A Generic Model for Integrated Sales, Product, and Production Configuration

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Abstract

Facilitating product customization, configuration has attracted much attention from both academia and industry alike. However, the available studies and the reported systems focus on sales or product configuration while leaving other important issues in developing customized products unaddressed. A new configuration concept: integrated Sales, Product and Production configuration (SPP configuration) is therefore proposed to accommodate the entire product customization process. SPP configuration addresses not only sales and product configuration but also production configuration. In light of its important role in managing knowledge in SPP configuration, this study focuses on the underpinning configuration model: the generic bill of functions, materials and operations (GBoFMO) and discuss it in detail. An industrial example is reported to demonstrate the GBoFMO of a family of customized light passenger aircrafts.

Keywords
Industrial engineering, design and manufacturing, computer and information systems

1. Introduction

Manufacturing companies nowadays pursue product customization for quickly providing customer-wanted products at low costs, in hopes of surviving. As a strategy to implement product customization, configuration has attracted much attention from both academia and industry alike (Stumptner, 1997; Zhang, 2013). It is advantageous to provide a right amount of product variety while effectively utilizing the available design and manufacturing capabilities. This is because in configuration, customized products are configured from a set of pre-designed components, be they parts or assemblies. Generally speaking, in configuration systems, companies organize data and knowledge pertaining to a product family into a reusable and maintainable form (also called configuration model); customers trigger configuration process by inputting their individual requirements; and finally the customized products with desired features are configured.

Many articles have been published to address, e.g., configuration models, configuration reasoning, configuration knowledge representation (Blecker et al., 2004; Falkner et al., 2011; Felfernig, 2007). Similarly, prototypical systems and commercial configurators have been reported to facilitate the management of high product variety and the quick definition of customer-wanted products (Forza and Salvador, 2002). The review suggests a feature common to the available studies, prototypes, and systems, that is, they touch on either sales configuration (i.e., the configuration of functional features describing a customized product) or product configuration (i.e., the configuration of components technically defining a customized product). On the other hand, it is well acknowledged that successful product customization relies on the efficiency in both designing and producing products. In this regard, with focus on sales or product configuration, the existing studies are insufficient to accommodate product customization from a holistic view, i.e., the entire product customization process ranging from functional feature determination to product configuration to production.

Pointed out by several authors, production configuration is promising for maintaining production of customized products to be as stable as possible, reducing production lead time, and improving product quality (Aldanondo and Vareilles, 2008; Zhang, 2007; Zhand and Rodrigues, 2010). Its rationale lies in configuring routings for customized products from existing process elements while exploiting design similarity and the resulting process similarity. A routing is for producing a product, and is formed by operations, operations precedence (i.e., the relationships among operations), and manufacturing resources that perform operations.

Complementing the available studies, in this paper, we put forward a new configuration concept: integrated Sales, Product, and Production configuration (SPP configuration), in attempting to help companies achieve successful product customization by facilitating the entire customization process. It addresses not only sales and product configuration but also production configuration. In addition, SPP configuration is expected to dynamically generate bills of materials (BOMs) and bills of operations (BOOs) visualizing the results of product and production configuration, respectively. Researchers have argued the importance and benefits of the automatic generation of these two important product documents, such as increasing quotation accuracy, improving product quality, and reducing product lead time (Ariano and Dagnino, 1996). Since the available studies on product configuration consider BOM generation only (if they do), another contribution of SPP configuration lies in the generation of both BOMs and BOOs in developing customized products.

Being fundamental to any configuration systems, a configuration model details the essential configuration data and knowledge, and data relationships as well, thus contributing to data/knowledge base construction and all other configuration activities (Zhang et al., 2005). Therefore, in light of its important role, in this study, we focus on the conceptual knowledge model underpinning SPP configuration, termed as generic bill of functions, materials, and operations (GBoFMO). In the following section, an overview of SPP configuration is presented, including its process flow and major modules.

2. Overview of SPP Configuration

SPP configuration is proposed to complement the existing solutions by addressing important, yet insufficiently considered issues: production configuration and generation of BOMs and BOOs. To achieve this, it necessitates a wide range of data and knowledge about sales, marketing, design, planning, process, production, manufacturing resources, costing, etc. The knowledge assists in assessing customer input requirements and evaluating the selected configuration elements (e.g., features, components, operations). For given customer requirements, SPP configuration outputs the sales configuration. It also outputs the product's technical design, BOM, routing, and BOO.

