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Integrated Vehicle Configuration System—Connecting the domains of mass customization

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ABSTRACT

Configuration design for mass customized vehicles necessitates the coordination of customer requirements, product characteristics, production processes, and logistics networks, in order to achieve rapid response to customer orders. Existing product configurators are mainly used as sales tools, and fail to account for the requirements of the entire customer order fulfillment process. In this regard, this paper proposes an Integrated Vehicle Configuration System (IVCS) to facilitate customer order processing based on information from multiple domains in a mass customization environment. An IVCS business model is proposed to incorporate the decision factors for configuration design related to different planning stages. The business model is supported by a comprehensive ontology framework, which enhances communications between different stakeholders involved in the order fulfillment process. The configuration approach is based on combinations of selective and generative rules and can be integrated with existing ERP systems. It also provides mechanisms to handle configuration rules that allow users to convert soft preferences into product specifications, bill-of-materials, and, furthermore, into logistics configurations. An example of a computerized configuration system showcases the process from customer engineering to design and production.

1. Introduction

Mass customization has reshaped the landscape of many industries such that rapid response to individual customer needs, coupled with high production efficiency, are vital for a firm's business success [1,2]. The automobile industry is no exception, in that the mass customization of such expensive and complex products is often very time-consuming and it is a complex issue to define product option combinations, formulate an offer for the customer and secure an order from it, generate bill-of-material (BOM) of the customized product, and link it to the logistics of the manufacturing process [3,4]. Notably, there is a gap between what the customer wants and what the producer can offer in terms of product characteristics, as well as the order fulfillment process.

In such a situation, automobile companies have developed product/sales configurators to automate the order handling process according to the customer requirements. Typically, a product configurator is a tool especially for the sale of component-based products and in some cases implemented within an Enterprise Resource Planning (ERP) system [5]. Without going into the details of the product design and manufacturing process, the product configurator signifies the producer's awareness of customer needs and the capacity to fulfill these needs with respect to its product offerings [6]. Thus, it allows for easy and quick product definition, guides the salesperson in a negotiation situation, and prevents the selection of components and option combinations that, for production or other reasons, are impossible or unprofitable.

However, viewing a product configurator as a sales tool may restrict its application in vehicle mass customization. In particular, existing configurators are inadequate to facilitate decisions in the customer order fulfillment process, mainly because of their inability to (1) capture the actual customer needs, (2) account for decision factors beyond the functional/physical domain, and (3) exchange information among different planning teams. Most legacy systems focus on the technical details of products and neglect the customer perspective [7]. However, it is unlikely that customers could make logical selections when they do not have adequate product expertise. Moreover, there seems to be an over-emphasis on the functional/physical aspect of products, e.g., engine type, automatic gearbox, ABS brakes, etc. Equally important, if not more so, is the customer's affective needs in the choice of an automobile, where the affect involves the emotional aspects of the customer requirements, such as aesthetics, prestige, and

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pleasure [8,9]. In fact, emotional aspects play an important role in forming customers' perceptions of an automobile, and thus influence their purchasing behaviors [10]. Furthermore, decisions related to the order fulfillment process do not rely solely on the product configuration. Other factors, such as logical production and logistics configurations, may also influence the performance of the order fulfillment in terms of time and cost [4,11]. Finally, a logical estimation of the cost and time for fulfilling a specific customer order may be hampered by the loose connections among different stakeholders, such as customers, sales staff, and production engineers. This can be attributed to the different terminologies and information systems used by them. It is desirable to develop a common ontology for configuration and to integrate the heterogeneous subsystems used by different stakeholders, thus achieving effective information exchange and reuse [12,13].

This paper aims to extend the scope of product configurators to the entire process of customer order fulfillment. Towards this end, an Integrated Vehicle Configuration System (IVCS) is proposed to facilitate the order fulfillment process by connecting customers with back-end product configuration options in a mass customization environment. The system can be used by customers and salespersons to demonstrate product offerings that take into account both affective and functional requirements. It can also assist the product planner to make preliminary estimations of the performance of the production based on product and manufacturing process information. A business model is proposed to incorporate the decision factors for vehicle configuration design in different domains, including customer, functional, physical and process domains (Section 3.1). The model is supported by a comprehensive ontology framework, which enhances communications between different stakeholders involved in the order fulfillment process (Section 3.2). An integrated configuration process is defined to streamline the activities of configuration design and provide decision support (Section 3.3). The configuration approach is based on combinations of selective and generative rules and can be integrated with existing ERP systems. A prototype system is presented with a case study of the configuration of truck products to demonstrate the overall configuration process (Section 4).

