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Highlights in Customer-driven Operations Management Research

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Abstract

The evolution from mass-produced to mass-customized and even personalized products, services, and product-service bundles leads to increasing complexity of operations management. These new realities challenge companies in both business-to-business and business-to-customer markets to compete not only on the traditional basis of cost, quality, and delivery time but also on the capabilities in managing this increasing operational complexity. The objective of this paper is to identify key challenges and opportunities in managing operations in complex customer-driven manufacturing covering the value network, requirements engineering, product configuration, and the production systems, as well as the opportunities for handling these through digitally-enabled methods and tools for materializing the Industry 4.0 vision of efficient lot-size-one productions.

Keywords: Operations Management; Customer-Driven; Complexity Management; Industry 4.0; Value Network.

1. Introduction

Dynamic stakeholder requirements coming from both the customer but also from the solution environment are exerting more and more pressure on enterprises in both Business-to-Business (B2B) and Business-to-Customer (B2C) setups. This pressure is intensified by the tough competition, which goes beyond the traditional focus on price and even the Time-Cost-Quality (TCQ) triangle to span over a multitude of criteria. Therefore, *Operations Management* (OM), *as the management of systems or processes that create goods and/or provide services* [1], has evolved as well to keep up with the pace of the social and economic contextual changes. For instance, the mass-production model focusing on increasing productivity and reducing costs is no longer prevailing, as it falls short on meeting the diversified customer demands while maintaining reasonable production costs. This traditional trade-off between high-variety and low-cost is met by the paradigm of mass-customization, which focuses on integrating mass-production principles with customization towards a "customer-centric enterprise" [2]. The "mass-customization strategy" relies on three capabilities: (1) robust design of processes and production systems, (2) a well-designed solution space where the product and service portfolios are aligned with diverse customer needs, and (3) choice navigation for supporting customers in identifying solutions while minimizing

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complexity and the burden of choices [3]. These capabilities allow enterprises to cater not only large markets, but also long-tail markets where further value can be generated for both the customer (getting exactly what is needed) and the supplier (customer loyalty and higher revenues). In fact, the notion of being *customer-driven* can be seen as the "capability" to deliver individualized products or services in high-volumes. The roots of "customer-driven strategies" are in the *agility* concept, which aims for demand and production alignment, and fast production and quick delivery of products in response to change in customer demands [2].

Furthermore, for being *customer-driven,* several enterprises have geared their value propositions from mere products to a combination of products and services bundles and even mere services. This ensures a significant competitive advantage since service delivery relies often on hard-to-imitate know-how [4].

Several enterprises find themselves at the cross-section between the above-mentioned trends, when they start diversifying their value offering and extending it with services (i.e., servitization strategies [4]). This leads to an increase in "internal" complexity resulting from the "external" offering variety. For instance, the more different variants are included in the portfolio of products and/or services, the more stock-keeping-units need to be managed in traditional Make-to-Stock (MTO) models. Moreover, these variety-induced costs and challenges occur across the entire solution life cycle and value chain/network [5]. This entails also higher changeover and setup time costs, higher material planning time costs, etc. Furthermore, the workers are likely to become overstrained within such a high-variety context and the related training needs. In addition, the assignment of the production resources to the different manufacturing and service processes and even the new investments need to be carefully balanced, not to neglect any important value-creating elements.

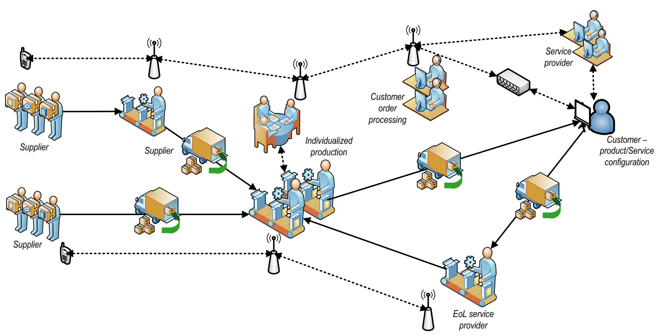

Figure 1. Manufacturing and Service Operations within Industry 4.0

Therefore, a common aim of the enterprises, regardless of where they stand in this myriad of strategies, is to keep the minimum internal variety (i.e., complexity) allowing for meeting the external variety [6]. In this sense, numerous theories have been developed and tested in practice, such as modularity, platforms, and differentiation postponement [5]. The success of their implementation depends however on a deep understanding as well as a holistic perspective spanning over a system approach of the enterprise. Emerging concepts like Industry 4.0 (I4.0) philosophy [7,8] or Smart Manufacturing seem to bring promising opportunities to address the above issues and push the *Customer-driven OM* forward. More concretely, the Industry 4.0 paradigm can be summarized in three axes, namely: (1) horizontal integration across the value network, (2) end-to-end engineering across the entire product life cycle, and (3) vertical integration and networked manufacturing systems [7,8]. Horizontal Integration refers mainly to inter- and intra-company cross-linking and digitalization of the value creation throughout the entire value chain/network. End-to-End Engineering refers to intelligent cross-linking throughout the entire product life cycle. Vertical Integration designates the cross-linking within different aggregation levels, e.g., manufacturing cell, manufacturing line, factory, etc.

