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Attribute-based integrated product process configurator for mass customization

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Abstract

Mass customization is currently a reality. It requires industries to rethink their product design to develop modular products and new approaches and tools for product configuration. Its main tool is a product configurator that should allow combining different product modules to satisfy individual customer needs. It impacts not only customer satisfaction but also manufacturing costs. The challenge is to propose an efficient product configurator allowing product configuration with highest customer satisfaction while ensuring production feasibility and efficiency. This paper proposes an integrated product configuration and process planning configurator that satisfies customer requirements while minimizing overall manufacturing costs. The configurator is attribute-based, hence instead of customer choosing a product variant to customize, she/he chooses required functions and the configurator chooses the most suited product variant to be customized. A demonstrator is developed and its preliminary testing results are presented.

Keywords: Mass Customization; Product configuration; Product Configurator

1. Introduction

Mass customization has motivated companies to move from the design of individual products to the development of product families [1]. In MC, the focus is on developing a generic modular product architecture from which multiple product variants from the same family will derive. Once customer needs are correctly understood, a product variant is developed within the previously developed generic product architecture to meet them [1]. This is done through the product configuration phase.

Product configuration can be summarized as the task of finding feasible solutions (product variants/configurations) from a set of well-defined sub-components/modules that will be combined to satisfy specific requirements while respecting product constraints (e.g., modules interface) [2, 3, 4].

In MC context, the customers are integrated into the value creation process during the product configuration phase. In this phase, customers can choose among many available product feature options the ones they desire in their product, allowing them to get what they want. One drawback of offering extensive options to the customers is that, in many cases, they do not even know what they want, or they do not have enough knowledge about the product to decide which features will be the most appropriate for them.

In such situations, the cognitive complexity can increasingly grow, and customers can experience confusion when facing attractive but excessive options, leading to the “mass confusion” paradigm [5, 6, 7]. That evidences the importance of helping customers to make their choices during the product customization process. Hence, it is crucial to propose a tool facilitating product configuration. These tools are usually called product configurators.

On another hand, product configuration impacts manufacturing costs, therefore, these should be taken into consideration while configuring the product. Product configuration can concern hundreds or thousands of configurable components leading to an increased probability of errors [1]. These errors can considerably increase production delays and costs, explaining why product configuration is crucial for efficiently mass customizing products [1]. Besides that, it also evidences how it is important to consider process decisions such as process planning and manufacturing costs while configuring products. The main issue becomes how to propose a product configurator that allows efficient product customization with highest customer satisfaction while ensuring production efficiency for the manufacturer.

This paper proposes a function based product configurator for MC that integrates process decisions such as process planning and overall manufacturing costs. It was proposed for configuring shoes. It is organized as follows: section 2 details a literature review related to product configuration and product configurators. Section 3 presents the proposed attribute-based integrated product process configurator. Section 4 shows the developed demonstrator. Finally, section 5 concludes the presented work and presents future works.

2. Literature Review

2.1. Product configuration

According to [8], there are three types of configuration solving strategies as follows:

I. Identification of prime product configurations based on past sale data analyses by using data mining techniques;

II. Generation of feasible product configurations according to given customer requirements. Generally formulated as a constraint satisfaction problem (CSP);

III. Optimization of product configuration focusing on selecting, among all feasible product configurations, the optimal one in terms of given criteria (e.g., cost, customer satisfaction, sustainability factors, etc.) [2, 9, 10, 11]. These problems are also often modeled as CSP when the product configuration is optimized according to given criteria while ensuring that all customer requirements are satisfied [3, 12]. The techniques used to solve optimization problems are generally heuristics.

Table 1 presents some papers found in literature addressing product configuration solving problems in MC contexts by using strategies II and III. All of them addressed the individual/specific requirements as constraints. They were selected based on abstract screening after a keyword search (product configuration, configurator, mass customization) in Emerald, Taylor & Francis, ScienceDirect, and Web of Science from 2010 till 2021.