2. Related work

Product configuration planning involves a number of research and application issues. The research perspective usually focuses on such issues as formulation of the configuration tasks, representation of configuration knowledge, and configuration problem-solving. Mittal and Frayman [14] propose a generic definition of the configuration task, based on which the knowledge required in configuration design is classified, and the problem-solving process is discussed. Sabin and Weigel [15] classify existing configuration methods into rule-based reasoning, modeling-based reasoning, and case-based reasoning in accordance with the knowledge representation scheme. Franke [13] identifies three major directions in configuration research, namely common ontology, function representation and functional reasoning, and scaling configuration to large problems. Considering the importance of understanding customer needs, Blecker et al. [7] propose an advisory system that guides customers to generate product configurations according to their profiles and preferences. Wielinga and Scheiber [21] emphasize the role of knowledge in configuration design problem-solving, and compare three types of knowledge-intensive methods, namely case-based methods, propose-critique-modify methods, and hierarchical configuration methods. Siddique and Rosen [16] have developed the Product Family Reasoning System (PFRS) to formulate product platform design as a configuration design problem. Corbett and Rosen [17] extend the PFRS approach and propose a partitioning method to reduce the size of the feasible design space. Fujita et al. [18] propose a modular design approach for product family configuration design, whereby simulated annealing is used to search for the optimal solutions [19].

While problem-solving has been extensively studied in the literature, the development of ontology for configuration is an equally important but constantly overlooked issue [12,20]. A general ontology for describing configuration information is a prerequisite for communication among different parties, including engineering, manufacturing, marketing staffs, as well as customers. Thus, the ontology framework emphasizes information exchange and reuse in vehicle customization, where ontological choices may include configuration specification, configuration result, configuration model and configuration solution techniques [13]. Gruber [20] views ontology as designed artifacts that are formulated for the purpose of being shared and reused in specific situations and evaluated against certain design criteria. Wielinga and Schreiber [21] distinguish four types of domain knowledge for configuration design (components, assembly, function, and constraint) and propose a hierarchical structure for organizing configuration knowledge. The product modeling strategy proposed by Yu and Skovgaard [3] involves four elements, namely object types, constraints, resources, and product modularization. Soininen et al. [12] present a generalized ontology of product configuration, where a detailed conceptualization of knowledge of product structures is introduced. The NIST design repository project involves the development of taxonomies and ontologies for representing product functions, artifacts and relationships, with the ultimate goal of achieving interoperability of product information [22,23].

However, the above-mentioned ontologies are inadequate for product configuration in two aspects. Firstly, they focus exclusively on the functional aspect of product configuration. For consumer products such as automobiles, the customers' affective needs play an important role in forming the value profile of the product, and thus should not be overlooked in the configuration process. Therefore, the ontology must incorporate affective needs in addition to functional ones. Secondly, the ontologies are usually limited to individual domains, i.e., they deal with the configuration knowledge used by specific stakeholders only, be they customers, salespersons, or designers. This inevitably restricts the application of ontology-driven configuration design because such decisions are made based on partial information of the whole system. Therefore, a more comprehensive ontology is needed which incorporates decision factors of multiple domains.

From the application perspective, various prototypical and commercial configuration systems have been developed with emphasis on customer relationship management and integrated solutions [24]. A number of general purpose commercial product configurators are available, such as SmartCatalog (http://www.smartcatalog.com/), Tacton (http://www.tacton.com/), Summium (http://www.summium.com/), among others. These systems aim at simplifying and expediting the configuration, pricing and quotation of complex products and services. In the automobile industry, major automobile manufactures are developing online product configuration systems that exhibit the vehicle product offerings with customizable options. These configurators are usually web-based, with the aim of rapid response to requests for quotations through enhanced customer–vendor interactions.

Yu and Skovgaard [3] have developed the salesPLUS system, which is a configuration tool used in real world configuration applications. Haag [25] enhanced the SAP's R/3 system with a sales configuration engine to support the engineer-to-order process. Regli and Cicirello [44] have developed digital libraries to facilitate collaboration in computer-aided design. Helander and Khalid [26] and Khalid and Helander [10] analyzed the customer decision-making process in e-Commerce. Fundamental issues of e-product development for mass customization are discussed by Helander and Jiao [27] and Helo [28]. Ma et al. [29], and Jiao and Tseng [30] have scrutinized the key techniques and implementation issues for developing electronic catalogs to support web-based sales automation. Simpson et al. [31] and Zhang et al. [32] discuss the issues involved in developing web-based support for product family design.

Although a number of web-based, interactive product configuration systems have been proposed, they fall short as integrated systems that connect customers, engineers, and production systems. This can be attributed to the lack of a holistic view of the customer order fulfillment process that addresses product lifecycle issues.

3. Integrated configuration system

3.1. IVCS business model

To implement the integrated configuration system, it is important to develop a coherent business model that accommodates the activities of customers, salespersons, designers, and production engineers. Such a business model provides a reference framework for identifying the decision factors belonging to different order fulfillment stages and the mapping of relationships among these stages.