2.1 Process Flow of SPP Configuration

Customers' answering online questions is the starting point of SPP configuration, and triggers the subsequent activities. The system will then assess customer inputs by checking their validity. In case the negative evaluation results, the system informs the customer, and asks she (or he) to consider modifying answers. If the evaluation is positive, the system generates the preliminary sales configuration.

With the preliminary sales configuration, SPP configuration first configures the customized products and the corresponding routings. Subsequently, the configured alternatives are evaluated in terms of production cost and completion time. The evaluation results include a list of configured product alternatives and routings. Also included are the computed production cost and completion time for each pair of product and routing. Based on such results, a company can determine the optimal product and routing configuration by making trade-off between cost and lead time and by considering other factors, such as its strategic objectives. With the final decision on product and production configuration, the system calculates the price and delivery lead time for preparing quotations. 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 routing, respectively. In case the customer is not satisfied with either the price, delivery lead time or features included in the sales configuration, the process will start again. While the above text summarizes the major steps involved in SPP configuration, the essential modules and the corresponding functions are discussed below.

2.2 Essential Modules of SPP Configuration

In SPP configuration, several modules are necessary, including the user interface, input evaluation, sales-product-production configuration, configuration evaluation, quotation preparation, and order-BOM-BOO generation modules. Due to the page limitation, these modules are briefly introduced below.

User interface module is to capture customer requirements, to present a customer the description of a configured product and the product's visualization, price, and delivery date. *Input evaluation module* evaluates customer inputs, checks whether or not the existing design and manufacturing capabilities are capable to produce a specific feature associated with the customer input. *Sales-product-production configuration module* consists of three submodules: the sales, product and production configuration submodules. The sales configuration submodule configures compatible functional features that can meet the evaluated customer requirements. Based on the sales configuration, the product configuration submodule determines technical specifications of the customized product. For each product alternative configured, the production configuration submodule configures the corresponding routings. *Configuration evaluation module* performs the evaluation function. It takes the result of the configuration module as input, and evaluates the input with respect to production cost and completion time. Because the accuracy of quotation wrt price and delivery lead time is very important in gaining customers (Veeramani and Joshi, 1997), *Quotation preparation module* prepares a quotation based on the products and routings after configuration evaluation, instead of the features after sales configuration (as in most of the existing configuration systems). Recognizing the importance of error-free BOMs and BOOs for smooth production, high product quality and reduced production lead time, SPP configuration is proposed to automatically generate both BOMs and BOOs for configured products and routings. The *order-BOM-BOO generation module* performs this function, and generates customer orders, BOMs, and BOOs.

3. GBoFMO Conceptualization

The GBoFMO is proposed as the conceptual knowledge model, organizing sales, design, planning, and process data and knowledge pertaining to a family of customized products. Consistent with the domain concept in product development, the GBoFMO encompasses data from three domains: the functional, design, and process domains. In practice, the functional, design, and process data describe products from three views: the sales, design, and production views. Hence, the GBoFMO consists of these three views along with the mapping between different views.

3.1 Domains in GBoFMO

The domain model helps organize elements in SPP configuration by associating characteristics of domain data to these configuration elements. For instance, the process domain interprets operations and manufacturing resources necessary for producing output items based on given input items. The interlocking relationships between domains are indicated by arrows. The inter-domain connections together with these in each individual domain are the basis for mapping between two views.

Embodying customer perceptions on product offerings available in a family, the functional domain captures a set of functional features and their values. These features collectively indicate what the products can do and how they look like. A feature can be an atomic one or a composite one. Atomic features individually define product functions or appearance without interacting with other features. For instance, color is an atomic feature describing a bicycle. Composite features describe system functions or appearance at a higher level, and can be decomposed into child features. For instance, as a parent feature, computer memory has two child features: temporary memory and permanent memory. A child feature can be further decomposed into its child features. Such decomposition ends with all features being atomic ones, resulting in a hierarchical structure. The combination of values of child features leads to a value instance of the parent feature (i.e., a specific feature). This is applied to parent and child features at any two adjacent levels of the hierarchy. Both the combination of different features and the combination of values of a same set of features contribute to variety in the product family to be configured. In other words, products configured differ from one another in either different features or different values of a same set of features.

