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A Decision Support System to Operationalize Customer-Centric Sustainability

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Abstract

This paper reports on a research work conducted within the framework of the SUSTAIN project aiming to unleash and operationalize the potential of customer centricity and sustainability requirements. More specifically, the paper presents a Decision Support System (DSS) intended to support the alignment of aggregate production planning with customer demand during the production ramp-up phase. The DSS consists of a mathematical model and an online product configurator. This will ultimately lead to a revised product portfolio and better align it with the market requirements before moving to series production.

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Keywords: Customer-Centricity; Sustainability; Mass-Customization; Decision Support System; Portfolio Management; Product Configurator; Operations Management; Production Ramp-Up.

1. Introduction

Project and operations management have evolved over the last decades in response to environmental and societal challenges and recent technological advances – prior to and aligned with the digital transformation of the manufacturing industry. Customers, whether businesses (B2B) or individual consumers (B2C) are demanding more customization of products, services, and solutions in general. To meet these market requirements, businesses are increasingly faced with the problem of "how diversifying their goods and services offerings to meet a wide range and variety of customer needs in a sustainable way". However, this diversification naturally leads to significantly increased internal complexity linked to the explosion in the volume of data to be processed, but also to the number of different resources and capabilities that must be implemented to ensure a satisfactory diversity of the offer. In addition, there is a need to shorten the development and commercialisation time for customized products and/or services to cope with market volatility and competition that goes beyond the traditional price war [1-3].

At the same time, alarming debates on climate change have affected the industrial landscape in the last decades in different ways. International agreements and government policies are driving forces behind the consideration of the environmental impact of industrial activities. Moreover, sustainable systems are characterized by the interactions that affect the economic, social, and environmental sustainability of the enterprise – the

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so-called: Triple Bottom Line *(TBL)* [4]. These interactions take place at several levels within and between enterprises and have been the subject of several studies in the scientific and grey literature [5,6].

Joint fulfilment of sustainability objectives and customer requirements become a key for the long-term survival of organisations [7]. However, the *synergies* between these two objectives are not sufficiently exploited and work in this field is rare [8,9].

This paper reports on research work conducted within the framework of the SUSTAIN project aiming to support the alignment of aggregate production planning with customer demand during the production ramp-up phase. The developed DSS consists of a mathematical model and an online product configurator. This will ultimately lead to a revised product portfolio and better align it with the market requirements before moving to series production.

The remainder of the paper is organised as follows, Section 2 reviews the literature highlighting the synergies between customer-centricity and sustainability, Section 3 presents the developed DSS, and Section 4 discusses the proposed DSS and provides research perspectives.

2. Related Literature

2.1. Value Co-Creation

The concept of value has evolved from a perception based on the resource management theory with classical economists [10], where value is created through a transactional model, to a more complete positioning integrating the customer [11]. Value – in the eyes of a customer – represents a compromise between perceived benefits and sacrifices associated with a product and/or service offering [11]. This trade-off depends on value attributes like quality, level of customization, and price. In this approach, which emphasises a subjective perception of value for the customer, the *Service-dominant logic* (SDL) emphasises the relational dimension of value, for instance, the value-in-use that results from the consumption of a service by the customer [12].

Over the last two decades [13,14], the concept of value has increasingly reflected the dimensions of sustainability. In this sense, creating sustainable value means generating economic, environmental, and social benefits associated with an industrial activity [13]. However, there is – no consensus – on what sustainable value actually is [13]. A prevailing perception is based on the principle of the *Triple Bottom Line* (TBL), which extends the value definition from a business perspective to people, planet in addition to profit. More recently, the evolution towards the notion of value co-creation has made it possible to extend the scope of value, which now involves additional stakeholders beyond only the supplier and the customer (e.g., subcontractors), thus forming a more appropriate, yet complex value network [14].

