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Mass Personalization with Industry 4.0 by SMEs: a concept for collaborative networks

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Abstract

Industry 4.0 (I4.0) increases flexibility of production processes to fabricate products with a level of customization that resembles the era of crafts manufacturing. Despite global competition, Personalization is a differentiation strategy applied by manufacturers to remain distinctive. By incorporating personalized products next to their core products, Small-, and Medium sized Enterprises (SMEs) can respond to the demand for personalized products where individualization adds value. Yet, personalization comes along with high variation due to small series, or even individually unique products. To cope with this variation, SMEs need cost-effective, intuitive solutions to benefit from I4.0 involving minimal efforts. This study presents a concept increasing the capacities of SMEs to capitalize on mass personalization via a collaborative network.

Keywords: Mass Customisation; Personalisation; Collaborative Network; Distributed Manufacturing

1. Introduction

Since the emergence of mechanical production in the 1850s, the manufacturing industry went through various production strategies (e.g., Fordism induced standardization, and Lean improved consistent product quality), thereby production volumes increased and variety reduced [1, 2]. During the late 1980s, mass customization emerged as a strategy that pursues differentiation against near mass production costs [3]. Thereby, mass customization relies on modularization of products, flexible processes and a close integration of supply chain partners, including the customer [4]. In recent years, the demand for personalized products and services increased because more consumers desire an individualized experience [5]. Responding to this trend requires manufacturers to pass the current

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limitations of mass customization, which is deemed to be possible by adopting the principles of a new production strategy called Industry 4.0 (I4.0) [6].

I4.0 was announced in 2011 as a strategy by the German government to sustain the competitiveness of the manufacturing industry [7, 8]. While equivalent strategies have been developed, the German initiative has obtained the most awareness according the number of results from academic search engines (2509), compared to e.g., Smart Industry (79), Smart Manufacturing (792) or Industrial Internet of Things (566). Hence, I4.0 is conceivable as a collective name for self-controlling and self-optimizing production environments that allow firms to better cope with the high variety of small series up to lot size one, and servitisation in manufacturing with innovative business models [9-12]. In general, large enterprises actively pursue I4.0, but the attitudes of SMEs towards I4.0 vary widely, while some appear reluctant, others embrace I4.0 to become leading in their industry [13]. Challenges for SMEs include limited financial resources, staff qualification, and transferring the benefits of I4.0 from vision to practice since most I4.0 findings are based on laboratory experiments [14]. Hence, a knowledge gap is perceived to contribute to solving current challenges of SMEs due to mass customization with I4.0 with cost-effective solutions [15].

From experiences in practice, I4.0 is often regarded as a marketing term instead of an industrial revolution because I4.0 builds upon existing technologies, albeit combined in new ways. Despite these different opinions, investigating how I4.0 can add value to organizations seems more meaningful than a debate about whether I4.0 is a revolution. Likewise, reducing costs of customization, increasing flexibility and quality control, while keeping times-to-market competitive to mass production, are convincing incentives for SMEs to consider adopting I4.0 practices. Hence, this article applies a pragmatic view by exploring how I4.0 is expected to contribute to handling variation efficiently and cost-effectively within local producers of personalized products.

Developing a new production strategy that is adaptable by a wide range of SMEs, should be divided in clear stages. In doing so, this paper takes the first step by identifying existing literature on the intersection of SMEs, mass customization, and I4.0. It concentrates on businesses that aspire to offer personalization in addition to their core products and aims to conceptualize how mass personalization could work. Hence, this paper is structured as follows. First, the differences between I4.0 and current production methods, so-called Industry 3.0 (I3.0), are outlined. Next, the challenges perceived by SMEs and the challenges of personalized production with I4.0 are addressed. Followed by an explanation of horizontal and vertical integration in the context of I4.0. The paper closes with a conceptualization of a collaborative network to let manufacturers cope with variety, and a conclusion.

2. Industry 4.0 and difference from Industry 3.0

Since plenty of I4.0 definitions are available (see for instance [11, 16-19]), it is not our intention to add another definition. Yet, for many companies it is unclear how I4.0 distinguishes from I3.0. Therefore, Table 1 briefly summarises the differences between I3.0 and I4.0 in manufacturing. Technology-wise the transition from I3.0 to I4.0 is arguably a gradual development that has taken place over the last few decades. However, how technology is applied in I4.0, by connecting all systems from shop-floor to enterprise level, is radically different than before.