Fig. 1 illustrates the business model of vehicle configurator that covers four domains, namely the customer, functional, physical and process domains. The division of domains is useful to decouple the decisions in relation to the customer order fulfillment process. Two types of customer needs (CNs) are defined in the customer domain, i.e., affective and functional CNs, which are collectively embodied by the Citarasa ontology [33]. In general, CNs tend to be imprecise and ambiguous due to their linguistic origins [34]. Hence, it is difficult to identify specific product configurations that address the CNs. As a quick fix, CNs are usually translated into explicit and objective statements, called functional requirements (FRs), which are defined in the functional domain. The distinction between CNs and FRs is in line with the domain mapping principle proposed by Suh [35]. Essentially, what a customer de facto perceives is the CNs in the customer domain, rather than FRs in the functional domain. A process of order configuration is needed to translate the customer-perceived diversity in CNs to the design specifications in product variety, which is what is meant by FRs. Next, the design specifications are mapped into the design parameters in terms of product components in the physical domain, where various indices (e.g., commonality and modularity) can be used to evaluate the advantages of product platforms. Similarly, the process domain defines the process variables in terms of production plans and supply chain configurations so as to realize the manufacturing and distribution of products. It should be noted that the process variables are not necessarily embodied as detailed routings and material requirement plans at this stage. Instead, the planner only requires a preliminary choice of process platforms and supply chain configurations in order to analyze how the master production plan deviates from the standard ones. This will lead to a logical estimation of the time and cost of product fulfillment.

A conventional product configurator is directed toward the product structures in the physical domain or the correlation between functional requirements and design parameters. In comparison with the IVCS business model, it lacks a holistic viewpoint of the order fulfillment process, thus falls short as a comprehensive decision facilitator. On the other hand, to make effective use of the reference model, it is necessary to develop a set of ontologies that can be communicated among different domains.

3.2. Ontology development

To develop the ontology, it is necessary to carry out a thorough analysis of the information exchanged in the customer order fulfillment process. A central theme is to determine the concepts relevant to styles and requirements, the terminology used, and the potential transformations and relationships between these concepts. In particular, three sets of ontology are developed, namely the Citarasa ontology, Do-It-Yourself-Design (DIYD) configuration ontology, and CSH (customer selection history) ontology. The role of the Citarasa ontology is to formalize the language in which the order configurator communicates with the customer, the product planning department, and the DIYD engine. The main focus is on

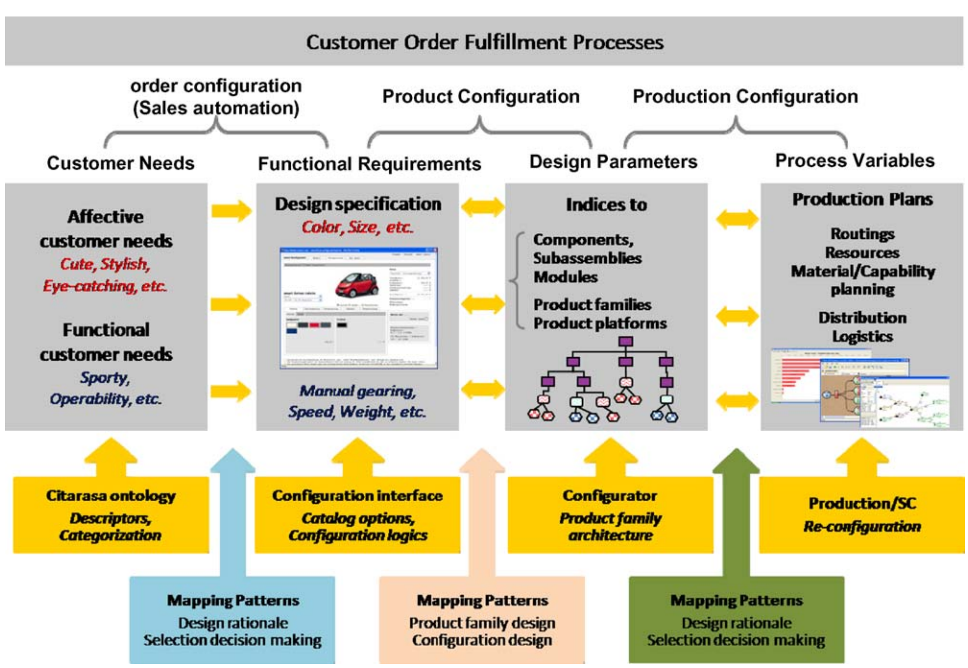


Fig. 1. IVCS business model.

the identification and formalization of the customer's emotional requirements and responses to different vehicle configurations. The DIYD configuration ontology governs the specification of new vehicle configurations. Its main role is the maintenance of configuration options and constraints which exist for different vehicle models. The CSH ontology formalizes a framework to record the history of how different customers have used the vehicle configuration system to select their preferred vehicle configurations.

3.2.1. Citarasa ontology

The purpose of the Citarasa ontology is to capture and formalize the affective and functional customer needs in a semantically meaningful way. The aim is to support requirements engineering for both more effective customer selection of specific vehicle designs and to inform new product development about customer preferences. The Citarasa ontology essentially prescribes how to define the profiles of different customers and their requirements and links them to vehicle design specifications.

