IOSUD - Politehnica University of Timisoara
Doctoral School of Engineering Studies

PRODUCT DEVELOPMENT FOR SMALL-VOLUME MANUFACTURING IN THE AUTOMOTIVE INDUSTRY, IN THE CONTEXT OF INDUSTRY 4.0

Doctoral thesis summary

in the doctoral field of Industrial Engineering

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The doctoral thesis, in the field of Industrial Engineering, has a topical theme, namely product development for small production runs in the automotive industry, in the context of Industry 4.0.

The doctoral thesis is inspired by the doctoral student's work over the 20 years he worked in companies in the automotive industry, from design engineer to general manager, having the opportunity to learn about and use the latest methods and means of product development.

New product development is a complex process of creativity and innovation capacity, and transforming an idea into a competitive finished product adapted to market requirements requires considerable financial resources and effort for any organization. In addition, when manufacturing runs are limited, through the traditional production process, costs increase to a level that is often not accepted in the market.

The automotive industry has been and continues to be a field where requirements are increasingly diverse, and competition is increasing. These require finding fast and competitive solutions, using the most advanced techniques.

Under these conditions, the need to develop new products, in small production runs or even customized and adapted to specific requirements, but at low costs, will represent the difference between performing or surviving in the market.

In the context of Industry 4.0, products are designed to become an active part of the production process. Conventional, centrally controlled and monitored processes will be replaced by decentralized control based on the self-regulating capacity of products and work units that communicate with each other. In this way, a higher level of flexibility is achieved, which allows manufacturing planning in different small and personalized production batches, with reduced time to market for launching products of superior quality.

Advanced technologies specific to Industry 4.0 are well known: the Internet of Things

(IoT), data security, data processing, cloud technology, Additive Manufacturing (*AM*), augmented reality, *Big Data.* (BD), autonomous robots, process simulation, vertical and horizontal system integration. The ability to collect data and process it in massive quantities (*Big Data*) in a short time frame is a direction that should be considered in the design process of new products.

Another essential element that plays an important role in choosing the theme of this paper is the trend of migration from mass production, characterized by large volumes of the same product, to small series of customized products configurable in several variants and even to individualized products with open architecture, to the development of which the customer for whom the respective product is intended contributes. Consequently, the need for integrated tools in the product development process was identified, which would facilitate direct customer involvement and good collaboration with and between the members of the design teams.

Even now, when in any field of activity more and more tasks are taken over by machines, the role of the human factor in the process of designing and developing new products should not be diminished, because the human brain is much more flexible compared to any type of existing technology and software, but for complex calculations and large volumes of information, we need to turn to new technologies, based on artificial intelligence.

The main objective of the research is to integrate new product development technologies for small and customized production runs, aiming to optimize production costs and investments, and reduce time to market.

The operational objectives that will ensure the achievement of the main objective are the following:

OP1: Conducting a bibliographic study and preparing a synthesis of knowledge regarding product development in the fourth industrial revolution.

OP2: Conducting a study on the product development process, to adapt it to the conditions imposed by the fourth industrial revolution.

OP3: Development of a product configurator.

OP4: Conduct a case study to reveal the usefulness of the developed configuration tool.

The doctoral thesis extends over 149 pages and is structured in 6 chapters.

Chapter **1**, "General Introduction", describes the context, reasons, and impact of the research, justifying the approach to the topic. Following the identification of the main objective and secondary objectives, these are developed in the following chapters.

Chapter **2** presents a "Synthesis of knowledge regarding product development in the fourth industrial revolution"; it highlights current situations to identify problems and define research directions. This required, in the first phase, the creation of an overview of Industry 4.0, the technologies used, and then the analysis of its impact and the prospects for transition to Industry 5.0. Considering the trends of manufacturing in small, personalized series, the characteristics of

current production paradigms were analyzed: mass personalization, mass individualization, and smart personalization.

With the help of advanced technologies associated with Industry 4.0, integrated into the development process of smart products, with communication functions and information collection during operation, the current way of designing a new product can be redefined. The development of smart products requires advanced technologies, both for design and manufacturing, and the integration of smart products into smart manufacturing systems, through IoT, is one of the pillars of the fourth industrial revolution.

The digital paradigm of intelligent personalization has three key characteristics, driven by the digital twin, the framework for data-driven intelligent personalization using the digital twin. There are three digital twins involved in intelligent personalization processes, including the product digital twin, the production system digital twin, and the user environment digital twin.

The methods of developing customized products with open architecture were also analyzed, identifying the criteria underlying the development process of these products and identifying possibilities for improvement.

Following the analysis of the current state of research on product development in the fourth industrial revolution, the limits were identified, and the conclusions were used to establish the main direction of this work.

In **Chapter 3**, "Contributions to the Product Development Process", an adaptation of the development process is presented, considering the innovations specific to the fourth industrial revolution and the conditions imposed by it.

In order to adapt the product development method in the context of Industry 4.0, the impact of digitalization and the need for the chosen design method and the developed configuration tool to take into account functional and cyber safety standards were analyzed in the first phase.

In order to find a solution that meets the requirements for the rapid development of safe and low-cost products, an updated version is proposed, adapted to the context of the digitalization of the product development process, based on the efficient use of reliable database systems.

It is considered that the customization and even individualization of products is achievable through modularization, even if the degree of customization is conditioned by the limitations related to the product family, process limitations, and potential quality problems generated by the wide variety of products.

By resuming the process of configuring products with open architecture, opportunities for improvement are identified.