Features in the functional domain are delivered by elements in the design domain. The design domain represents products' technical specifications, more specifically product components, component attributes, and design parameters. A component can be either an assembly or a part. By delivering variants of the same features (i.e., specific features characterizing the customized products), component variants of same types form families. In accordance with the hierarchical structure of features in the functional domain, assemblies are formed by immediate child assemblies and/or parts. These immediate child assemblies have their child assemblies and/or child parts.

As with features describing customized products, attributes together with their values characterize specific components. These component variants are, in turn, technically defined by design parameters and the corresponding values. An attribute shows a certain property of a component, indicating component uniqueness. It can be the derived result of a combination of multiple design parameters; it can also be a design parameter (depending on the design parameter). For examples, as an attribute of a steel block, weight is determined by a number of design parameters: length, width, and thickness; the attribute: color is a design parameter at the same time.

Components defined in the design domain are produced using elements in the process domain. These elements include operations, manufacturing resources, and cycle times. To produce component variants, an operation type has various operations variants, each of which differs from one another in detailed process parameters. In addition, different machines together with other manufacturing resources can perform the same operations while incurring different cycle times, costs, and operations precedence. The operations and manufacturing resources along with operations precedence for producing a customized products form a routing.

3.2 Views and View Mapping

In practice, from the sales view, sales people see a product as a set of functional features; from the design view, designers see the product as a list of components; from the production view, production personnel see the product as a list of ordered operations together with manufacturing resources. Since a GBoFMO organizes data and knowledge both within and between the respective domains, it enables the integration of several business functions, such as sales, design, and production, in a context coherent framework for configuring product families. It accomplishes this by establishing mapping relationships between the three views of a product family.

In the sales view, the GBoFMO exhibits a product line that is perceived by customers. It manifests diverse functional features and their interrelationships that involve both decomposition and dependency. The design view reveals technology application to a product design, and describes the product design using components and their hierarchical structure. The hierarchical structure describes not only the decomposition of components into smaller units but also the interrelationships between components (e.g., require, exclude). Further, corresponding to specific features in the sales view, component attributes are defined to highlight differentiation and variety in configuration. Based on these attributes, design parameters are determined to uniquely define component variants. Production variations resulting from configuration differentiation in the design domain are addressed by the production view of the GBoFMO. This view represents product information by a description of the physical realization of product configuration, thus concerning product construction. More specifically, it consists of manufacturing and assembly operations along with manufacturing resources.

Mapping relationships exist between any two views of the GBoFMO. First, different customer requirements are identified by a number of functional features in the sales view. Essentially, this identification entails the sales configuration activities. Functional features are mapped from the sales view to component attributes in the design view. In accordance with these component attributes, the technical specifications of components (i.e., design parameters and their interconnections) are further mapped. This mapping from features to component attributes and finally to technical specifications embodies product configuration activities. The mapping between the design and production views reflects the considerations of manufacturing and logistics such that routings are configured to produce customized products by assessing available manufacturing capabilities, production cost, and lead time. The mapping between the production and sales views captures the correspondence between a physical product structure and its functionality, thus providing the necessary information about cost and lead time to facilitate quotation preparation.

3.3 Concept Implications

The GBoFMO entails a conceptual structure and overall logical organization of a product family from the sales, design, and production views. It acts as a generic umbrella, under which each new sales, product, and production configurations can be determined to fulfill individual customer requirements. In this regard, the GBoFMO involves two aspects: 1) a unified common structure within which variations in functions, technical design, and routings for customized products can be differentiated, and 2) the configuration of specific functional features, components, and operations from the unified common structure.

Figure 1 shows a representation example of the unified GBoFMO structure. Each node in the structure, be it product-related or process related, is a generic concept in the sense that it represents a family of item variants of a same type. In line with the earlier discussion, a product family is characterized by a set of features. There are many interconnections among features, feature values, as well as features and feature values shown as mapping relationships in the figure. These mapping relationships can be require meaning the selection of one feature (or a feature value) requires the selection of another, exclude indicating the selection of one feature (or a feature value) excludes the selection of another, and or denoting either one feature (or a feature value) among a number of alternatives can be selected. By satisfying these mapping relationships, the appropriate features and the corresponding values can be determined, resulting in the sales configuration of a customized product.