In order to allow for a semantically meaningful interpretation of the requirements expressed by different customers, it is important to have a finite set of descriptors which have a known meaning to both the customer who is choosing them and the person/system which has to propose design configurations based on them. Both affective and functional CNs are classified through Citarasa descriptors. Examples of Citarasa descriptors include, e.g., elegant, sporty, spacious, etc. Furthermore, the same descriptors should be used to express the intended style of the specific vehicle design configurations in order to be able to match what is wanted against what is being offered. To close the loop, feedback from the customer should be obtained, which expresses the level of achievement between the originally desired affective requirements and the eventually chosen vehicle design.

3.2.2. DIYD configuration ontology

The DIYD configuration ontology governs the construction and configuration of vehicle design options during the DIYD design phase. It specifies how different elementary design components can be combined and adapted to form valid vehicle configurations. Furthermore, the IVCS targets the styling of vehicles based on the affective needs of the customers. Consequently, each design component, as well as the resulting design configurations, needs to be annotated with Citarasa descriptors, expressing their intended style in a form that can be linked to the affective requirements of different customers.

Each vehicle design configuration can be broken down into lower level design configurations and basic design components. Thus, a hierarchical configuration structure can be formed, where the lower level design components are graphical elements that constitute a configuration. These components are linked to specific files which contain the two-dimensional (2D) and three-dimensional (3D) representations in different formats.

The vehicle model defines the constraints for the configuration of specific vehicle instances. It is assumed that each model has a set of customizable features constituting a pre-defined list of customization options. The customization options can either be linked to specific attributes of design components or define the selection of alternative design components. Each design component and design configuration has a number of design parameters which define how the component or configuration can be adapted to the individual needs expressed by the customers. Examples of customization options include the main color of the vehicle, interior trim options, type of alloy wheels, type and design of the steering wheel, etc. It is also possible to group a number of specific customization options together to form option packages. These packages are often used to group multiple popular choices together to simplify the configuration activity and achieve a sense of unity. This normally results in more competitive prices for the customers and also better utilization of the manufacturing and logistics operations from the manufacturers' viewpoint.

3.2.3. Customer selection history ontology

The purpose of the CSH ontology is to provide a suitable semantic framework for recording customer selections within the IVCS. A record of customer selections and choices is used to define a comprehensive and semantically meaningful history of, e.g., how customers from different demographic backgrounds originally wanted the configuration that the IVCS suggested to them, how they proceeded to change the first proposal to a closer match of their personal preferences, and whether or not they eventually decided to proceed and order the vehicle configuration of their choice. Furthermore, each customer can also record their feedback on how closely the final configuration matched their original requirements in order to enable continuous improvement of the DYID selection rules.

The format of the CSH ontology is the customer selection record. The record of configurations is established through the definition of the first proposed configuration and an ordered list of modification actions applied to it. The final vehicle configuration is recorded to improve the readability of the selection record. When processing the order, the existing vehicle ordering system will be triggered and the chosen vehicle, together with any feedback, will be recorded. This will give the user access to both the configuration chosen and the rejected customization options for a given profile and set of requirements. Thus, the ontology establishes a link between the customers' original requirements, their profiles, and their subsequent configuration choices.

3.3. Configuration process

The configuration process for vehicle customization consists of five major steps, which are supported by, and communicate with, different ontology sets. The input to the configuration process is the customer needs, which range from vague customer intentions to specific customer requirements on the product features. The output of the process includes two parts. The first part is a summary report of the customer order that lists the detailed specifications of the customer options and the expected delivery time and cost. The summary report is shared with the respective customers. The second part is used internally by the product planners. It contains the BOM of the product and preliminary production and logistics plans that guide subsequent production processes. Fig. 2 illustrates the flow chart of the configuration process.

3.3.1. Citarasa configuration

The configuration process starts with the customer's interest in purchasing an ''ideal'' automobile. Using the IVCS system, the customer's profile is retrieved, depending on whether a purchase or selection record exists for that customer. The Citarasa configuration process incorporates Citarasa questions that include 'soft' user parameters related to the usage of vehicles or other preferences. These characteristics may be demographic parameters, such as location, income, and age group. Each Citarasa question is connected to the product configuration with a weighting scale. Once the user has selected a general preference about the intended usage of the product, the system ranks product configurations that match closest to these selections. Thus, an analysis of the customer's profile, together with the customer's articulation of his/her intentions, leads to a preliminary preference report that is expressed using the Citarasa ontology. In this sense, Citarasa configuration supports reverse engineering and mass customization in the automotive industry through more efficient