Using customer requirements (CRs) to constrain CSP and mathematical optimization problems ensure that the final product will fulfill all specific requirements. In some cases, CRs are directly associated to product components/modules while in others the CRs are addressed as functions, which are mapped into product components/modules. The presence of the components/modules on the product means that the CRs or functions were satisfied.

Most of the papers focused on optimizing a given criteria in product configuration tried to minimize costs [3, 11, 12, 13, 14, 15]. Besides them, [3, 12, 15] appear to be the only ones that concurrently optimized product configuration and process planning. Although [14] addressed manufacturing and assembly costs, they considered these costs as constants according to the type of module/component selected.

Table 1. Summary of papers addressing product configuration solving problems in mass customization contexts.

	Optimization objectives		Modelling Approach	Solving Technique
	Min	Max		
[15]	Cost, cycle time	-	CSP	CFB-EA+
[16]	-	Total profit	MILP	CPLEX
[11]	Cost (of modules and of purchasing carbon emissions)	-	MILP	GA
[17]	-	Profit	MINLP	Stochastic optimization
[10]	greenhouse gas (GHG) emissions	Customer satisfaction index	MINLP	GA
[14]	Cost (manufacturing, assembly, others)	Product performance index	CSP + ILP	Pareto GA
[12]	Cost, cycle time	-	CSP	CFB-EA
[13]	Cost, time	Performance	MILP	NSGAII+ fuzzy-based select mechanism
[18]	-	-	GCSP	Asynchronous Backtracking algorithm
[3]	Cost, cycle time		CSP	Branch and bound + filtering system/ adapted SPEA2
[19]	-	-	CSP	Depth-first search + backtracking search algorithm
[20]	Cost		MILP	CPLEX
[21]	-	-	Dynamic CSP	Augmented backtracking method
[22]	Total number of components		CSP + ILP	Depth-first search + backtracking search algorithm
[9]	Cost	Performance	Constraine d AND/OR tree	Genetic programming
[23]		Utility value	MCDM	Fuzzy-based method
[2]	Cost, time		MINLP	GA
[24]	-	-	CSP	Search algorithm based on back-jumping

CFB-EA: Constraint Filtering Based – Evolutionary Algorithm; CSP: Constraint Satisfaction Problem; GA: Genetic Algorithm; SPEA: Strength Pareto Evolutionary Algorithm; MCDM: Multi-criteria decision making problem.

Besides costs, some papers tried to maximize the product performance [9, 13, 14] and profit [16, 17]. Two papers recently published addressed environmental issues through the minimization of greenhouse gas emissions and costs of purchasing carbon emissions [10, 11].

Regarding the approaches to model the configuration problems, it is possible to see from Table 1 that they were mainly modeled as CSP or mathematical programming problems using integer variables; Papers using CSP approaches were mainly focused on addressing more complex interactions between components through the consideration of structural rules (e.g., mandatory, cardinality, has attribute, etc.) and a higher number of more complex configuration rules (e.g., requires, exclusion, connection type, etc.) [16, 19]. In contrast, papers modeling their problems using mathematical programming considered fewer and simpler configuration rules (e.g., compatibility) [11, 17].

When works were focused on finding feasible product configurations without optimizing a given criteria, they were often modeled as a CSP only, being solved by algorithms specific for solving this kind of problems such as backtracking and depth first search algorithms which are constraint programming (CP) techniques [18, 19, 21]. However, some papers modelling their problems as CSP used heuristic approaches to optimize a given criteria [3, 12, 15].

Works modelling their problems as mixed integer linear models solved them by using CPLEX and Genetic Algorithm (GA)-based algorithms [11, 13, 16, 20]. Heuristic techniques, such as GA and stochastic optimization, were used to solve product configuration problems modeled as nonlinear mixed integer programming problems, (MINLP) [2, 10, 17].

In summary, papers addressing configuration-solving problems in MC contexts for meeting specific customer needs always address CRs (or functions) as constraints assuming that they are directly mapped into product components. Therefore, the presence of a given component automatically means that a requirement was satisfied. When product configuration solving problems involve optimization criteria, the main techniques used are heuristics. Few papers have considered process issues when optimizing the product configuration.