Also, the efficiency proposal was presented, which targets the pre-development phase and integrates axiomatic design as a development method and product configuration tool.

In the last part of this chapter, some of the contributions of artificial intelligence to the product development process were identified and analyzed. Its potential is constantly growing and will be realized with the advancement of AI technology and algorithms.

In **Chapter 4, "** Contributions on the development of product configurators", the proposed configuration tool model is presented in response to the disadvantages and limitations identified in relation to existing configuration tools.

Mass personalization (MP) has motivated companies to move from designing individual products to developing product families. In MP, the focus is on developing a generic modular product architecture, from which multiple variants of the same family will be derived. Once the customer's needs are properly understood, a product variant is developed within the previously developed generic product architecture to meet their needs. This is done through product configuration.

Product configurators are indispensable tools that offer the ability to create a customized product to exact specifications, reducing development time and costs. The efficiency and effectiveness of such a configurator are dependent on the integrated robust design principles and data management strategies.

The proposed configurator offers flexibility and efficiency in the process of developing personalized and individualized products. It allows for direct customer involvement in the product development phase, facilitating collaboration between design team members. Existing configuration tools have disadvantages and limitations, such as high costs and long design and development times. The market is also shrinking as customized products meet the specific needs of a particular customer.

Two approaches to developing product configurators were analyzed: the attribute-based approach and the alternative-based approach. In an alternative-based approach, customers are invited to create their product from a set of several alternative product parts (modules), while in the attribute-based approach, customers are asked about their preferences regarding product attributes and based on their answers, a whole product proposal is chosen from a large set of options.

The custom product configurator model is designed in the context of open architecture products and is based on the *Axiomatic Design* (AD) methodology. The configurator is designed so as not to limit the choices made to pre-existing modules, but when the customer's requirements are not covered by the available modules, there is the possibility of developing one or more modules and integrating them with the existing ones, in order to generate a new design solution. This approach has as its central point the principle of module independence.

Finally, the premises for the development of product configurators are presented.

In **Chapter 5,** a "Case Study in the Automotive Industry" is presented, which demonstrates how to use the configurator in the product development process and its usefulness in the customer

requirements collection phase, but also in the overall reduction of the time required to launch a product.

The developed product configurator is applied to configure the "Work lamp" product used in commercial vehicles.

The importance of using a configurator in product development is highlighted, showing how it can streamline the requirements gathering process and significantly reduce time to market. This demonstrates that implementing such tools can bring considerable benefits in terms of time and resources saved, contributing to the success of product development projects.

Chapter 6 presents "Conclusions, personal contributions and future research perspectives".

The doctoral thesis entitled "Product Development for Small Series in the Automotive Industry, in the Context of Industry 4.0" highlighted the importance of integrating new digital technologies into the product development process, especially for small series. Industry 4.0 offers an innovative framework that allows for a higher level of flexibility and customization of production, reducing time to market and optimizing production costs.

The thesis highlighted the need for collaboration between different departments and actors involved in the product development process, to ensure efficient integration of new technologies and to respond to market demands in a competitive manner.

In conclusion, research on the development of products for small production runs and customized, based on the principles of Industry 4.0, represents a significant opportunity for companies in the automotive industry, which want to increase competitiveness and develop innovative, customized, high-quality products that meet specific market needs, aiming to optimize production costs and investments, reducing time to market.

Thus, it is considered that the proposed objectives have been achieved.

The main contributions made to the product development process for small series production in the automotive industry, in the context of Industry 4.0, are:

In the field knowledge, based on research of specialized literature: synthesis on Industry 4.0 – definitions, characteristics, technologies; inventory and analysis of current production paradigms – mass customization, mass individualization, smart personalization; analysis of the strategic objectives of circular manufacturing; definition and characterization of smart products; analysis of the process of developing new products, smart products and the framework of intelligent personalization based on data, using the digital twin; analysis of the process of developing products with open architecture for mass customization and individualization, with a configuration view.

In the field of conceptual research: adapting the product development method in the context of Industry 4.0, based on digitalization, taking into account the role of databases and modularity, for product customization; proposal to streamline the product development process, with a focus on the pre-development phase; highlighting the role of artificial intelligence in the product

development process; the configurator designed as an integrated solution of two configuration methods - *Configure to Order* and *Engineering to Order*; integrating *Axiomatic Design* into the architecture of the product configurator with open architecture.

In the field of applied research: validation of the concepts developed by creating a product configurator used to collect customer requirements, directly involving the customer in the development process, ensuring product customization and individualization, and reducing the time required for launch into manufacturing. The configured product was a work lamp used in utility vehicles.

These contributions highlight efforts to integrate new technologies and optimize product development processes in the automotive industry, in the context of Industry 4.0.

The paper highlights several future research directions, especially in the context of using artificial intelligence (AI) in product development and optimizing manufacturing processes.

Artificial intelligence can be used to analyze data collected from smart products and identify opportunities to improve their design and functionality. By using *Machine Learning* algorithms, predictive models can be developed to anticipate customer requirements and optimize the product development process.

AI can facilitate product personalization by analyzing customer data and identifying their preferences. Digital Twin *is* a key technology in this context, allowing products to be simulated and optimized in a virtual environment before actual production. This can lead to more efficient personalization and reduced production costs.

AI can also help develop smart products that can adapt to their conditions and provide real-time information about their status. These products can be integrated into smart manufacturing systems, helping to increase efficiency and productivity.

These research insights highlight the importance of integrating AI into product development and optimizing manufacturing processes, contributing to increased competitiveness and the development of innovative and high-quality products.