Based on the developments in mass-customization and the technological environment (i.e., I4.0), this paper investigates the challenges and opportunities towards Customer-driven OM in particular in the context of Industry 4.0.

2. Research Methodology

An "explorative research" approach was adopted in order to collect preliminary information about the problem stated above. The main sources of information are scientific articles and books published during the last decade: 2010-2019. More specifically, the authors analyzed a total of 53 publications referenced in this paper, including 28 journal papers and 10 conference papers.

The analysis of the articles and books was guided by the *Collaborative Manufacturing Model (CMM)* (see Figure 2), which offers a holistic vision into the whole value network. With its different views, the CMM provides a partial but multifaceted perspective of OM. Indeed, with reference to Figure 1, CMM is quite consistent with the scope of the paper. More specifically, the following areas have been identified in our analysis and will be addressed: value and value network (i.e., value chain domain), requirements engineering (i.e., product and process design), product configuration (i.e., customer order fulfilment), and manufacturing system (i.e., plant/factory operation). This allows for a quite comprehensive overview involving the system design function of OM. For each of these domains, challenges towards customer-driven operations are analyzed and potentials related to the Industry 4.0 paradigm are investigated.

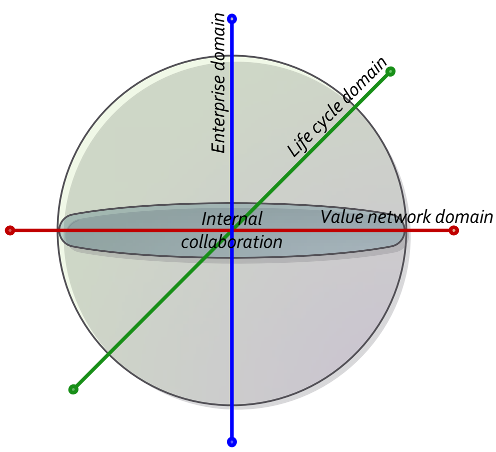

Figure 2. Collaborative Manufacturing Model (CMM) – Functional View, Adapted from [9]

3. Value Chains / Networks

The rapidly changing business context has shifted the focus of value from efficiency to a broader perspective involving other stakeholders beyond the company. For instance, the tough competition and the increasingly challenging customer requirements compelled companies to seek more sustainable value. The latter is often thought out "collaboratively" by considering different perspectives namely the market (price), the customer (satisfaction), and the traditional engineering perspective (function-cost) to name a few [10]. Furthermore, value co-creation goes beyond the boundaries of a given company and involves several stakeholders with a common objective but different expectations [11,12,13,14]. Focusing on the value for multiple stakeholders implies a paradigm shift from managing physical products manufacturing operations to managing the operations of products and services. Ultimately, physical products can be used only as a means for delivering a service, and thus to create shared value.

The main features of the value network within the Industry 4.0 environment are the decentralized structure of the value creation activities, and of the decision-making process, as well as the automation [10,15]. Examples of *Horizontal Integration* enablers include intelligent transportation systems that are able to foresee changes and adapt accordingly due to the interchange of "smart data" in a decentralized way, e.g., Automated Guided Vehicles (AGVs), RFID chips. *Vertical Integration* relies on Cyber-Physical Systems (CPSs) that are no other than "smart systems" with sensors, data processing capabilities and actuators for manipulation embedded in them for tracking and monitoring the value being created, and decentralized process(es) optimization. The communication among the different CPS' is supported by the Cloud paradigm (see Figure 3).

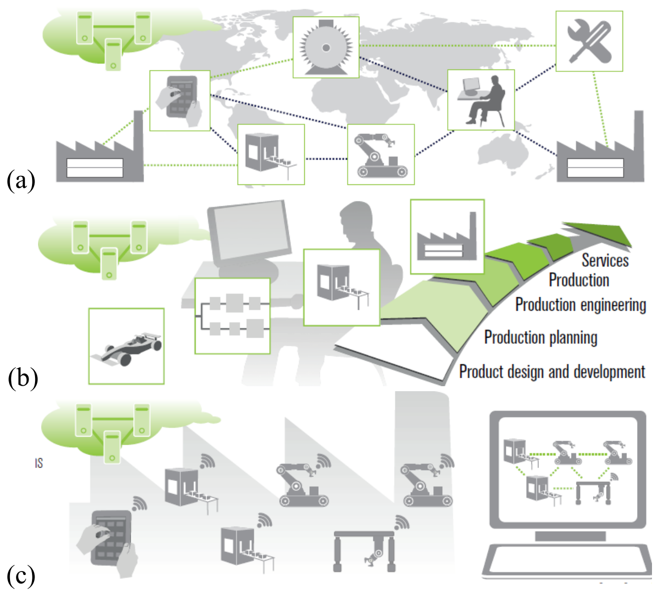

Figure 3. (a) Horizontal Integration through Value Network, (b) End-to-End Engineering across the Value Chain, and (c) Vertical Integration and Networked Manufacturing Systems [7]