2.2. Product configurators

Product configuration systems, also known as product configurator or mass customization toolkits [25] are knowledge-based systems responsible for adapting a product according to specific customer needs [18, 26]. They have received increasing interest from academia and industry since Digital Equipment Corporation established the R1 program (after called XCON) to configure VAX (Virtual Adress eXtension) computer systems for meeting diverse customer requirements [27].

There are several benefits associated with the use of product configuration systems, such as increasing customer satisfaction and the quality of product specifications as well as the product profitability, but also reducing lead times and routine work [28]. It is no wonder that several companies selling mass-customized products have invested in product configuration systems, such as Dell, Cisco Systems, Rebook, and Nike [7, 29].

In MC, customers can co-design the product with the manufacturer. This strong interaction between customer and manufacturer takes place in the product configuration phase through the product configuration system, which integrates the customers into the value creation by allowing them to configure their products according to their own needs from a set of pre-defined options [6, 25]. This is why these toolkits are recognized as critical drivers for MC implementation's success or failure [6].

Although product configurators allow customers to contribute into value creation, configuring customized products through these toolkits is one of the main drivers for complexity from customers' perspective due to the knowledge gap between companies and customers [6, 30]. The large set of choices and the unfamiliarity of the customer with the product features can lead to the paradox of choice in mass customization, also known as "mass confusion" [5, 7]. Too many options can lead the customer to indecision and, therefore, in many cases, dissatisfaction [7].

Further, customers usually have no clear idea of what solution (product variant/configuration) might fit their needs. In some cases, they still have to understand their needs [25]. Consequently, customers can be uncertain during the product configuration process which potentially leads to their dissatisfaction.

According to [5], there are two approaches to present the product varieties in an MC toolkit: (1) attribute-based and (2) alternative-based. In an alternative-based approach, customers are invited to create their product from a set of many product parts (modules) alternatives. While in the attribute-based approach, customers are asked about their product attribute preferences and, based on their answers, a whole product proposition is chosen from a large set of options. [5] state that presenting products in terms of their attributes reduces perceived complexity and favors customers' enthusiasm to make their choice and increases their satisfaction. It means that customers prefer not to choose from a long list of customization options but instead express their personal needs [25].

This shows the importance of guiding customers during the product configuration process, helping them find a product option that fulfils their personal requirements. This is why many researchers have been working on the optimization of product configuration driven by individual customer requirements, in which the focus is on getting the customer uniqueness [9, 20, 31, 32]. Although these papers have focused on optimizing product configuration in terms of individual customer needs, they did not address process issues (e.g., cost/time of performing operations, changing machine configuration, handling material, etc.) that can affect the final product cost. Currently, and up to our knowledge, there are no product configurators including an integrated product, process optimization module that considers individual customer requirements.