2.2. Sustainable mass-customization

Mass-Customisation customisation is a strategy that aims to meet specific customer needs with an efficiency close to that of mass production [15]. When industrial companies take this route, it presents both opportunities as well as challenges with respect to sustainability in the environmental, social, and economic sense. For example, while standardization and lean management practices – inherited from mass production contribute to optimizing the use of resources and reducing waste, pure customization risks running counter to these objectives when responding to the diversity of individual customer demands [16,17]. The challenge is to meet and align the objectives of mass customization and sustainability together. While there are a few selected studies available in the literature addressing the possible complementarities between mass customisation and sustainability, a shortage has been highlighted in terms of design tools and decision support methods that favour the deployment of sustainable mass customisation [16-18]. This gap can be partly explained by an implicit assumption that traditional evaluation frameworks are also valid for customised products and their production. However, customisation leads to a diversity in the range of products or services, which adds complexity to the evaluation and requires more adapted evaluation methods [19,20]. The S-MC-S (Sustainable Mass Customization – mass customization for Sustainability) project promoted the concept of sustainable mass customization and resulted in a set of decision support tools for implementing it. For instance, a set of indicators and guidelines were proposed to support the design of sustainable mass customized products [21]. However, the S-MC-S model does not consider the interactions between the various dimensions and requires a large amount of data to be successfully implemented – data that is not always readily available [18, 22]. The model proposed by [23] aims to strengthen the connection between economic and environmental issues to manage product variety. They propose a mathematical model coupled with simulation and LCA based tools to enable indicators calculation and variety management.

Most of the research works addressing sustainability and customization or customer centricity focus more on the product design phase. This aligns well with the strong impact of the decisions taken during the design phase on the whole product lifecycle. Subsequent phases such as production ramp-up received much less attention despite their potential in reinforcing agility and customer-centricity.

2.3. Ramp-up of sustainable mass-customized products

The development of sustainable customer-centric products depends on strategic, tactical, and operational decisions made during all phases of the product or service lifecycle [7]. Most of the work contributing to this issue focuses in particular on the design phase, given its impact on the whole product lifecycle.

However, at this point, the production ramp-up phase is poorly addressed despite its potential impact on successful product commercialisation. In fact, ramp-up presents an opportunity to enhance the sustainability of industrial systems, for example, through decisions on industrial strategy, portfolio management, production resources, skills, and integration of customer feedback [20,24].

Ramp-up refers to the phase of the product lifecycle that identifies and deploys the means and methods to move from the study phase to the active production phase. The decisions made during this phase have a strong impact on the company's activities [24]. These decisions relate to several aspects such as investments and capacity management [25,26], collaboration and information sharing [27], industrial strategy [28], skills and human resources [29], and quality management of the product or service in question [30]. These decisions are more complex in ramp-up than in series production for various reasons such as the uncertainty about customer demands, limited resources, and challenging process control [20,25,27,30].

3. A DSS for sustainable portfolio management during ramp-up

3.1. DSS overview

The DSS extends a previously published version in [20] by detailing the models and tools used for capturing customer data and managing product portfolio accordingly. The framework relies on three basic components meant for (i) supporting the alignment of portfolio and planning decisions with customer requirements; (ii) product/service configuration (operational horizon), data maintenance, and quotation process management (operational/tactical horizons); and (iii) variety and portfolio management (tactical horizon) (see Fig. 1).

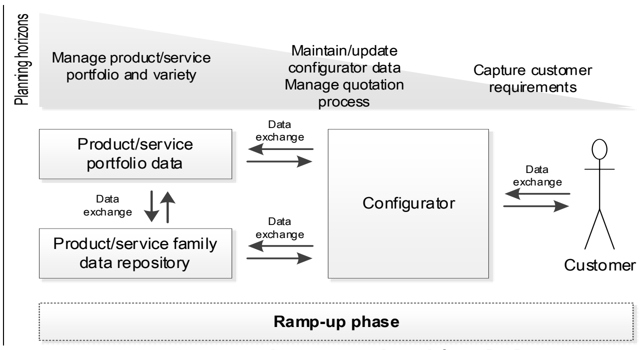


Fig. 1. Framework Design (Adapted from [20])

- *Capturing Customer Requirements* – is supported by a stepwise configuration process allowing customers to customize the product or service to be ordered. The whole process is enabled by a configurator where all feasible combinations are implemented allowing to offer a high variety to the customers. The ease of the configuration process is a key capability to facilitate choice negation for the customers [2].
- The *Quotation Process* – aims to provide economic and environmental indicators estimates based on the selected configurations and on the data about the product, process, and supply chain. Therefore, configuration data employed by the system needs to be regularly updated (e.g., bill-of-materials, processes, suppliers, cost data, materials). Economic and environmental indicators should be measurable and significant for decision-making to both the customer and the company [20].
- *Portfolio and Variety Management* – aims to collect and process data about customer orders (extracted from the configurator) and the product, process, and supply chain data to determine aggregate plans during the production ramp-up phase. It is also concerned with continuously assessing product or service architecture and standardizing as much as feasible the product and the supporting process. Analytical models are the backbone of this part of the framework [20].