4. Requirements Engineering

Customization and *personalization* will naturally lead to a higher variety of products and services, hence presenting new challenges for marketing, manufacturing, warehousing, and logistics and distribution. A highly relevant research topic is *Requirements Engineering* (RE) that sets the interface between the designer/manufacturer and the customer [16]. The importance of RE cannot be overstated for the success of a development project. For the traditional paradigm of mass-production, the large batch-size operations can look back at years of experience as well as many methods, tools and practices to support the process of soliciting, specifying, classifying, and validating requirements. These tools and practices are mostly built on statistics and generally provide good insights into the requirements of future users.

However, within Industry 4.0, the system environment of stakeholders, technology and constraints is more dynamic, and changes have an impact on the requirements for the solution. This makes *End-to-End Engineering* challenging (complex) as requirements will change over the solution life cycle. Such characteristics can be described with the elements of *VUCA* [17]: Volatility denotes strong fluctuations of a state over a relatively short period, making it hardly predictable. Uncertainty means that causal relationships of the system under consideration are known, but not their probability of occurrence to forecast future developments. Complexity describes the unpredictability of system behavior due to the abundance of elements and connections. Ambiguity refers to the obscurity of causal relationships when an event cannot be clearly assigned to a potential effect, leading to false assumptions. Hence, system engineering and development is particularly difficult under these conditions. Influences from the *volatile* system environment have a direct impact through technological interfaces, e.g., the real-time processing of big data. As future operation scenarios are often vague and can only be described by probabilities, there is uncertainty about the requirements for the solution. Furthermore, "complex systems" with a large number of different elements and connections make it impossible to predict precisely the behaviour of the system. For one-of-a-kind solutions, there is no pattern to derive requirements, leading to *ambiguous* specifications.

Thus, to determine the unique requirements of a mass-customized or personalized product or service, manufacturers need to directly connect, communicate and collaborate with small groups of target customers, if not individual customers [18,19]. Not only the customer requirements are constantly changing, but also they are oftentimes inconsistent with each other. Furthermore, today's customers are increasingly motivated to share their personal experiences on the Internet. As a result, customer requirements tend to influence each other. Lastly, requirements should be formulated in consideration of not only customer satisfaction but also various aspects of manufacturing effectiveness (e.g., quality, reliability, and productivity). The integration of requirements from different disciplines, processes, and systems will further escalate the difficulty of requirement management [20].

In short, the growing *variety* of products and/or services significantly increases the "complexity" of RE. The variety of stakeholders involved in the value network leads to exceptionally distributed activities with isolated RE approaches. This leaves requirements fragmented among many disciplines and sometimes conflicting, unstable, unknowable or not fully defined. Main topics that need to be addressed for *horizontal integration* across the value network include: involving users and other stakeholders from different domains actively in development from the beginning; adaption of the solution to needs, habits and competencies of the users; specification of formal requirements models; detailing of requirements and mapping them to system elements; and integration of mechanical engineering models with digital models from software and systems engineering for the collaborative description of requirements, as well as their implementation, validation, evolution, and communication between stakeholders from different disciplines [21].

At present, although the product and/or service variety is generally accepted as an OM problem, little efforts have been devoted to managing customer requirements in the interest of OM. Therefore, the increasing complexity of customer requirements management triggered by a product or service personalization should be incorporated into the catalogue of emerging OM problems.

Another aspect that highlights the changing nature of RE is the shift from traditional technical or business requirements to customer [22]. In other words, the purpose of mass-customization and personalization is to create new values for customers beyond simply fulfilling their requirements [23]. In the past, it has been repeatedly proven that customers not necessarily know what they need and want. As a result, it often results in a huge waste of OM resources to satisfy redundant requirements that add little value. With the shift to the more inclusive and intangible notion of 'value', it will further increase the difficulty of requirements engineering. A requirement for 'value' has to be passed down vertically into the manufacturing system (i.e., vertical integration) and broken down into functional requirements for the system and its tangible and non-tangible elements. The ability to understand individual customer voices and formulate informed requirements, and add new values for products and/or services will determine a global manufacturer's competitiveness against the trends of mass-customization and personalization.