3. Attribute-based Integrated Product Process Configurator for Mass Customization

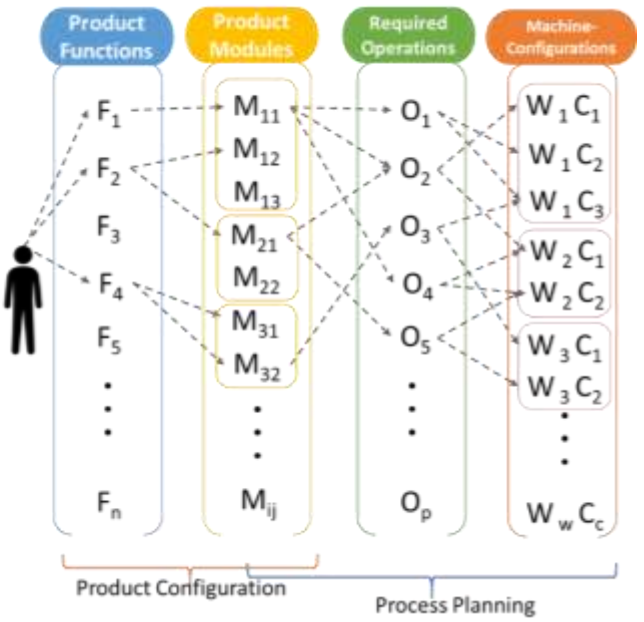

Fig. 1. Integrated product configuration and process planning

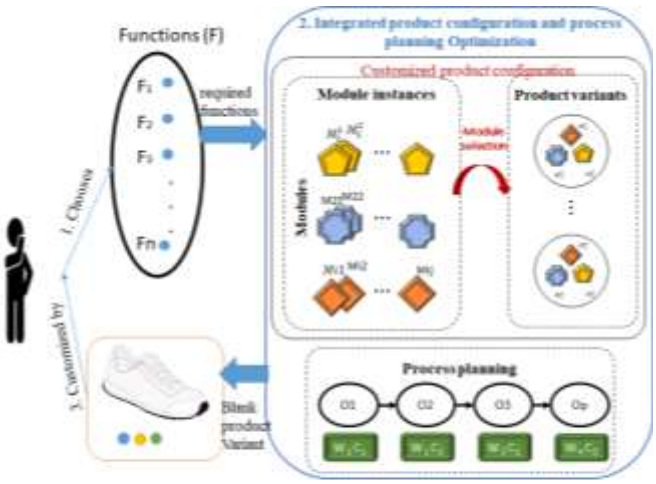

Fig. 2. Overall proposed product configuration and customization process

The proposed approach is attribute/function-based. As shown in Fig.1. A full set of all product related functions is developed. Each function is linked to several modules that can satisfy it. Each module is linked to a sequence of required operations to manufacture it. Finally, each operation can be executed by several combinations of machines-configurations. Each machine has several configurations. The problem is how to choose the set of modules satisfying all customer requested functions while optimizing the process planning to minimize overall manufacturing cost. This cost is formed of raw materials cost, operations processing cost, machines configuration cost and materials handling cost. The mathematical model and resolution approach are detailed in [33,34].

The product configuration process is described in Fig.2. At first, the customer chooses the functions she/he needs from the proposed set of functions. These chosen functions are the input for the customization problem that optimizes simultaneously the product configuration and the process planning to propose for the customer the best product variant that satisfies all her/his requested functions and at the same time minimizes overall manufacturing costs. Finally, the customer can aesthetically customize the proposed blank product variant by choosing the color of the different product components from the proposed colors.

4. Demonstrator

4.1. Demonstrator description

A demonstrator was developed for mass customizing sneakers. The demonstrator included the two customization approaches to compare them: alternative based and attribute-based. The alternative-based approach, allows the customer to choose one blank sneakers' alternative among eighteen proposed models and then customize it by choosing for each shoe part the material and the color (Fig.3).

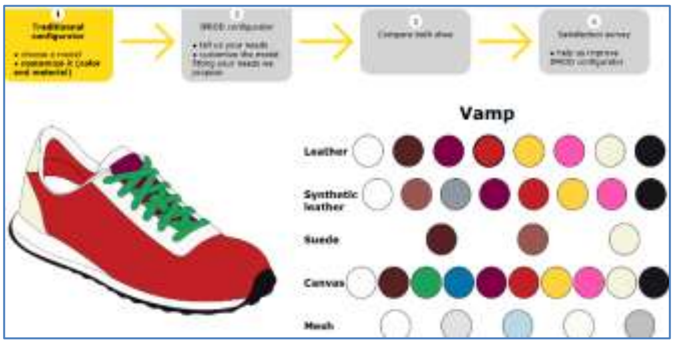

Fig. 3. Customizing the product in alternative-based configuration

The attribute-based approach allows the customer to choose among proposed sneakers' functions and attributes, those she/he needs (See Fig.4). Based on customer choices, it launches an optimization of product configuration integrating process planning optimization and manufacturing costs. The mathematical model is a non-linear integer programming problem. A Genetic Algorithm (GA) is used for the optimization. The mathematical model as well as its resolution approaches are detailed in [33, 34]. This phase takes between 3 and 5 minutes. There are still possible improvements to reduce the computation time.