Table 1 Comparison between characteristics of Industry 3.0 and Industry 4.0 in manufacturing

Characteristic	Industry 3.0	Industry 4.0
Processes	Automation	Autonomous decision making
Industry defining technology	Industrial robots	Collaborative robots
Production planning	Demand forecasting	On-Demand manufacturing
Alignment	Interconnection of production processes	Interconnection of the whole value chain
Variation	Delimited variation	Individually unique products
Goal	Efficiency	Flexibility
Base for revenue model	Selling products	Servitisation

3. Small- and Medium Enterprises

Nowadays, a decade after the financial crisis of 2008, the manufacturing sector in the European Union (EU) has almost been restored to its initial peak level [20]. Yet, despite the recovery of the sector, the competitive position of manufacturing is threatened by both low-wage countries, and advanced competitors. Hereby, SMEs play an important role, because in the EU manufacturing industry, which predominantly consists of SMEs, accounts for 21 % of the GDP and 20 % of employment by providing over 30 million jobs in 230.000 businesses [21]. External threats provide incentive to SMEs in the EU manufacturing industry to stay competitive. Thereby SMEs could distinguish themselves by focusing on areas with potential growth, high-margin products, extensive automation to reduce excess costs, and servitisation [22].

4. Ultra-Personalized Products and Services

Personalization lets businesses adapt a differentiation strategy to compete on added value for the customer instead of competing on price. Ultra-Personalised Products and Services (UPPS) are examples of focussing on added value. UPPS belong to a market segment which involves products tailored to the needs of the individual in small series, up to lot size one. By customising products and services and thereby delivering a more personal experience, UPPS add more value to the customer than standard offerings. Although personalisation itself is not a new concept, in recent years, additive manufacturing and collaborative robots (cobots) have become accessible to a broad audience. and up to the year 2025, prices of cobots are expected to decline by 3-5% annually [23]. Moreover, due to additive manufacturing UPPS deliver a level of personalisation at an affordable price that was not possible in the past [24]. In addition to decreasing acquisition costs, the market for personalisation is expected to grow because consumers have become more demanding [5, 25].

Figure 1 shows three examples of existing UPPS. Figure 1a shows a “super thumb” for assembly workers that reduces the tension on their hands. The super thumb is individualised with 3D-scanning and additive manufacturing to fit each worker’s hand seamlessly. Figure 1b depicts a legging with sensors for women that measures their body size at different places. Based on these measurements, an app recommends jeans that will fit best from a catalogue of brands, so hereby a personalised service is offered for common products. Finally, Figure 1c displays a personalised ring for which the customer supplies the text. The three examples demonstrate that the level of customisation achieved by UPPS exceeds the level of customisation that is currently conventional in production.

Figure 1 Existing UPPS: (a) super thumb [26]; (b) smart leggings [27]; (c) personalised ring [28].

5. Challenges for personalised production with I4.0

The large emphasis on design of UPPS introduces challenges related to manufacturability and supply chains. In fact, the inclusion of the customer as co-designer increases the number of stakeholders and a high degree of design freedom poses challenges for material- and production planning. Ideally, design choices are communicated in real-time to all involved parties to monitor the decisions' effects on, for instance, manufacturability, costs or throughput time. When this information is accessible to suppliers, manufacturers and clients, unnecessary costs are avoidable, and time-to-market will be transparent. This sketched scenario to address the challenges of mass personalisation is expected to become feasible with the implementation of I4.0 innovations. Although I4.0 is expected to make personalisation more efficient, SMEs should consider for which products, or product components individualisation adds value since offering personalised products does not always imply more profitable products.

SMEs are widely regarded as capable innovators due to their flat organisational structure and are more flexible to change than large corporations [13]. While SMEs lack the financial resources of large enterprises and have less capacity in terms of human capital to conceptualise new knowledge, they still aspire to benefit from the advantages of I4.0. Thus, SMEs are expectedly inclined to implement existing intuitive and cost-efficient solutions that are developed elsewhere or applied in other companies.