3.2. Mathematical model

Several analytical models are available in the literature to support portfolio and/or variety management [20,23,31]. The proposed framework relies on linear programming to determine an aggregate production plan during the ramp-up phase. The ultimate objective is to align planning decisions with customer requirements despite the lack of data during ramp-up. The model is detailed in the following.

Notations:

i	product variant
V	set of available variants in the product portfolio
B^i	bill of material of variant i
A^i	set of operations involved in the realization of i
M^i	set of materials used to build i
F	product family
t	ramp-up period
T	set of ramp-up periods
PC^t	total production capacity during period t
D_{it}^-	lower demand limit of variant i during period t
D_{it}^+	upper demand limit of variant i during period t
P^i	unit profit margin generated by variant i
S^i	unit selling price of variant i
C^i	unit greenhouse gas emissions allocated to variant i
b_k^i	quantity of purchased component/material k used to build one unit of i
c_k	unit purchasing cost of k
a_p^i	duration of operation p to realize one unit of i
c_p	unit cost of operation p
b_j^i	quantity of material j used to build one unit of i
f_k	characterization factor of greenhouse gas emissions related to material k
nP_i	unit profit generated by variant i
nC_i	unit CO_2 emissions allocated to variant i
x_{it}	decision variable representing production volume of variant i during period t

The objective function uses weighted normalized values of profit and CO_2 emissions indicators. For a given product or service variant, the profit is obtained by calculating the difference between the selling price and unit cost (Eq. 1); CO_2 emissions are calculated based on a unit CO_2 emission associated with the raw material and with the production process (Eq. 2).

$$P^i = S^i - \sum_{k\in B^i} b_k^i \times c_k - \sum_{p\in A^i} a_p^i \times c_p \qquad (1)$$

$$C^i = \sum_{j\in M^i} b_j^i \times f_j \qquad (2)$$

The normalization of the indicators is enabled by an improved sigmoid function allowing for a pseudo-linear mapping of the original values (values between x and x_{max}) [32] as shown in Eq. 3, with $a = 2 + \sqrt{3}$ and $b = 7 - 4\sqrt{3}$.

$$G(x) = \frac{1-b^{\frac{x}{xmax}}}{ab^{\frac{x}{xmax}}+1}\ ,\ G(x) \in]0,1[\qquad (3)$$

The normalized values of P^i and C^i obtained following Eq. 3 are referred to by nP^i and nC^i. Weights are then assigned to each of the indicators which reflect the importance from the customer point of view.

The weights of the indicators are derived from the configuration data over a given time horizons. The determination of the weights depends on data availability and may use linear multiple linear regression (short/midterm) or moving average (short term).

The objective function, H is presented in Eq. 4, the aim is to maximize it. Eq. 5, 6, and 7 represent, production capacity, demand and positivity constraints, respectively.

$$H = \sum_{i\in V} \omega_p.nP^i - \omega_c.nC^i \qquad (4)$$

$$\sum_{i\in F} x_{it} \le PC^t\ ,\ \forall t \in T \qquad (5)$$

$$D_{it}^- \le x_{it} \le D_{it}^+\ ,\ \forall i \in F, \forall t \in T \qquad (6)$$

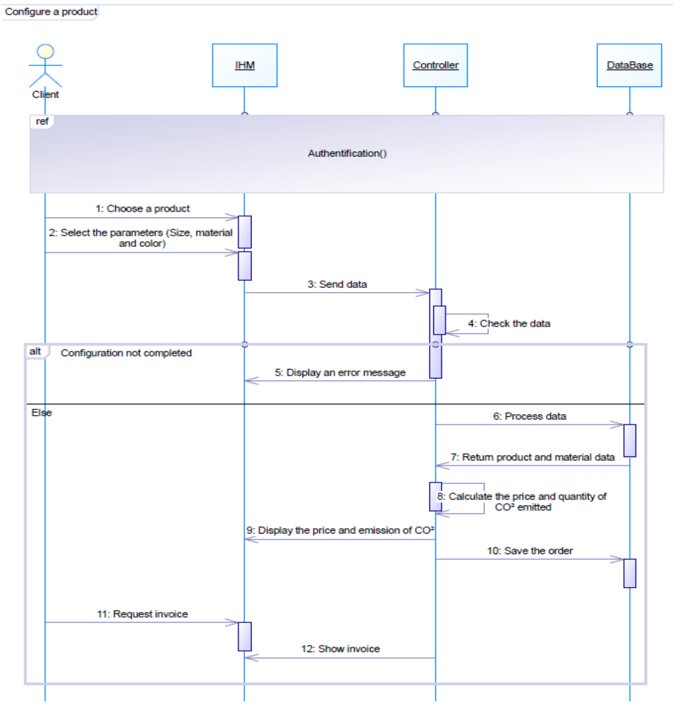
$$x_{it} \ge 0\ ,\ \forall i \in F, \forall t \in T \qquad (7)$$