The child component families of a product family have multiple descriptive attributes, each of which can assume a number of values. Mapping relationships exist between features of a product family and child components. Figure 1 shows such mapping relationships between End Product Family and Assembly Family 1. As a result of these mapping relationships, the determination of component inclusion and component attribute values is based on features. While specific components are described by attribute values, they are technically defined by design parameter values. Thus, there are mapping relationships between component attributes and design parameters, as shown in the figure. In addition, mapping relationships exist among design parameters, parameter values, as well as parameters and values. Figure 1 gives some examples of these mapping relationships between Assembly Family 2 and Assembly Family 3, between Assembly Family 2 and Part Family 22, and between Part Family 21 and Part Family 22. This is consistent with the fact that design of parent components influences that of child components and that design of sibling components influences design of other sibling components. As with the combination of specific features leading to a customized product, a set of compatible design parameters and the respective value defines a component variant.

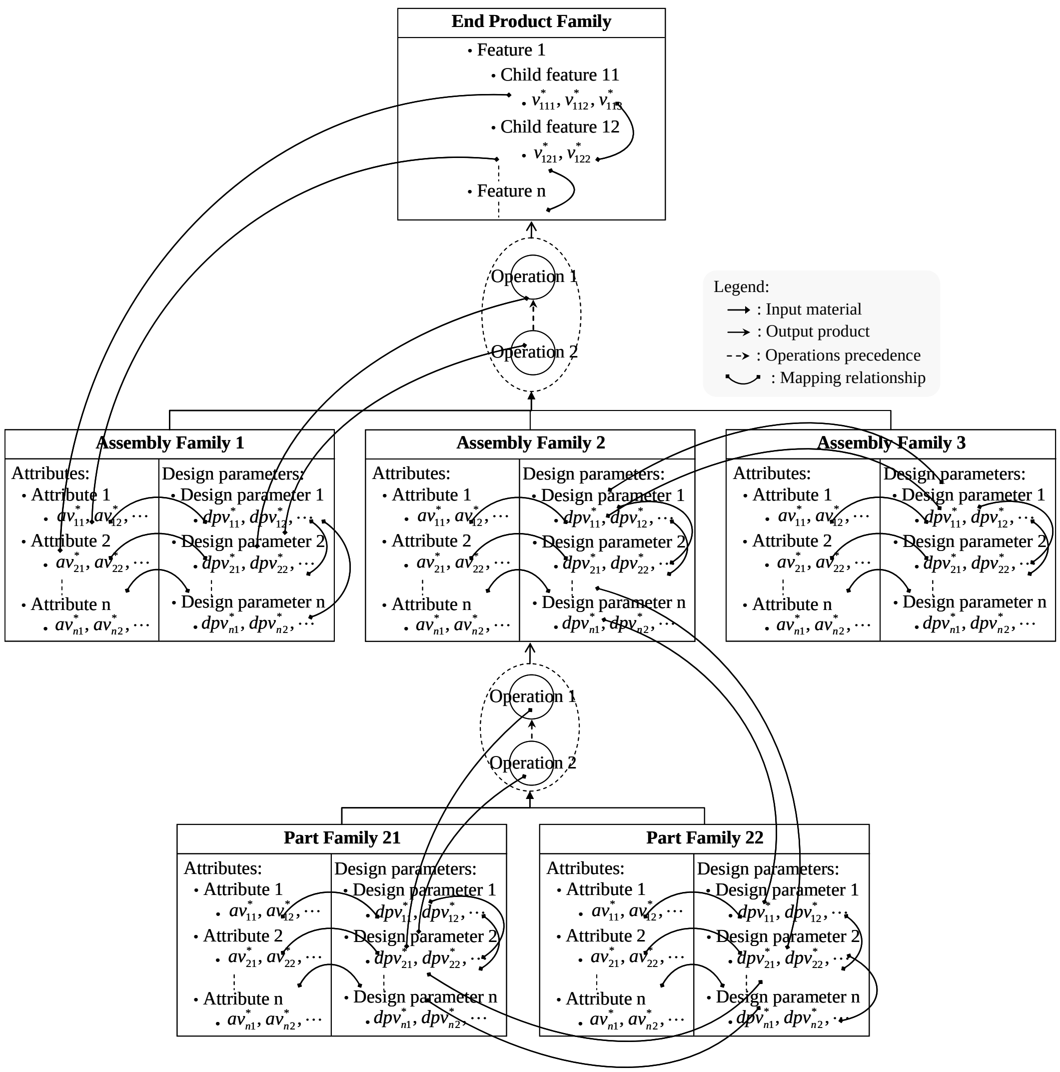

Figure 1: GBoFMO representation

Producing parent components, operations, be they assembly operations or manufacturing ones, along with their precedence relationships form subroutings. Connecting all these subroutings by following the parent-child relationships among components leads to a routing to produce a customized product. Similarly, mapping relationships exist between operations and components' design parameters, as shown in the figure. They determine specific operations, manufacturing resources, and operations precedence for given child component variants.

With all the above mapping relationships inherent in the GBoFMO, given a sales configuration, the product configuration in terms of components and their relationships can be obtained. Subsequently, as a result of production configuration, the routing can also be determined, consisting of ordered operations, manufacturing resources, and cycle times.

4. Industrial Example