5. Product Configuration

Configuration systems are among the most successfully applied *Artificial Intelligence (AI)* technologies in industries [24] and can be traced back to the late 1970s, where XCON was developed as an expert system supporting customers in navigating increased product variety [25]. Applications of "configurators" are numerous, ranging from internal configurators for large project-based capital goods [26] to a vast number of web-based configurators for consumer goods, such as cars and shoes (visit: http://www.configurator-database.com). The purpose of *Product Configuration Systems (PCSs)* is to enable mass-customization of products by allowing the user to combine product characteristics under a given set of constraints, thereby offering a vast range of product variants based on a global description of the product´s functional and structural design [27]. PCSs has over time developed from rule-based expert systems, like XCON, to *Mass-Customization (MC) toolkits* enabling users to design and innovate products based on diverse requirements [28]. However, current configurators and MC toolkits are still mainly based on expert system architectures [29]. In this regard, knowledge must be acquired from experts and represented in the system's knowledge base, accessible through a user interface and inferred by an inference engine hosted locally.

With increased customer-driven operations, current PCSs face various challenges, particularly in terms of providing support for optimal configurations, particularly in highly volatile environments [30], which entails both a higher degree of *End-to-End Engineering* to support configuration of market-leading product offerings and a higher degree of Horizontal Integration in the configuration process to ensure accurate information and data when choosing optimal products (e.g., data on lead-time, logistics, etc.). However, with Industry 4.0 technologies, the fundamental system architecture can now transition as described in Table 1.

Table 1 - Configuration in an Industry 4.0 Context

Today	Industry 4.0
Knowledge Acquisition	Internet of Things (IoT) & Machine Learning
Knowledge-base and Representation	Big Data Representation
Configuration Inference	Simulation/Optimization
On-premise and Server Hosting	Cloud Computing & Cybersecurity
User Interface	Augmented Reality & Digital Twins
Configuration Embedded Systems	Cyber-Physical Systems & IoT

An alternative to acquiring knowledge from experts and representing knowledge in a knowledge-base, products can transmit operating conditions from the field and store them in a *Cloud* solution [31]. This type of data is referred to as *Big Data* since data volume is significant, variety of data types such as landscape, documentation and performance output is large, and velocity of the data is high due to real-time data requirements [32]. The concept enabling the collection of data from both new product development and operations mgmt. is referred to as *the Internet of Things (IoT).* IoT is the domain of "connecting physical things to the Internet", thereby accessing operation conditions on demand and potentially re-configuring these "things" (i.e., smart connected products) via the Internet as well using *Machine Learning* as a catalyst to transform data to configuration knowledge [33]. Reaching the preferred product during the configuration process is currently archived through inference from characteristic selections, but in the context of Industry 4.0, this is instead archived through simulations and optimizations acting on big data and machine learning (i.e., *Big Data Analytics*). With product knowledge available in a *Cloud* solution, it is further possible to transform the interaction with the product portfolio into *Augmented Reality* using the *Digital Twin* concept [34] [34]. Lastly, moving from products with embedded systems to reach autonomous configuration, to CPSs configuring themselves based on, not only internal sensors but also information from interacting products and the operating environment. This enables the product to constantly obtain the optimal performance and thereby configuration in diverse fluctuating operating environments [35].

6. Factories and Manufacturing Systems

Customer-centricity in manufacturing system design and operation has evolved over many decades and can be seen as one of the main drivers of today's requirements of increased changeability on all system levels and processes [36,37]. Thus, being able to quickly adjust manufacturing systems to produce variants within part and product families, adjust to new mass-customized or even personalized offerings, as well as expanding systems to new product generations or market demands are main components of "customer-driven manufacturing" [38,39]. Thus, while previous manufacturing system paradigms relied on highly dedicated equipment and systems operated through lean principles in mass-production environments, increased customer-centricity forces factories and manufacturing systems including hardware, software, and humans to be highly flexible and agile and/or dynamically reconfigurable to meet "customer-driven changes" more efficiently, faster, and frequently [36,40]. Accordingly, manufacturing systems must be co-developed jointly with product families and platforms and modules, as well as need to incorporate not only traditional functional requirements but also "non-functional requirements" of changeability and supportive enablers of reconfigurability such as modularity and integrability [36,41]. Further, the complexity of making decisions within traditional OM areas such as process planning and scheduling, layout planning, part/product family formation, ramp-up and quality management increases as well [42].

While the concept of the *Reconfigurable Manufacturing System (RMS)* was introduced almost 20 years ago and continues to increase its relevance in manufacturing, these design and operational issues remain a challenge in the industry, where the wide realization of "reconfigurability" principles remains limited [41,43]. However, new smart technologies and digital capabilities associated with Industry 4.0 have been emphasized as having the potential to enable and elevate reconfigurability to extents not previously possible and play a vital role in its realization [36,44]. Key aspects of this may include the use of virtual commissioning, digital twins, and augmented reality to aid reconfigurations and ramp-up; advanced automation solutions that are easily reconfigured; simulation and optimization of real-time data in networked machines and products; joint configuration and modelling of products, processes and manufacturing systems; connectivity of system components and modules through the Internet of Things; additive manufacturing for increased flexibility; etc. [44,45,46]. Thus, Industry 4.0 related opportunities offer the possibility to increase *changeability* and *reconfigurability* of factories and manufacturing systems significantly, covering both higher *Horizontal* and *Vertical Integration* to provide seamless integration and coordination of inside and beyond systems and factories, and a higher extent of *End-to-End Engineering* entailing system design for change and dynamic product requirements. Thus, the concept of CPSs, autonomous reconfigurable systems, being self-adapting and self-organizing, can be viewed as an extension of the RMS concept proposed by [36] in the following way [47]:

- *Interoperability* having system modules that can be easily integrated through standard interfaces and are inter-connected is essential to enable customized production, lot-sizes of one, scalable system setups, fast ramp-up, reduction of assets, etc. Interoperability between order planning and scheduling and the actual system is also a key to achieving this goal.
- *Transparency* having transparent operations and real-time information available. For example, a digital twin of the manufacturing system, enables a faster ramp-up, quick recovery to system failures, and more reliable production. Transparency of information towards the customer and suppliers is also essential.
- *Autonomy* having system modules that are connected and can be integrated "autonomously" to suit a product's processing requirements. For example, by autonomous reconfiguration; autonomous failure detection, diagnosis and recovery; autonomous order scheduling; etc. is fundamental to achieve efficient handling of customized orders.

However, the idea of "reconfigurability" appears to be requiring a paradigm shift in the industry, as dedicated rigid and static systems are traditionally designed and operated in manufacturing enterprises [47,48]. The technological aspects of realizing this vision of smart, connected and autonomous reconfigurable systems are either present or advancing very quickly. However, the organizational, management-related and human barriers towards its realization are perhaps even more challenging and dominate. Thus, a viable first step towards meeting these challenges is to develop industry-applicable methodologies that support consideration and implementation of reconfigurability principles, such as scalability, convertibility, modularity, etc. in both new and existing systems. Having this as the foundation will likely lead to an evolution towards the implementation of an ideal Industry 4.0 reconfigurable manufacturing system.

7. New Value Stream Patterns based on Customer-driven Operations Management

An overview of the drivers spanning over the CMM dimensions is shown in Figure 4. This summary is intended to provide guidance to decision-makers in particular, within SMEs, exploring the paths to customer-driven operations.

Displaying the drivers as per the CMM model allows enlightening decision makers about new dimensions of the enterprise where the potential of Industry 4.0 comes into play. However, in order to unleash this potential both the investment policy (i) and integration issues (ii) should be addressed. Furthermore, customer value should be at the heart of the company strategy, shifting the value focus from the product function(s) to a solution or a system function(s) (iii). To this end, economic, organizational and technological perspectives should be considered holistically (iv). Next paragraphs elaborate on the points i, ii, iii, and iv, respectively.

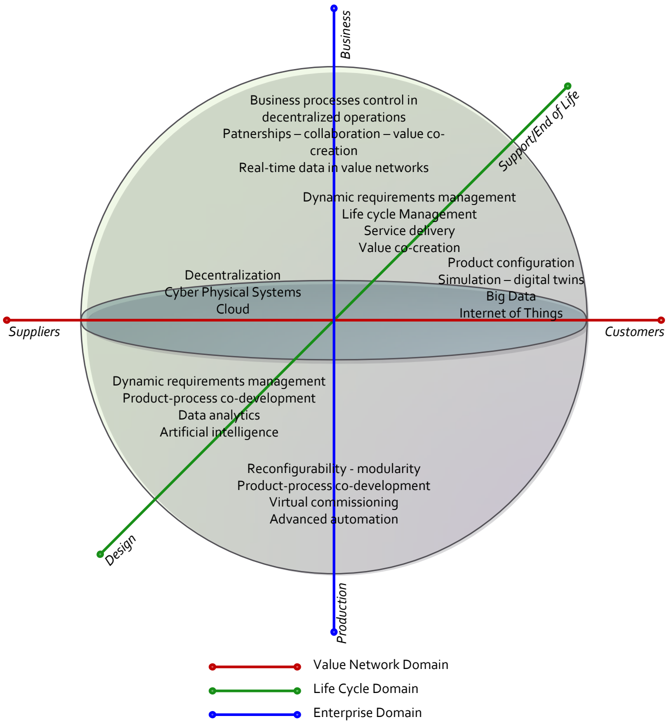

Figure 4. Overview of Industry 4.0 Drivers

The decision to invest in more IT-based processes is hindered by a lot of uncertainty regarding technical difficulty because of lack of skills and Return on Investment (ROI), for instance. Indeed, the interdisciplinary nature and complexity of the solutions require a significant investment without a full estimation of the break-even point from the start. The reliance on collaboration creates a barrier because the subsequent possibilities of process and organizational improvements are hard to measure. Therefore, a proper cost-benefit analysis is important to foster the tools and methods adoption, in particular within SMEs. This is because both, big corporations and SMEs are interested in and communicate about Industry 4.0. However, the decision to really invest is harder and with a higher risk for SMEs. In this sense, costing tools and methods should be fine-tuned to support a seamless evaluation process of the different options to pursue any initiative.