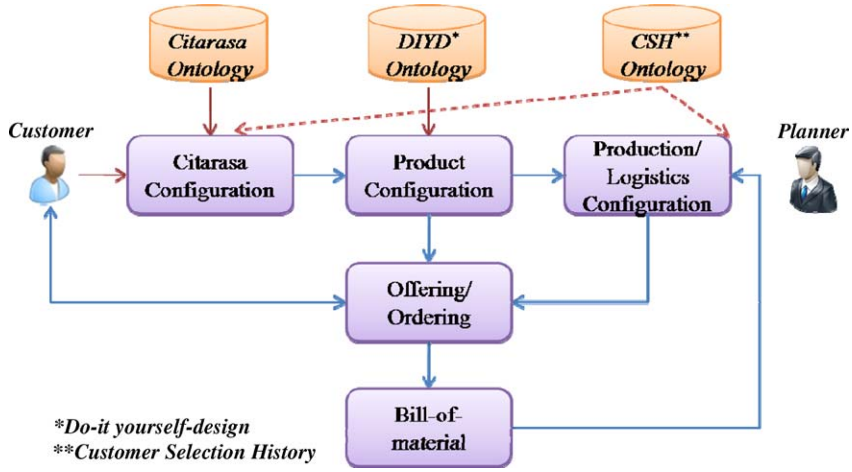


Fig. 2. IVCS configuration process.

and accurate identification of the customer preferences. It helps customers to select the most suitable model after a basic selection process.

3.3.2. Product configuration

The product configuration process manages all functional and technical aspects of a selected product model. With the support of DIYD ontology, the optional product features are retrieved and are listed in a hierarchical structure. This process is governed by a set of design or configuration rules that determine which options can be combined, and in which fashion. Such rules are normally expressed as compositional and topological constraints. However, these configuration rules are invisible to the customers, i.e., the screening process happens at the back-end, such that invalid or unavailable options are screened out whenever the customer selects a particular feature. Thus, the list of options is automatically updated, depending on the customers' selection sequence. Upon the completion of product configuration, the detailed specifications of a product model are generated.

3.3.3. Product offering/ordering

The product specifications are forwarded to the production configuration module, as well as the product offering module. In the production configuration module, the specifications trigger a preliminary estimation of the cost and time of producing the product. Such estimation is carried out by using pre-defined variant price-lists or by analyzing prior transactional records contained in the customer order history database. The expected cost and time of the new configuration is estimated based on records of similar configurations. Various data mining techniques can be used to perform the analysis, such as conjoint analysis [36] and neural networks [37]. The cost and time estimation is combined with the product specifications, thus forming an offer for the customer. The customer may choose to accept the offer by placing an order, or decline the offer. Alternatively, he/she may make further requests by consulting with the product configurator again and compare different product features, usage and cost.

3.3.4. Bill-of-materials

The offering/ordering module is connected to the bill-of-materials module. A BOM consists of a list of the parts, materials and the compositional relationships of a product. There are different types of BOMs available, depending on the purpose and discipline for which they are intended [38]. In practice, many manufacturing firms employ ERP systems to manage the product development and production processes, where BOMs are always used to organize compositional elements of product varieties. Therefore, the IVCS is integrated with the existing ERP system by connecting the product offerings with the BOMs. Moreover, to allow for generic representations of product varieties, product architectures are developed in accordance with product families such that a particular BOM with respect to a product order is an instant from the product architecture [39]. Maintaining the BOMs using the product architecture is conducive to analyzing the commonality of products and to reducing the manufacturing costs.

3.3.5. Production/logistics configuration

As a structure part list, the BOMs are usually employed in production management to explode in the Master Production Schedules (MPSs) into component requirements and manufacturing routings from the generic building blocks [40]. In the IVCS, the BOMs are mapped into the production/logistics configuration such that the actual production process is activated. The production/logistics configuration allows the generation of MPS and the visualization of different supply chains that suit different scenarios [41]. This network provides the planner with easy access to the facilities for different manufacturing steps, and ensures the smooth flow of raw materials, sub-assemblies or finished products among those facilities. The purpose of this network is to optimize different supply and distribution channels. It also helps to design different strategies planning, such as design of transportations facilities, communications equipment, and data processing methods.

4. Case example implementation

In order to present the integration aspects and technical implementations of IVCS a demonstration system was built. A vehicle configuration system was developed for the Volvo truck product family to automate the order fulfillment process, from the customer front-end to manufacturing and logistics. This case example involves five basic truck models that address different market niches (http://www.volvo.com/trucks). For each product model, a number of customizable features are available, such that customers can make selections to satisfy their own needs.

4.1. Ontology development

As a prerequisite of configuration design, the ontology used by different stakeholders must be developed. The ontology is developed based on customer surveys and existing product data.