SMEs that embrace open innovation by mutually sharing proofs of concepts of new technologies, are expected to end up with a stronger competitive position than SMEs that develop innovations individually. A survey among 152 SMEs in German speaking countries indicated that 32,5% was involved in open innovation [29]. Due to shorter product life cycles and growing dependency on networks for innovation resources, it is expected that open innovation will be increasingly embraced by SMEs [30]. Despite, a probable threat for open innovation is the reluctance towards information sharing between companies in the same core business, but since UPPS are so diverse, direct competition is less likely compared to manufacturers of common goods. Therefore, open innovation in a broad sense, from exchange of know-how to capacity sharing, is likely a suited method for developing easily implementable, cost-efficient and generalisable solutions across different fields, to enable SMEs to take advantage of I4.0.

Currently, the highest adoption rates by SMEs are found within the least expensive and least revolutionary I4.0 technologies such as simulation and cloud computing, whereas Cyber-Physical Systems, Machine-to-Machine communication and cobots are still mostly unexplored, expectedly, because of their long return on investment and the involved financial risks induced to the organisation [31]. However, instead of building a production facility from scratch, SMEs could consider upgrading their current equipment or by replacing the most critical machines first, thereby, transition costs can be spread over a longer period.

This can be translated to the following, personalised manufacturing with I4.0 in SMEs involves the following challenges: a transition from business models that engage customer pull instead of market push; efficiently manufacturing small series up to lot size one; integrating the customer in the production process; preparing employees for a change of required skills; and keeping time-to-market competitive to mass customisation while drawing upon cost-effective and intuitive solutions.

6. Horizontal and Vertical integration

Horizontal and vertical and integration are mentioned as the two necessary integration features that businesses should pursue to achieve I4.0 [16]. Vertical integration, see Figure 2, describes the cross-linking of the hierarchical levels within a single organisation by the exchange of information between machines, products, Manufacturing Executing Systems (MES) and Enterprise Resource Planning (ERP). Horizontal integration refers to information sharing between multiple organisations of the value chain whereby a network beyond the company's borders is formed, for instance between sellers and buyers, but also between manufactures from different core businesses. For both types of integration, interoperability is an essential condition, which is realisable only when information exchange is standardised.

Vertical integration is arguably a prerequisite for horizontal integration because sharing information with external partners seems more meaningful when the interplay between internal processes is well understood. In addition, unlike improving internal processes, firms appear reluctant to share information with the outside world, whereby current providers of data analysis (e.g., Google Cloud, Microsoft Azure, SAP) capitalise this reluctancy and simultaneously seize the potential benefits of horizontal integration from individual businesses. Existing literature on I4.0 acknowledges the need for horizontal integration, but it is generally regarded as a form of mutual collaboration or as a new way of competition through supply chain networks [6]. This leads to the shortcoming of these holistic views in which cooperation expectedly adds value on the long term; they provide little incentive for companies on short-term notice. Therefore, a different view is desired that provides businesses short-term incentives for horizontal integration.

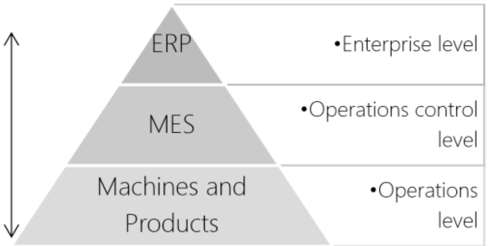

Figure 2 Vertical integration within an individual organisation (adapted from: [32]).

7. Collaborative Network

It is expected that organisations that consider offering personalised products in addition to their core business want to devote as little time and funds as possible to their niche. To summarise, businesses want to reap the benefits of personalisation, but not its limitations. Moreover, due to a rising trend for personalisation, other companies across various branches of the manufacturing industry, will likely face the same challenges since they share the need to respond to a high degree of variation. Hereby, horizontal integration via a collaborative network between companies that have the personalisation of a part of their product range in common, could contribute by providing a solution for handling variety.

A collaborative network is a collective name for networked entities, inter or intra organisational, that collaborate to achieve collective or compatible goals [32]. For SMEs it is already common to join a network, so this seems an adequate approach [33]. Figure 3 illustrates a collaborative network for the interchange of knowledge and tools based on supply and demand, as a possible solution for this purpose. It is assumed that due to the high variation of on-demand manufacturing, organisations often experience alternately excess capacity or shortages. To better cope with variety, companies within the network could, for instance, outsource the production of personalised parts to other participating SMEs with similar production facilities. When production capacity is easily tradable, the physical barriers of the factory will disappear to facilitate distributed manufacturing between the connected firms.