Similarly, prior to engaging in any projects, it is important to carefully study and plan the interoperability of the various systems with versatile technologies. The interfacing should be well thought out to gain in connectivity and flexibility, and to move towards more customer-driven OM. Successful application examples or lighthouse projects are a good way to analyze interoperability issues and establish benchmarks highlighting the potential of such an investment. This is quite consistent with findings from previous research highlighting the role of Industry 4.0 in a systemic performance improvement of the company [49].

Furthermore, looking at the drivers it can be inferred that services continue to play a major role in customer-driven OM. The implementation of Industry 4.0 tools can be seen as a catalyst and accelerator of this change. As a matter of fact, companies' offering in the manufacturing sector is experiencing a shift to a broader scope spanning over both products and services, taking advantage of the various possible IT services [50]. The gathering and evaluation of data support processes like design, operation or maintenance and can lead to optimized industrial value networks in the medium and long term. Manufacturing companies can create a unique selling point in an addressed market niche by offering an attractive bundle of products and services, and artificial intelligence (e.g. smart bundles), using the potential of new technologies for sensors, actuators and data processing [51]. One could speak about delivering the value to the customer instead of delivering a product and or a service. This is quite interesting as it allows to consider a new perspective for customer-driven OM, namely "value network". Variety and complexity management issues can then be addressed in a broader perspective across value network, life cycle, and enterprise. This inference is consistent with findings from [7] putting forth Industry 4.0 as a means for increasing the value through delivering mass-customized and even one-off items. Therefore, new methods, tools and practices need to be developed to (i) connect effectively with target customers to better understand and characterize the patterns of customer requirements, (ii) track the dynamic evolvement of existing requirements, and (iii) predict the future emergence of new requirements. All three tasks are perfectly aligned with the key missions of Industry 4.0, for which, data analytics and artificial intelligence play critical roles.

In order to provide value to the customer along the complete lifecycle, both the technological as well as the economic perspective have to be considered. The combination of Industry 4.0 technology with innovative business models has the potential to enable new and innovative value propositions. Their relationship can be seen as interdependent, or symbiotic. When looking from a technological perspective, the physical and ICT domains are complemented with services to deliver the solution. From a business perspective, Industry 4.0 enables smart services and new business models [23]. As such, the extended technical opportunities have to be applied in a way to enhance customer value. Furthermore, the possibility to measure usage and performance of the system supports business models based on value delivery, guaranteeing the availability of the system or pay-per-use models. Along the life cycle of such a system, stakeholders, scope and configuration will change, and consequently, this affects the overall solution design. Therefore, OM requires a permanent orchestration of distributed product, service and information technology elements adapted to a dynamic environment [52].

Several of the identified drivers are in the focus of applied research and prototypical implementations. The realization of value-driven, one-of-a-kind solutions, for example, needs fully dynamic cross-company value networks that can be configured for the required competencies and capacities in a minimum of time [53]. In these cases, however, there are barriers to a rapid response, such as finding one or more partners with free capacities or the high manual effort required to integrate new suppliers into existing ordering and logistics processes. A current German research project is working on supporting the dynamic formation of value networks by means of a modular broker service system. This includes the matching of supply and demand for short-term availability of production capacities while at the same time ensuring the necessary transport capacities through the short-term onboarding of suppliers, i.e. rapid integration production, logistics and quality assurance and the possibility of making complex assembly activities compatible for outsourcing [54]. Another example focusing on the customer side is the use of a *Virtual Reality (VR) digital twin* to involve the customer into solution development and train him/her for operation before delivery of the physical product.

8. Concluding Remarks

The dawn of “Industry 4.0” provides a favorable and nurturing climate for improving “customer-driven OM”. This includes manufacturing, services as well as integrated manufacturing-services OM. This impact on OM goes beyond being purely technology-based, but the human element remains crucial. An example is the case of requirements engineering, where for example a human expert has to interpret the increasingly available data and label the data set in order to utilize the power of supervised machine learning. This paper sheds more light on the tools and practices supporting customer-driven OM within the Industry 4.0 context. The results of the paper are likely to enlighten decision-makers during the early investigation steps prior to adopting any of Industry 4.0 tools. The content of this paper complements the literature by putting together customer-driven OM and Industry 4.0. However, there are open research issues, in particular, a full roadmap supporting companies and particularly SMEs.

