotics and Computer-Integrated Manufacturing*, 21, 109–118.

Zhang, L. (2007) Process platform-based production configuration for mass customization, PhD Thesis, Nanyang Technological University, Singapore.

Zhang, L. (2014) Product configuration: A review of the-state-of-the-art and future research. *International Journal of Production Research*, 52(21), 6381-6398.

Zhang, L. and Jiao, J. (2013) A graph rewriting system for process platform planning. *Decision Support Systems*, 54(2), 1174-1191.

Zhang, L. and Rodrigues, B. (2013) A Petri net model of process platform-based production configuration, *Journal of Manufacturing Technology Management*, 24(6), 873-904.

Zhang, L., Lee, C.K.M., and Xu, Q. (2010) Towards product customization: An integrated order fulfillment system. *Computers in Industry*, 61, 213-222.

Zhang, L., Vareilles, E., and Aldanondo, M. (2013) Generic bill of functions, materials and operations for SPP configuration. *International Journal of Production Research*, 51(2), 465-478.

Zhang, L., Xu, Q., Yu, Y., and Jiao, J. (2012) Domain-based production configuration with constraint satisfaction, *International Journal of Production Research*, 50(24), 7149-7166.

Zheng, P., Xu, X., Yu, S., and Liu, C. (2017) Personalized product configuration framework in an adaptable open architecture product platform, *Journal of Manufacturing Systems*, 43, 422-435.