3.3. Configuration and Quotation Process

A product configurator refers to a software-based expert system that supports the user in the creation of product or service specifications [33]. The literature identified several challenges for the successful development of configurators, such as resource constraints (e.g., time and effort related to configurator development projects), product complexity, IT infrastructure, and organisational burdens (e.g., acceptance within the organisation) [34]. Therefore, the development of a (product) configurator should be driven by the requirements of the business and should allow for smooth integration within the company information system as well as work procedures.

The configurator should support a clear configuration process allowing for capturing customer preferences and a transparent quotation process informing the customer of the economic and sustainability implications of the selected configuration. Fig. 2 illustrates the configuration and quotation process in a typical and basic scenario of product customization and ordering. The modelling of the scenario allows for deriving the technical requirements of the configurators.

Fig. 3 shows an excerpt of the graphical interface of the configurator with an illustrative example of a 3D printed customized product. The user is guided through the definition of the product using a set of customization attributes (e.g., colour, material, dimensions). The configurator is linked to a database where all data about material types, unit costs, and environmental characterization factors are available. This allows for providing the customer with a rough quotation (estimate) including price and CO_2 emissions associated with the selected configuration of the product highlighting the impact of certain decisions and features. The example is purposely chosen and represents a simple product that allows for a clear depiction of the potential features of the configurator. Several additional features of the configurator are not discussed in this paper since configurator development is ongoing.



** IHM: Human-Machine Interface*

Fig. 2. Sequence diagram of the configuration and quotation process

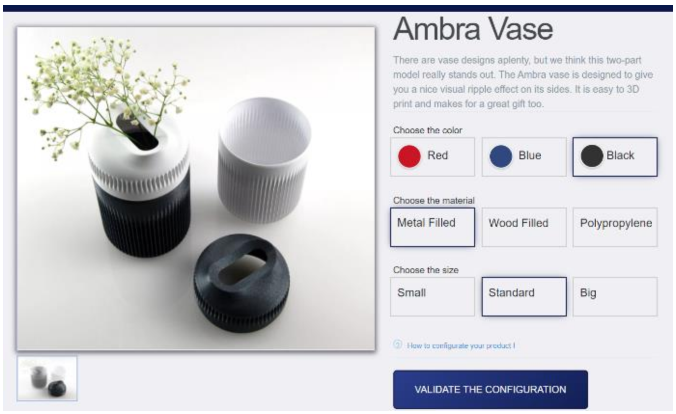


Fig. 3. Graphical Use Interface supporting choice navigation

This version of the configurator extends the work of [35], which specifies the general architecture of the configurator and provides a proof of concept. The current version involves the development of a prototype including a database of available product variants and a module for customer order and configuration process treatability.

4. Discussion and perspectives

In order to ensure long-term competitiveness, a continuous challenge for manufacturing and service companies is to combine customer-centricity with increased sustainability in the environmental, economic, and social sense [7].

The scientific literature related to project and operations management in the broadest sense highlights the lack of research works related to production ramp-up, one of the key stages of the industrialisation phase. This research gap is amplified by the current economic and social context where the development of innovative solutions has become a recurrent activity to meet demand and survive the competition. The context of the current COVID-19 health crisis illustrates the need for agility and rapid adaptation, in quantity and quality, to market changes [36,37]. In this context and at present, production ramp-up has become a key issue for which all means are deployed not only at the level of manufacturing and service companies, but also at the level of public authorities. However, decisions linked to industrialisation and production ramp-up are subject to constraints of uncertainty and urgency. Such decisions must also take into account the priority needs of the market and the specific demands of customers or groups of customers. They also have a social, societal, environmental, and economic impact that must be anticipated.