The collaborative network for distributed manufacturing can be understood as a complicated algorithm that optimises throughput time and monitors quality, fuelled by the information flow provided by a network of SMEs. When the information exchange within the collaborative network is based on open standards (e.g., for reading machine data), then the networked SMEs themselves are in control of the information flow to reap the benefits of data analysis instead of external enterprises. Contrary to current suggestions for horizontal integration with prospective long-term benefits, the collaborative network presented in this study provides direct financial incentive to SMEs because the network allows them to sell excess production capacity to reduce machine downtime or buy additional production capacity to satisfy unexpected demand.

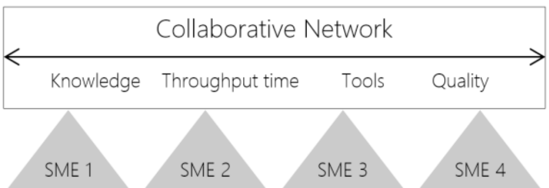

Figure 3 Horizontal integration between vertically integrated SMEs via a Collaborative Network.

8. Conclusion

I4.0 enables increased flexibility of production processes to fabricate products with a high level of customisation that resembles the era of crafts manufacturing. This is especially applicable to SMEs due to their agile nature. I4.0 allows manufacturers to respond to the trend of increasing customisation, since customers attribute a higher added value to personalised products and services than standard offerings. By focusing on high-margin products and innovation in production processes, SMEs can sustain their competitive advantage over international competitors by delivering customised products with low waiting times for customers. However, the added difficulties that this strategy generates require concepts that are supported across the manufacturing industry. Hence, this paper conceptualises a collaborative network a cost-effective concept based on open standards to make horizontal integration (one of the key enablers of I4.0) more attractive to SMEs. It is expected that a collaborative network increases the responsiveness and flexibility of individual firms by making production capacity tradeable. Implementing horizontal integration will require more research on integration between product specifications, machine data and manufacturing execution and enterprise resource planning systems by research on developing harmonised standards (e.g., [34]) but also research on preventing opportunism in collaborative networks. In addition, further research is needed to investigate to which degree and for which types of products, personalisation is expectedly profitable.

9. Next UPPS

This paper is part of Next UPPS, the Integrated design methodology for Ultra Personalised Products and Services. Next UPPS is a collaborative project between three Dutch technical universities: TU Delft, TU Eindhoven and University of Twente. The project comprises the successive phases of personalised products, from analyse to use. Hereby Delft focuses on analysis, Eindhoven on design, and Twente on manufacturing and supply chains. The collaborative network is an initial conceptualisation to explore how businesses can cost-effectively offer personalisation in addition to their core products.

References

[1] Y. Koren, X. Gu, W. Guo. Reconfigurable manufacturing systems: Principles, design, and future trends. Frontiers of Mechanical Engineering. 2018;13(2):121-36.
[2] Y. Koren. The global manufacturing revolution: product-process-business integration and reconfigurable systems: John Wiley & Sons; 2010.
[3] D. Mourtzis. Challenges and future perspectives for the life cycle of manufacturing networks in the mass customisation era. Logistics Research. 2016;9(1):1-20.
[4] F. S. Fogliatto, G. J. C. da Silveira, D. Borenstein. The mass customization decade: An updated review of the literature. International Journal of Production Economics. 2012;138(1):14-25.
[5] C. Fenech, B. Perkins. Made-to-order: The rise of mass personalization. The Deloitte Consumer Review. 2015;11(1).
[6] M. Brettel, N. Friederichsen, M. Keller, M. Rosenberg. How virtualization, decentralization and network building change the manufacturing landscape: An industry 4.0 perspective. International Journal of Mechanical, Industrial Science and Engineering. 2014;8(1):37-44.
[7] H. Kagermann, W.-D. Lukas, W. Wahlster. Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution. VDI nachrichten. 2011;13:11.
[8] B. Bunse, H. Kagermann, W. Wahlster. Industry 4.0: Smart Manufacturing for the Future. Germany Trade and Invest. 2014.
[9] J. Huxtable, D. Schaefer, editors. On Servitization of the Manufacturing Industry in the UK. Procedia CIRP; 2016.
[10] G. Bressanelli, F. Adrodegari, M. Perona, N. Saccani. Exploring how usage-focused business models enable circular economy through digital technologies. Sustainability (Switzerland). 2018;10(3).
[11] H. Lasi, P. Fettke, H.-G. Kemper, T. Feld, M. Hoffmann. Industry 4.0. Business & Information Systems Engineering. 2014;6(4):239-42.