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9. References

[1] Stevenson, W.J. Operations Management. 9th Edition, New York: McGraw-Hill/Irwin; 2007

[2] Lyons, C.A., Mondragon, A.C., Piller, F., Poler, R. Customer-Driven Supply Chains: From Glass Pipelines to Open Innovation Networks, London: Springer Verlag; 2012

[3] Salvador, F., Holan, P.M., Piller F. Cracking the Code of Mass Customization. MIT Sloan Management Spring Issue; 2009

[4] Baines, T., Ziaee Bigdeli, A., Bustinza, O.F., Shi, V.G., Baldwin, J., Ridgway, K. Servitization: Revisiting the State-of-the-Art and Research Priorities. International Journal of Operations & Production Management, 37(2):256-278; 2017

[5] ElMaraghy, H., Schuh, G., ElMaraghy, W., Piller, F., Schonsleben, P., Tseng, M., Bernard, A. Product Variety Management. CIRP Annals 62(2):629-652; 2013

[6] ElMaraghy, W., ElMaraghy, H., Tomiyama, T., Monostori, L. Complexity in Engineering Design and Manufacturing. CIRP Annals 61(2):793-814; 2012

[7] Kagermann, H., Wahlster, W., Helbig, J. Recommendations for Implementing the Strategic Initiative Industry 4.0. Francfort: Acatech – National Academy of Science and Engineering; 2013.

[8] Stock, T., Seliger, G. Opportunities of Sustainable Manufacturing in Industry 4.0. 13th Global Conference on Sustainable Manufacturing; 2016.

[9] Gorbach, G., and Nick, R. Collaborative Manufacturing Management Strategies, Whitepaper, ARC Advisory Group; 2002

[10] Kaihara, T., Nishino, N., Ueda, K., Tseng, M., Vancza, J., Schonsleben, P., Teti, R., Takenaka, T. Value Creation in Production: Reconsideration from Interdisciplinary Approaches. CIRP Annals 67(2):791-813; 2018.

[11] Ramaswamy, V., and Ozcan, K. The Co-Creation Paradigm: Stanford University Press; 2014

[12] Romero, D., Molina, A. Collaborative Networked Organisations and Customer Communities: Value Co-Creation and Co-Innovation in the Networking Era. Journal of Production Planning & Control, 22(5-6):447-473; 2011

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

[14] Medini, K., Boucher, X., Peillon, S., Vaillant, H., Economic Assessment of Customer-driven Value Networks for PSS Delivery. International Conference on Advances in Production Management Systems, Seoul, Korea; 2018.

[15] Mittal, S., Khan, M.A., Romero, D., Wuest, T., A Critical Review of Smart Manufacturing & Industry 4.0 Maturity Models: Implications for Small and Medium-sized Enterprises (SMEs). Journal of Manufacturing Systems, 49, 194-214; 2018

[16] Wiesner, S., Peruzzini, M., Hauge, J.B., Thoben, K.-D. Requirements Engineering. Concurrent Engineering in the 21st Century: Foundations, Developments and Challenges, Springer, pp. 103-132; 2015

[17] Bennett, N., Lemoine, G.J. What a Difference a Word Makes: Understanding Threats to Performance in a VUCA World. Business Horizons 57(3): 311-317; 2014

[18] Cavalieri, S., Pezzotta, G. Product–Service Systems Engineering: State of the Art and Research Challenges. Computers in Industry, 63(4):278-288; 2012

[19] Pezzotta, G., Cavalieri, S., Romero, D. Engineering Value Co-creation in Product-Service Systems, Section 1, Chapter 2, Handbook of Research on Strategic Alliances and Value Co-Creation in the Service Industry, IGI Global, 22-36; 2017

[20] Ncube, C.: On the Engineering of Systems of Systems: Key Challenges for the Requirements Engineering Community. Workshop on Requirements Engineering for Systems, Services and Systems-of-Systems, Trento, Italy, pp. 70-73; 2011

[21] Geisberger, E., Broy, M. CPS: Integrierte Forschungsagenda Cyber-Physical Systems, Berlin, Heidelberg; 2012

[22] Bertoni, M., Rondini, A., Pezzotta, G. A Systematic

Review of Value Metrics for PSS Design. Procedia CIRP, 64:289-294; 2017

[23] Hehenberger, P., Vogel-Heuser, B., Bradley, D., Eynard, B., Tomiyama, T., Achiche, S. Design, Modelling, Simulation and Integration of Cyber-Physical Systems: Methods and Applications. Computers in Industry, 82:273-289; 2016

[24] Russell, S., Norvig, P. Artificial Intelligence: A Modern Approach; 3rd ed. New Jersey: Pearson Education, Inc.; 2010

[25] McDermott, J. R1: A Rule-based Configurer of Computer Systems. Artificial Intelligence, 19(1):39-88; 1982.

[26] Hvam, L., Pape, S., Nielsen, M.K. Improving the Quotation Process with Product Configuration. Computers in Industry, 57(7):607-621; 2006

[27] Oddsson, G., and Ladeby, K.R. From a Literature Review of Product Configuration Definitions to a Reference Framework, AIEDAM, 28(4):413-428; 2014

[28] Franke, N., and Piller, F. Key Research Issues in User Interaction with User Toolkits in a Mass-Customisation System. International Journal of Technology Management, 26(5/6): 578-599; 2003

[29] Hvam, L., Mortensen, N.H., Riis, J. Product Customization. SpringerVerlag, Berlin; 2008

[30] Christensen, B., Brunoe, T. Product Configuration in the ETO and Capital Goods Industry: A Literature Review and Challenges. Customization 4.0, 423-438; 2018.