The proposed approach suggests combining product configurators with mathematical models to align the aggregate production plan based on customer orders during the ramp-up phase to inform decision makers early of the impacts of their choices and thus allow for adaptations before the associated sunk cost becomes too high. This will ultimately lead to a revised product portfolio and to align it with the market requirements before moving to series production. Therefore, the failure risk of product introduction into the market is mitigated through the quick adaptation of the portfolio to sustainability and customer requirements.

The research concerning customer-centric sustainability seems in its infancy. The current paper provides one step forward to operationalize this concept while focusing on the ramp-up phase of the product life cycle. Therefore, there is still much to be desired in terms of improvements and extension of the proposed DSS. First, the technical implementation needs to be finalized and the whole system needs to be tested. This activity is planned for within the short term. A set of customers with different preferences with regards to environmental sustainability will be selected. The configurator will be used to customize and order a 3D printed product. The mathematical model will be used to align the planned production with the demand based on customer past orders. This research is ongoing, and the test is planned for the short term.

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References

[1] Blecker, T., Abdelkafi, N. Complexity and Variety in Mass Customization Systems: Analysis and Recommendations', Management Decision, 44(7):908-929; 2006.

[2] Salvador, F., de Holan, P. M., Piller, F.T. Cracking the Code of Mass Customization. MIT Sloan Management Review, 50(3):71-78; 2009.

[3] Lyons, A., Mondragon, C., Piller, F. et al. Customer-Driven Supply Chains From Glass Pipelines to Open Innovation Networks. Edited by R. Roy. Springer London; 2012.

[4] Sarkar, P., Rachuri, S., Suh, H.W., Lyons, K., Sriram, R.D. A Measure of Product Sustainability Based on Triple Bottom Line. ASME 2009 Int'l. Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2009, San Diego, CA, https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=902061

[5] Labuschagne, C., Brent, A.C., Van Erck, R.P.G. Assessing the Sustainability Performances of Industries. Journal of Cleaner Production, 13(4):373-385; 2005.

[6] Ageron, B., Gunasekaran, A., Spalanzani, A. Sustainable Supply Management: An Empirical Study. International Journal of Production Economics, 140(1):168-182; 2012.

[7] Pardo-Jaramillo, S., Muñoz-Villamizar, A., Osuna, I., Roncancio, R. Mapping Research on Customer Centricity and Sustainable Organizations. Sustainability, 12(19):7908; 2020.

[8] Hora, M., Hankammer, S., Canetta, L. et al. Designing Business Models for Sustainable Mass Customization: A Framework Proposal Designing Business Models for Sustainable Mass Customization. International Journal of Industrial Engineering and Management, 7(4):143-152; 2016.

[9] Baldassarre, B., Calabretta, G., Bocken, N.M.P. et al. Bridging Sustainable Business Model Innovation and User-driven Innovation: A Process for Sustainable Value Proposition Design. Journal of Cleaner Production, 147(1):175-186; 2017.

[10] Bowman, C., Ambrosini, V. Value Creation versus Value Capture: Towards a Coherent Definition of Value in Strategy. British Journal of Management, 11(1):1-15; 2000.

[11] Prahalad, C.K., Ramaswamy, V. Co-Creating Unique Value with Customers. Strategy & Leadership, 32(3):4-9; 2004.

[12] Vargo, S.L., Lusch, R.F. Service-Dominant Logic: Continuing the Evolution. Academy of Marketing Science, 36(1):1-10; 2008.

[13] Bocken, N.M., Rana, P., Short, S.W. Value Mapping for Sustainable Business Thinking. Journal of Industrial and Production Engineering, 32(1):88-102; 2015.

[14] Aquilani, B., Silvestri, C., Loppolo, G. et al. The Challenging Transition to Bio-economies: Towards a New Framework Integrating Corporate Sustainability and Value Co-creation. Journal of Cleaner Production, 172:4001-4009; 2017.

[15] Pine, B.J. Mass Customizing Products and Services. Planning Review, 21(4):6-55; 1993.

[16] Pourabdollahian, G., Taisch, M., Piller, F.T. Is Sustainable Mass Customization an Oxymoron?. 7th World Conf. on Mass Customization, Personalization, and Co-Creation, Springer, pp. 301-310; 2014.