In this study, a family of customized light passenger aircrafts is used to demonstrate the GBoFMO concept. The major components of a light passenger aircraft include engine, wings, cabin and electronics, as shown in Figure 2. Cabin and electronics form the body of an aircraft. For the light passenger aircraft family, its sales view is shown in Table 1. The major features that describe this aircraft family include the number of passengers (NPA), the finishing level (FIN), the speed (SPE) and the flight range (FRA). Each of them can take on a specific value for a customized aircraft. Relationships exist among these features. An example of such relationships is also given in the table.

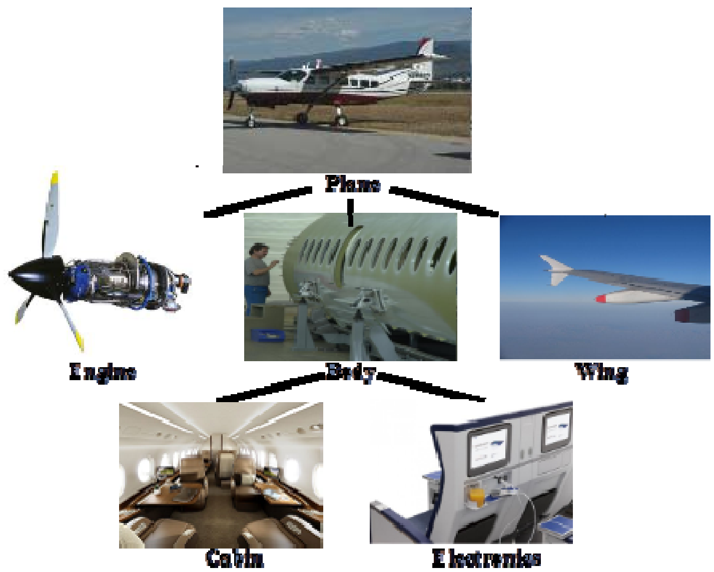

Figure 2: A light passenger aircraft and some major assemblies

Table 1: The Sales View of the Aircraft Family

Features	Feature values
FIN : Finishing level	Low, Medium, High
NPA : Number of passengers	4, 6, 8, 10
SPE : Speed (Km/Hour)	300, 400, 500, 600
FRA : Flight range (Km)	300, 400, 500, 600, 800, 1000
Relationships among features	If speed = [400, 600], the flight range ≤ 600

Similarly, the design and production views of the light passenger aircraft family are constructed based on data analysis.

Each of the major component assemblies is described by a number of attributes and technically defined by design parameters. While the configuration of attributes is influenced by the combination of feature values of aircrafts, it determines design parameter values of aircraft components. For assembling an aircraft, two assembly operations, namely assemble wings and mount engine, are necessary. In addition, assemble wings must be carried out before mount engine. The specific manufacturing resources required and the estimated cycle times to be incurred are influenced by the design parameters of input components.

Upon analyzing the sales, design, planning, and production data and knowledge pertaining to the aircraft family, the GBoFMO is constructed shown in Figure 3. The GBoFMO represents the sales data (e.g., features of the aircraft family), the design data (e.g., wing attributes and design parameters) and the production data (e.g., the assembly operations to assemble an aircraft) in one unified structure. Thus, it enables a corresponding configuration system to consistently configure the set of features of a customized aircraft, component designing aircrafts and operations producing aircraft.