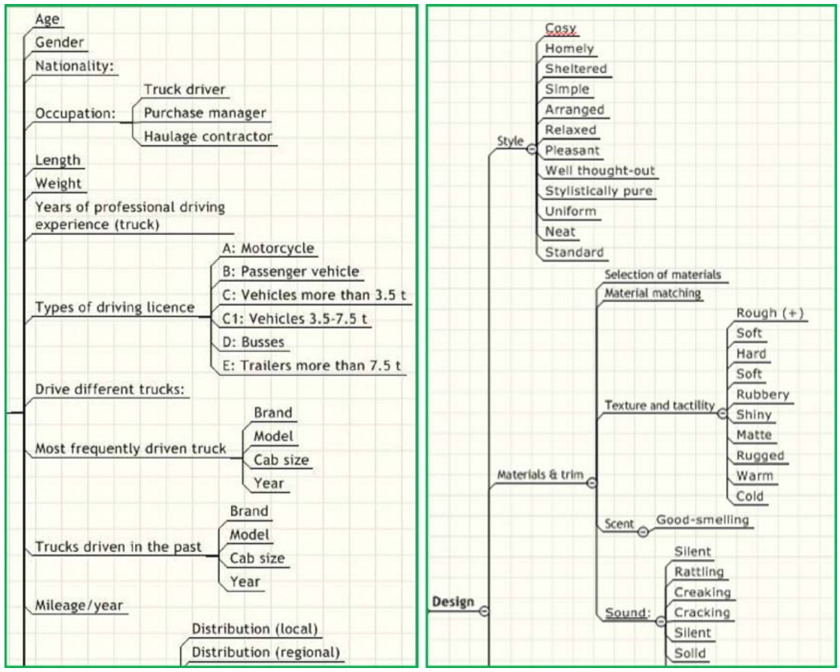


Fig. 3. Citarasa ontology for customer profile and design impression.

Thorough analysis is carried out to extract useful information for the configuration design. As an example, Fig. 3 illustrates the Citarasa ontology for describing the customer profiles and design impression. Fig. 4 shows the partial examples of DIYD configuration ontology and the CSH ontology, respectively.

4.2. Customization process

The first stage of IVCS is the Citarasa configuration, where customers are asked Citarasa questions, including basic measures, behavioral measures and reflective measures of the truck and how the customer uses it. The basic measures deal with the customer's profiles, especially demographic information. The behavioral measures are concerned with the usage of the vehicle, such as steering a smooth and well-balanced truck, driving on mountainous roads, and intuitively finding the controls. The reflective measures have to do with the knowledge and experience a customer has gained over time. These questions are useful to explore the basic preferences of customers such that the system may suggest certain models that are most suitable for the customer. The questionnaire hierarchy is shown in Fig. 5. These questions are linked to the customization process by choosing between some describing expressions. For example, if the user chooses that he or she would like the truck to be a "luxury", used for long distance freight transport, the suggested model would be possibly FH or FH16, and the right cabin type might be Globetrotter

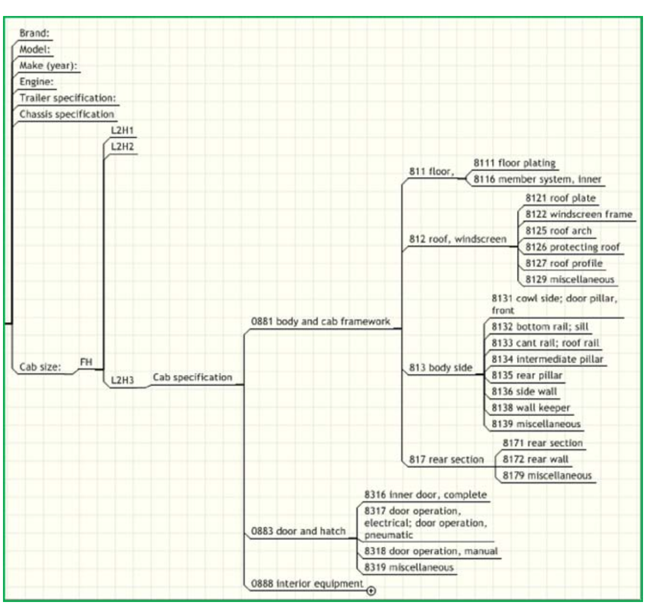


Fig. 4. Ontology for DIYD (product configuration).

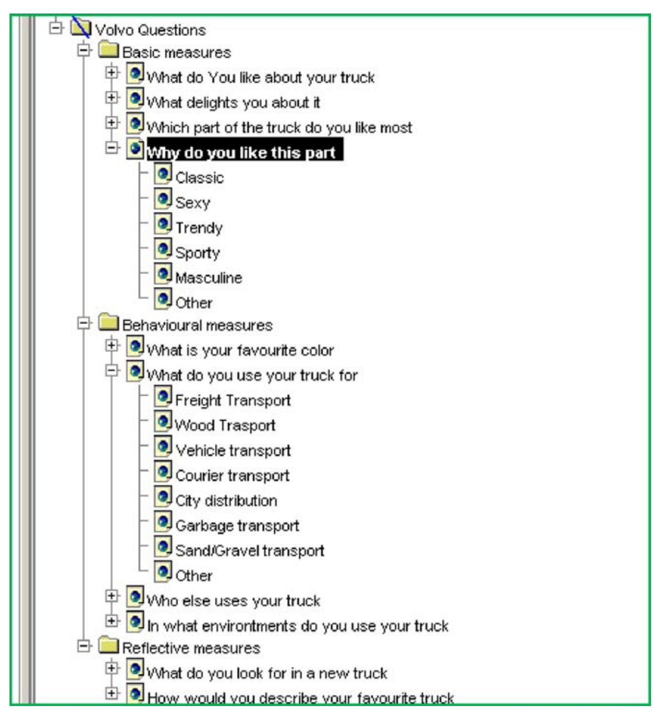


Fig. 5. Example of pre-defined Citarasa questions.