[31] Porter, M.E., Heppelmann, J.E. How Smart, Connected Products Are Transforming Companies, Harvard Business Review, 94(1-2):24-24; 2016

[32] Hilbert, M. Big Data for Development: A Review of Promises and Challenges, Development Policy Review, 34(1): 135-174; 2016

[33] Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M. Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions. Future Generation Computer Systems, 29:1645-1660; 2013

[34] Feiner, S., Macintyre, B., Seligmann, D.D. Knowledge-Based Augmented Reality. Communications of the ACM, 36(7):53-62; 1993

[35] Nie, K., Yue, T., Ali, S., Zhang, L., Fan, Z. Constraints: The Core of Supporting Automated Product Configuration of Cyber-Physical Systems. Model-Driven Engineering Languages and Systems, Springer, 370-387; 2013

[36] Koren, Y., Gu, X., Guo, W. Reconfigurable Manufacturing Systems: Principles, Design, and Future Trends. Frontiers of Mechanical Engineering, 13(2):121-136; 2018

[37] ElMaraghy, H. Smart Changeable Manufacturing Systems, Procedia CIRP, 28:3-9; 2019

[38] Urbani A., Molinari-Tosatti L., Bosani R., Pierpaoli F. Flexibility and Reconfigurability for Mass-Customization. In: Tseng M.M., Piller F.T. (Eds.), The Customer-Centric Enterprise. Springer, Berlin, Heidelberg; 2010

[39] ElMaraghy, H., Azab, A., Schuh, G., Pulz, C. Managing Variations in Products, Processes and Manufacturing Systems. CIRP Annals, 58(1): 441-446; 2009

[40] Gershwin, S.B. The Future of Manufacturing Systems Engineering. International Journal of Production Research, 56(1-2):224-237; 2018.

[41] Andersen, A.L., ElMaraghy, H., ElMaraghy, W., Brunoe, T., Nielsen, K. A Participatory Systems Design Methodology for Changeable Manufacturing Systems. International Journal of Production Research, 56(8):2769-2787; 2018

[42] Bortolini, M., Galizia, F.G., Mora, C. Reconfigurable Manufacturing Systems: Literature Review and Research Trend. Journal of Manufacturing Systems, 49: 93-106; 2018

[43] Maganha, I., Silva, C., Ferreira, L.M. Understanding Reconfigurability of Manufacturing Systems: An Empirical Analysis. Journal of Manufacturing Systems, 48:120-130; 2018

[44] Singh, A, Gupta, S, Asjad, M, Gupta, P. Reconfigurable Manufacturing Systems: Journey and the Road Ahead. International Journal of System Assurance Engineering and Management, 8:1849-1857; 2017

[45] Mortensen, S.T., Madsen, O. Operational Classification and Method for Reconfiguration & Recommissioning of Changeable Manufacturing Systems on System Level. Procedia Manufacturing, 28:90-95; 2018

[46] Napoleone, A., Macchi, M., Pozzetti, A. A Literature-Based Analysis of the Cyber-Physical Systems Under the Lens of Reconfigurability. International Conference on Advances in Production Management Systems, Seoul, Korea; 2018.

[47] Andersen, A.L., Larsen, J.K., Brunoe, T., Nielsen, K., Ketelsen, C. Critical Enablers of Changeable and Reconfigurable Manufacturing and their Industrial Implementation. Journal of Manufacturing Technology Management, 29(6):983-1002; 2018

[48] Rosio, C., Bruch, J. Exploring the Design Process of Reconfigurable Industrial Production Systems: Activities, Challenges, and Tactics. Journal of Manufacturing Technology Management, 29(1):85-103; 2018

[49] Fettermann, D.C., Cavalcante, C.G., Almeida, T.D., Tortorella, G.L. How does Industry 4.0 Contribute to Operations Management? Journal of Industrial and Production Engineering, 35(4):255-268; 2018

[50] Qu, M., Yu, S., Chen, D., Chu, J., Tian, B. State-of-the-Art of Design, Evaluation, and Operation Methodologies in Product-Service Systems. Computers in Industry, 77:1-14; 2016

[51] Thoben, K.D., Wiesner, S.A., Wuest, T. “Industrie 4.0” and Smart Manufacturing – A Review of Research Issues and Application Examples. International Journal of Automation Technology, 11(4):4-19; 2017

[52] Wiesner, S., Thoben, K.-D. Cyber-Physical Product-Service Systems. Multi-Disciplinary Engineering for Cyber-Physical Production Systems, Springer Cham, 63-88; 2017

[53] Romero, D., Cavalieri, S., Resta, B. Green Virtual Enterprise Broker: Enabling Build-to-Order Supply Chains for Sustainable Customer-Driven Small Series Production. Innovative and Knowledge-based Production Management in a Global-Local World, IFIP, AICT 439, Springer, 431-441; 2014

[54] DPNB; 2019 - https://www.dpnb.de/en/