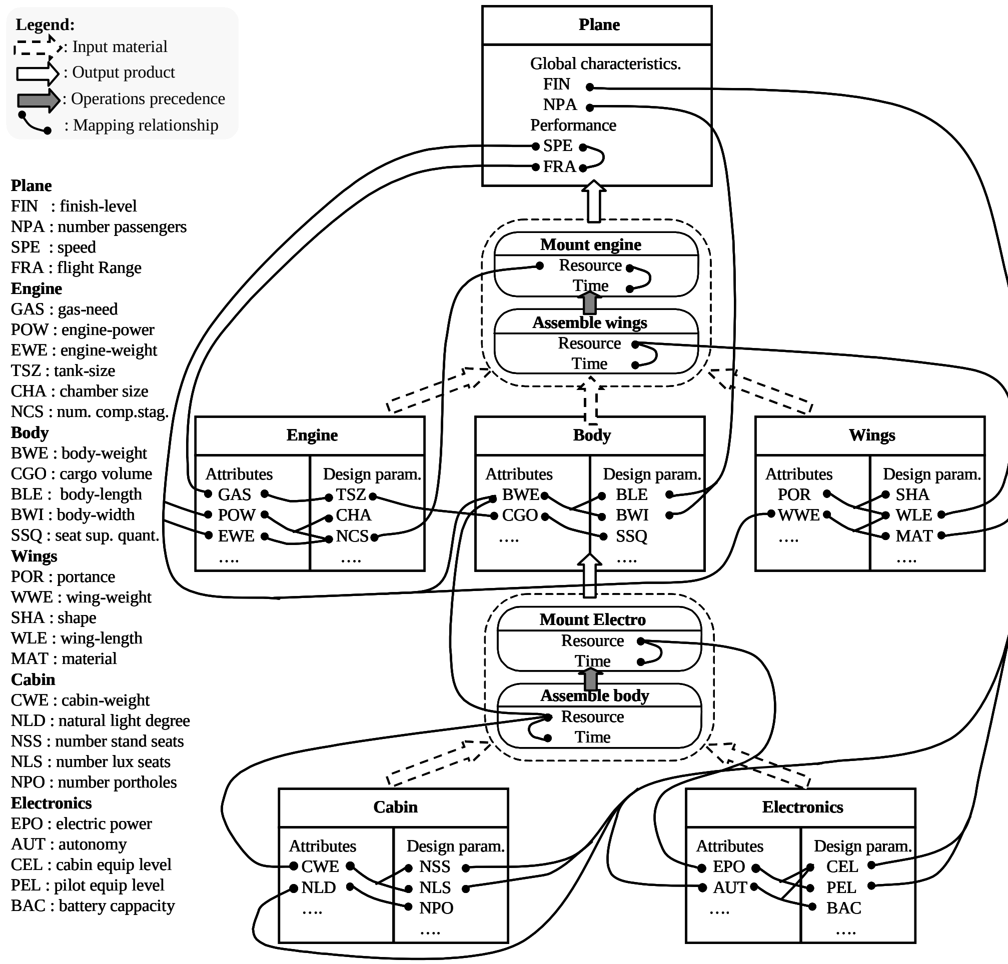

Figure 3: The GBoFMO of the aircraft family

5. Conclusions

In view of the limitations of the available studies on configuration, a concept of SPP configuration is put forward to accommodate product customization from a holistic view. Built upon the principle of automating most of the processes associated with specification, engineering, and production of a customized product, SPP configuration enables the configuration of functional features, physical components and their relationships, operations and manufacturing resources based on individual customer requirements. It is also expected to dynamically generate the technical documents, such as BOMs and BOOs, to contribute to improve production performance by having error-free BOMs and BOOs. As a starting point, this study discussed in detail the knowledge model underpinning SPP configuration: the GBoFMO. In accordance with the functions of SPP configuration, the GBoFMO involves knowledge and data within and between the functional, design, and process domains, and embodies a product family from the three associated views: the sales, design, and production views. A family of light passenger aircrafts was also used to demonstrate the GBoFMO. Built on top of this study, other issues in SPP configuration, including configuration evaluation, data and knowledge modeling, configuration modeling, system architecture design and prototype development, pave the avenues for future research.

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Biography

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