[17] Medini, K., Da Cunha, C., Bernard, A. Tailoring Performance Evaluation to Specific Industrial Contexts – Application to Sustainable Mass Customisation Enterprises. International Journal of Production Research, 53(8):2439-2456; 2015.

[18] TTS – Technology Transfer System. S-MC-S – Sustainable Mass Customization – Mass Customization for Sustainability. European Commission; 2010. Available at http://smcs.ttsnetwork.net/

[19] Barrows, G., Ollivier, H. Cleaner Firms or Cleaner Products? How Product Mix Shapes Emission Intensity from Manufacturing. Journal of Environmental Economics and Management, 88:134-158; 2018.

[20] Medini, K., Wuest, T., Romero, D. et al. Integrating Sustainability Considerations into Product Variety and Portfolio Management. Procedia CIRP, 93:605-609; 2020.

[21] Osorio, J., Romero, D., Betancur, M.C., Molina, A. Design for Sustainable Mass-Customization: Design Guidelines for Sustainable Mass-Customized Products. 20th International ICE-Conference on Engineering, Technology and Innovation, pp. 1-9; 2014.

[22] Medini, K., Bettoni A., Fontana, A., Corti, D., Zebardast, M. S-MC-S Project D3.1 – Assessment Model. European Commission, 2011.

[23] Medini, K., Boucher, X. An Approach for Steering Products and Services Offering Variety Towards Economic and Environmental Sustainability. CIRP Journal of Manufacturing Science & Technology, 15:65-73; 2016.

[24] Dal Pont, J-P. L'Entreprise Industrielle. Techniques de l'Ingénieur; 2007.

[25] Hansen, K.R.N., Grunow, M. Modelling Ramp-Up Curves to Reflect Learning: Improving Capacity Planning in Secondary Pharmaceutical Production. International Journal of Production Research, 53(18):5399-5417; 2015.

[26] Pierné, A., Medini, K., Masmoudi, M. Economic Assessment of Ramp-Up Strategies in Multi-Variant Production. MOSIM 2020, Agadir, Morocco; 2020.

[27] Fjällström, S., Säfsten, K., Harlin, U., Stahre, J. Information Enabling Production Ramp-Up. Journal of Manufacturing Technology Management, 20:178-196; 2009.

[28] Szabó, K. Ramp-Up Process Improvement Practices for Time-to-Market Reduction. Periodica Polytechnica Social and Management Sciences, 26(1):19-29; 2018.

[29] Glock, CH., Jaber, M., Zolfaghari, S. Production Planning for a Ramp-Up Process with Learning in Production and Growth in Demand. International Journal of Production Research, 50:5707-5718; 2020.

[30] Colledani, M., Tolio, T., Yemane, A. Production Quality Improvement during Manufacturing Systems Ramp-Up. CIRP Journal of Manufacturing Science and Technology, 23:197-206; 2018.

[31] Cooper, R.G., Edgett, S.J., Kleinschmidt, E.J. New Product Portfolio

Management: Practices and Performance. IEEE Engineering Management Review, 28:13-29; 2000.
[32] De Marsico, M., Nappi, M., Riccio, D., Tortora, G. NABS: Novel Approaches for Biometric Systems. IEEE Transactions In Systems, Man, and Cybernetics, Part C: Applications and Reviews, 4(41), pp. 481-493; 2011.
[33] Haug, A., Hvam, L., Mortensen, N.H. Definition and Evaluation of Product Configurator Development Strategies. Computer Industry, 63:471-481, 2012.
[34] Kristjansdottir, K., Shafiee, S., Hvam, L., Forza, C., Mortensen, N.H. The Main Challenges for Manufacturing Companies in Implementing and Utilizing Configurators. Computers in Industry, 100:196-211; 2018.
[35] Rousseau, M., Medini, K., Romero, D., Wuest, T. Configurators as a means to Leverage Customer-Centric Sustainable Systems – Evidence from the 3D-Printing Domain. Procedia CIRP, 96:103-108; 2020.
[36] Ahmad, A., Masood, T., Kousar, R. Reconfiguring and Ramping-Up Ventilator Production in the Face of COVID-19: Can Robots Help, Journal of Manufacturing Systems. https://doi.org/10.1016/j.jmsy.2020.09.008.
[37] Vogel-Heuser, B., Medini, K., Boissier, O. et al. Ramp-Up. Available at: https://www.futureindustry.org/research/advanced-manufacturing/ramp-up/