Once the optimization is achieved, it proposed a sneakers for the customer who can aesthetically customize it by choosing the color of each part from a set of predefined colors depending on the part material (See Fig.5).

Fig. 4. Attribute-based configurator step 1: customer choosing required functions and attributes

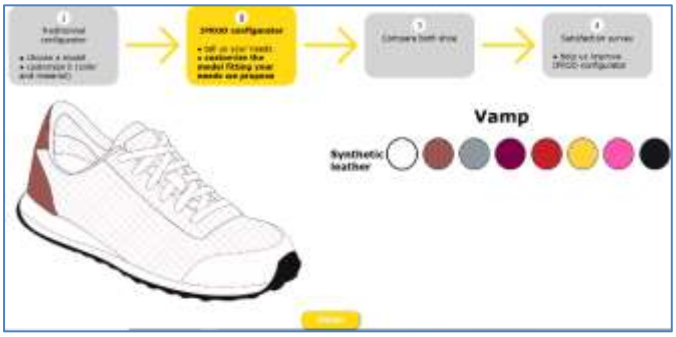

Fig. 5. Aesthetic customization of the proposed product variant

Fig. 6. Shoe comparison

A comparison between the two customized shoes is proposed. It compares them based on the attributes and functions chosen by the customer. The comparison is presented in Fig.6. Finally, a questionnaire is used to compare the two approaches and to analyze whether the proposed attribute-based approach satisfies potential customers.

4.2. Demonstrator testing

Table 2. Demonstrator preliminary testing evaluation results

Criteria	%		%		%	
Gender	55	F	45	M		
Alternative-based configurator sneakers appreciation	40	Fine	60	Great		
Alternative configurator obtained sneakers performance	56	acceptable	23	Fine	21	Great
Proposed configurator sneakers appreciation	17	acceptable	51	Fine	32	Great
Proposed configurator obtained sneakers performance	10	Fine	90	Great		
Proposed configurator vs. alternative configurator sneakers appreciation	36	Less	28	Equal	22	Better
					14	Much Better
Proposed configurator vs. alternative configurator sneakers performance	20	Equal	39	better	41	Much Better
Proposed configurator customization delay	30	Too Long	40	Little Long	30	Appropriate

A testing campaign for the demonstrator was launched at the Université de Technologie de Compiègne. Mainly engineering students are the testing population. They are between 18 and 25 years old. The testing campaign is still at its first steps and for the moment 100 students tested the online demonstrator. The current results are presented in table 2. For every question, the user was asked to choose among four possible answers (not acceptable, acceptable, fine, great). On questions comparing the proposed approache to the alternative-based configurator the user chose between less, equal, better, much better. The obtained results are not statistically sufficient to make final conclusions, yet they show that the attribute-based approach better satisfies customers on sneakers performance, but its calculation delay is considered long (only 30% find it appropriate). Only 36% appreciated more the alternative-based approach. This encourages to continue working on the attribute-based approach.

The main difference between this configurator and existing attribute-based configurators is the optimization module that optimizes the product configuration for the customer compared to proposing a feasible solution and also optimizes overall manufacturing costs. The main question remaining is whether the customer is willing to wait the needed optimization time and whether an attribute-based configuration combined with integrated product, process optimization is more satisfactory than basic alternative-based configuration.

5. Conclusion

This paper presented an integrated product configuration with process planning aiming at satisfying individual customer requirements while minimizing overall manufacturing costs. It is attribute (function in this case) based. A demonstrator was developed and preliminary testing, even not statistically sufficient, shows promising customer appreciation from using such type of configurators. Further research will focus on improving the optimization computation time by testing other metaheuristics than GA. Also, environmental performance evaluation could be of benefit especially that customers are more sensitive to it. Finally, the testing campaign will continue.

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