[12] L. Monostori. Cyber-physical production systems: Roots, expectations and R&D challenges. Procedia CIRP. 2014;17:9-13.
[13] J. M. Müller, O. Buliga, K.-I. Voigt. Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. Technological Forecasting and Social Change. 2018.
[14] Y. Liao, F. Deschamps, E. d. F. R. Loures, L. F. P. Ramos. Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal. International Journal of Production Research. 2017;55(12):3609-29.
[15] Mittelstand 4.0-Kompetenzzentrum Dortmund. So geht digitalisierung Erfolgsgeschichten aud dem Mittelstand. Digital in NRW. 2017.
[16] H. Kagermann, J. Helbig, A. Hellinger, W. Wahlster. Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry; final report of the Industrie 4.0 Working Group: Forschungsunion; 2013.
[17] T. D. Oesterreich, F. Teuteberg. Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. Comput Ind. 2016;83:121-39.
[18] R. Schmidt, M. Möhring, R.-C. Härting, C. Reichstein, P. Neumaier, P. Jozinović, editors. Industry 4.0-potentials for creating smart products: empirical research results. International Conference on Business Information Systems; 2015: Springer.
[19] D. Kolberg, J. Knobloch, D. Zühlke. Towards a lean automation interface for workstations. International Journal of Production Research. 2017;55(10):2845-56.
[20] Eurostat. Industrial production (volume) index overview 2018 [Available from: http://ec.europa.eu/eurostat/statistics-explained/index.php/Industrial_production_(volume)_index_overview#Main_statistical_findings.
[21] European Commission. Innovation in Manufacturing [Available from: http://ec.europa.eu/research/industrial_technologies/innovation-in-manufacturing_en.html.
[22] G. Lay, G. Copani, A. Jäger, S. Biege. The relevance of service in European manufacturing industries. Journal of Service Management. 2010;21(5):715-26.
[23] Barclays. The facts about Co-Bot Robot sales. 2016.
[24] Fieldlab UPPS. 2016 [Available from: http://www.upps.nl/.
[25] L. Thomas. From mass production to mass personalization: Hewlet Packard; 2017 [Available from: https://hpmegatrends.com/from-mass-production-to-mass-personalization-1ad6746dc24d.
[26] BMW. Ergonomics from the 3D printer 2014 [Available from: https://www.bmw.com/en/innovation/3d-print.html.
[27] LikeAGlove. LikeAGlove smart legging 2014 [Available from: http://likeaglove.me/.
[28] SUUZ. SUUZ Personal Jewelry 2012 [Available from: https://www.suuz.com/nl.
[29] U. Lichtenthaler, H. Ernst. Developing reputation to overcome the imperfections in the markets for knowledge. Research Policy. 2007;36(1):37-55.
[30] V. Van de Vrande, J. P. De Jong, W. Vanhaverbeke, M. De Rochemont. Open innovation in SMEs: Trends, motives and management challenges. Technovation. 2009;29(6-7):423-37.
[31] A. Moeuf, R. Pellerin, S. Lamouri, S. Tamayo-Giraldo, R. Barbaray. The industrial management of SMEs in the era of Industry 4.0. International Journal of Production Research. 2018;56(3):1118-36.
[32] L. M. Camarinha-Matos, H. Afsarmanesh. Collaborative networks: a new scientific discipline. Journal of intelligent manufacturing. 2005;16(4-5):439-52.
[33] Eurostat. Statistics on small and medium-sized enterprises 2015 [Available from: http://ec.europa.eu/eurostat/statistics-explained/index.php?title=Statistics_on_small_and_medium-sized_enterprises#Main_statistical_findings.
[34] Bundesministerium für Wirtschaft und Energie. CoCoDeal 2015 [Available from: https://www.cimsource.com/cocodeal/projekt.html.