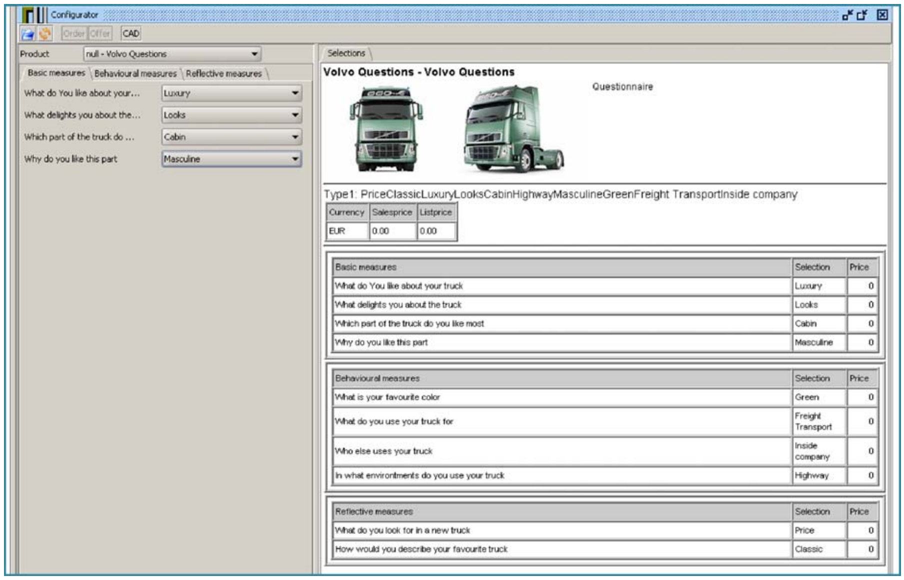


Fig. 6. User interface of Citarasa configurator.

or Globetrotter XL. Fig. 6 shows the user interface of the Citarasa configurator.

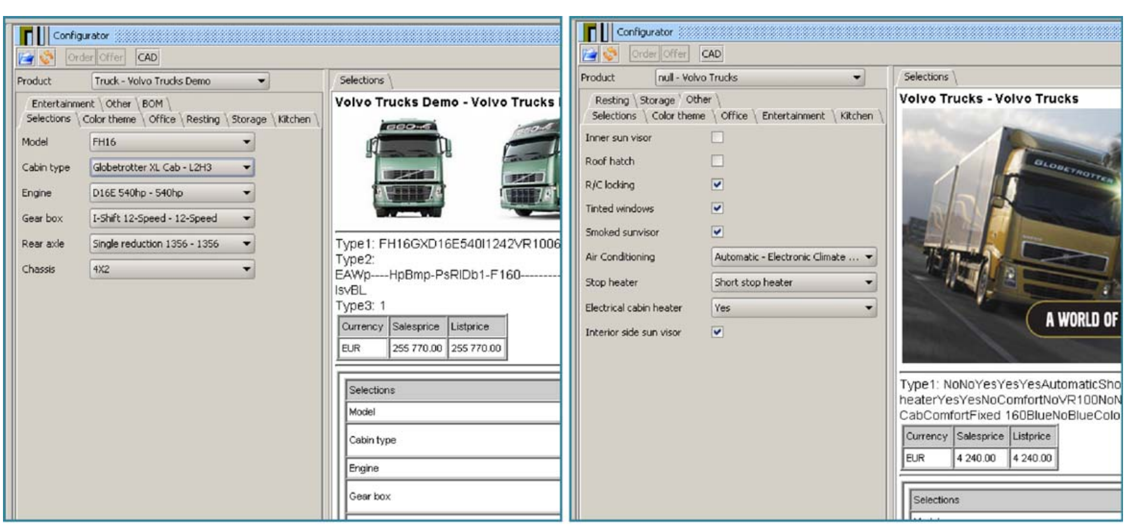
The configurator must be able to customize the product specifications from the customer's initial intentions. The configuration model is built separately for each product family. The model is built hierarchically, including, e.g., all the models, all cabin types and all accessories. The configuration is done by choosing the basic selections, such as model and cabin type, as illustrated in Fig. 7(a). There is also an interface for advanced selections such as color theme and accessories selections, as shown in Fig. 7(b).

In the system, the estimated price of the product is updated instantly with the selection of different features. Thus, the customers are appraised of the product offerings, which they may accept, negotiate or decline. If they decide to place an order for the present product configuration, the BOM is generated and sent to the back-end production site. The BOM structure triggers the generation of the preliminary production and logistics configurations, based on which the planner can initiate the production and delivery plans to fulfill the customer order.

4.3. Configuration rule generation

The configuration model has to account for the constraints of the product offerings, e.g., a certain truck model has certain cabin types and certain comfort levels. Furthermore, only certain accessories and variants of the accessories can be chosen in certain combinations of model and cabin type. This structure is taken into account in the configurator by defining design rules and customizing restrictions. The full model includes all the features that are available in any one case. These features are then limited by rules and restrictions based on some basic questions, which leaves only those selections that are possible and can be actually manufactured. This means that the configuration is valid such that the BOM can be created, and the offering/ordering and logistics network configuration can be formulated.

The configuration rules are designed ex-ante based on domain expertise or using data mining methods. The rules can be maintained manually by using simple "If-Then-Else" logic and setting combinations of parameter values to be allowed, denied or set default. For example, if the chosen model is not an FL model of



(a) Basic selection (b) Advanced selection

Fig. 7. Product feature selections in product configurator: (a) basic selection and (b) advanced selection.

the product, the configurator disables the possibility to choose Crew Cab for the Cabin type. This rule can be formulated as $IFModel \neq FLTHENDenyCrewCab$.

The same logic applies to the creation of BOM rules and the connection between the BOM items and supply network nodes and edges. A simple rule engine can interpret these selections from customer preferences to product configuration, production order, bill-of-material and, finally, supply-demand structure. There are several approaches to model these expression based on ontology [13] and rule expressions [42].

5. Conclusions

Configuration for vehicle customization necessitates rapid response to diverse customer requirements and rational decisions for planning products, production processes and logistics networks. This paper has proposed an Integrated Vehicle Configuration System (IVCS) which establishes a comprehensive decision framework for handling customer orders in vehicle mass customization. The development of ontology enables effective semantic-driven design process and facilitates standardized communications between multiple stakeholders. The ontology leads to the standardization of semantics, and yields a common vocabulary and platform that connects and integrates customers, designers, and suppliers within an integrated framework.

The product configurator is an important facilitator of customer order fulfillment that showcases the best practice of networked business, with the ultimate goal of achieving mass customization over the Internet. This will be realized through coherently integrated communication between sales-service support, engineering design, manufacturing automation, and supply chain management. The proposed configuration system presents a solution to streamline the customer order fulfillment process, whereby customer needs are quickly aligned with the producer's product offerings in order to reach a rational purchase decision.

The IVCS provides an integrated business model for customer order fulfillment, thus facilitating comprehensive decision support rather than acting simply as a sales tool. At the front-end, the IVCS enhances understanding of customer requirements by capturing the customer profiles and correlating them with categories of customer needs. For example, the system is capable of suggesting best-matched product models based on preliminary customer preferences such as "*a sporty and durable truck for long distance freight transport in North Europe*". Thus, the system can act as an intelligent decision-maker for the customer, instead of passively "listening" to and "drowning" the customer in an immense pool of features. At the back-end, the system is capable of generating BOMs with respect to product specifications, and making rough estimations of the performance of the production and logistics configurations. Moreover, by integrating with existing ERP systems, the actual production schedules and delivery networks can be quickly consolidated once a customer order is issued. This is conducive to improving the responsiveness of the customer order fulfillment process.

The ontology framework establishes a foundation for information exchange and reuse among multiple stakeholders. It addresses the need for a semantic-driven system that ties together customers and designers in a collaborative and mutually supporting endeavor. The Citarasa ontology not only captures the customers' needs in terms of product functionality, but also includes the affective aspects of customer requirements. Such a strategy contributes to the creation of high value-added products by increasing the level of customer satisfaction. Moreover, by connecting Citarasa with DIYD and CSH ontology, different uses can refer to the same set of basic descriptors, thus avoiding confusion and misunderstanding. This is an improvement on traditional methods, such as Kansei engineering [43] in the sense that decisions can be better coordinated among multiple stages of the customer order fulfillment process.

However, the current ontology framework does not include terminologies used in the production and logistics configurations [32]. This is because the IVSC system is connected to existing ERP systems, such that information belonging to the back-end production and logistics systems is extracted from these existing systems. Such an integration strategy has dual effects on the configuration efficiency. On the one hand, it alleviates the effort to develop a separate ontology and enjoy the rich resources provided by existing ERP systems. On the other hand, it presents difficulties when the ERP systems cannot meet all the requirements of production planning in relation to the product configurations. In such a situation, it is advisable to develop a new set of ontology for production and logistics.

Another limitation is related to the maintenance of the design rules. While design rules provide a straightforward and flexible mechanism to organize the interrelations among the configuration elements, the maintenance of a large rule base for complex products becomes a daunting piece of work. Without a comprehensive solution for managing the rules, errors and incompatibilities may occur, thus jeopardizing the effectiveness of the entire system. Currently, the rule base is handled manually in the IVCS. As a useful extension, research is being carried out to generate rules automatically and evaluate their validity and compatibility using data mining methods.

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