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THE RELATIONSHIPS AMONG MASS-CUSTOMIZATION ENABLERS: A REVIEW OF THEORY-TESTING RESEARCH

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Abstract: *Understanding the relationships among mass-customization enablers is crucial for the development of mass-customization implementation guidelines. The guidelines reviewed by Suzić et al. (2018, Production Planning & Control. 29 (10), 856-871) collectively focus on eight enablers and suggest a mainly sequential implementation process, mostly on the basis of analytical conceptual research and single case studies. The present paper complements Suzić et al.'s (2018) work by reviewing prior theory-testing research on the enablers of mass customization and on the relationships among them and by comparing the results of this stream of research with those of Suzić et al. (2018). This work not only leads to a richer picture than the literature on mass-customization implementation guidelines had offered, but also indicates several research gaps and mixed findings as interesting opportunities for future research.*
Key Words: ***Mass-Customization Enablers, Interdependencies, Literature Review***

1. INTRODUCTION

The evolution of the manufacturing industry continues to be shaped by customers' demands for product customization (Hughes et al., 2022). In the face of these demands, a mass-customization strategy seeks to combine the best of custom manufacturing, in terms of individualized products, with the best of mass production, in terms of cost, delivery, and quality performance (Duray, 2002; Squire et al., 2006). Accordingly, mass-customization capability is defined as the ability of a manufacturer to provide customized products that fulfill each customer's idiosyncratic needs without substantial trade-offs in cost, delivery, and quality performance (Pine, 1993; McCarthy, 2004; Squire et al., 2006; Trentin et al., 2020).

Developing mass-customization capability is a complex endeavor that 'requires putting multiple enablers in place' (Suzić et al., 2018a, p. 856). To help practitioners cope with this complexity, a number of previous studies has developed guidelines for mass-customization implementation (Suzić et al., 2018a; Suzić et al., 2018b). A crucial part of this effort is to specify the relationships among mass-customization enablers, so that firms pursuing a mass-customization strategy are supported in their decisions not only on what enablers to put in place, but also on the order in which to implement the various enablers (Suzić et al., 2018a; Suzić and Forza, 2023).

Taken together, the guidelines analyzed by Suzić et al. (2018a) focus on eight mass-customization enablers (i.e., group technology, part standardization, product modularization, process modularity, product platform development, information technology-based product configuration, form postponement and concurrent product-process-supply chain engineering) and agree on a mainly sequential implementation process: group technology should be implemented before product platform development, which in turn should be implemented before information technology-based product configuration; in addition, product platform development embeds part standardization and product modularization, where the former should be implemented before the latter.

While the body of knowledge analyzed by Suzić et al. (2018a) mostly relies on analytical conceptual research and single case studies, there are many theory-testing studies that remained out of the scope of their literature review but offer additional insights into the enablers of mass customization and into their interdependencies. Therefore, the present study reviews this stream of theory-testing research and compares its results with those of Suzić et al. (2018a). This work leads to a richer picture of the enablers of mass customization than the literature on mass-customization implementation guidelines had offered. Furthermore, this work suggests interesting opportunities for further research by highlighting research gaps and mixed findings that deserve additional investigation.

The rest of the paper is organized into five sections. Section 2 provides details of the method used to select the body of knowledge to review, while Section 3 reports the results of our review and compares them with those of Suzić et al. (2018a). Section 4 concludes by providing suggestions for future research.

2. METHOD

Consistent with our focus on empirical research that tests hypotheses on mass-customization enablers and on their interrelationships, we used the search phrase “mass custom*” AND (“test*” OR "data" OR "survey" OR "experiment" OR "case study“) in the “Topic” field of Web of Science database as of April 11th, 2024. This search, limited to the articles in English, produced 1,125 results, of which 10 were excluded because of their being nonetheless published in conference proceedings. By reading the titles and abstracts of the remaining 1,115 journal papers, we identified 47 articles that test hypotheses predicting mass-customization capability. We then selected the 28 papers published in journals with the highest rankings (i.e., 4*, 4 and 3) in the Academic Journal Guide 2021 from the Chartered Association of Business Schools. One of these papers was discarded because of its focus on when mass customization is an appropriate strategy for firms to follow, rather than on how it is implemented. Finally, three articles were added through snowballing, leading to a final set of 30 analyzed articles.

For each of these studies, we identified the hypothesized enablers and the hypothesized relationships—if any—among them, distinguishing between the hypotheses that were supported and those that were not. In addition, whenever a study had proposed an enabler modeled as a second-order construct, we identified the first-order constructs comprising that enabler and checked if the study had offered additional insights into their inter-relationships beyond the mere fact that, if reflective, a valid second-order construct implies that the underlying constructs tend to co-vary (Jarvis et al., 2003). Noteworthily, this covariation, *per se*, does not allow to draw any conclusion as to the existence of a positive interaction effect among the underlying constructs. This is because testing for a possible synergistic effect also requires comparing the effect that the valid, reflective, second-order construct has on the dependent variable of interest (in our case, mass-customization capability) with the effects that the individual first-order constructs have on the same outcome variable (Tanriverdi and Venkatraman, 2005).

3. RESULTS

This section begins with summarizing the results of our analysis of the selected papers. Subsequently, it compares these results with those of Suzić et al. (2018a).

3.1. Summary of the reviewed body of knowledge

Collectively, the analyzed studies have tested the positive effect of 75, at times overlapping, constructs on mass-customization capability, finding empirical support for the mass-customization-enabling role of 61 of them (Table 1). Out of these 61 enablers, 13 are second-order constructs (those bolded in Table 1), reflected (in 11 cases) or formed (in two cases) by an average of four first-order constructs. However, most of these first-order constructs coincide with enablers tested individually for their positive effects on mass-customization capability in other studies, while only 15 (those italicized in Table 1) have not been tested individually.

As regards the relationships among mass-customization enablers, if we exclude the covariation of the constructs that underlie a valid, reflective, second-order construct (covariation explicitly posited only by Huang et al. (2008; 2010) and Kristal et al. (2010)), there remain 29, at times overlapping, hypotheses that were tested by the analyzed body of literature, 25 of which were empirically supported. However, with the only exception of Salvador et al.'s (2015) three-way complementarity hypothesis, the posited relationships always involve only pairs of enablers, usually in the form of a positive direct effect of one enabler on the other and, more rarely, in the form of a positive interaction effect of two enablers on mass-customization capability. In three cases (i.e., Zhang et al., 2014; 2015a; 2017), the concatenation of hypotheses concerning the interplay of pairs of enablers outlines causal chains that link together three enablers, but no explicit hypothesis involving the triplet is formulated. Similarly, Sandrin et al. (2018), while reporting data showing that four high (employee) involvement practices have a synergistic effect on mass-customization capability, did not propose any hypothesis on this synergistic effect.

3.2. Comparison with Suzić et al.'s (2018a) results

Suzić et al.'s (2018a) review of the body of knowledge on mass-customization implementation guidelines identified eight enablers of mass customization. For only four of them, however, the selected set of theory-testing studies has offered empirical corroboration. Two are product modularity and process modularity, whose positive effects on mass-customization capability found empirical support in Ahmad et al. (2010), Peng et al. (2011) and Zhang et al. (2014; 2019), the former, and in Liao et al. (2013), the latter. The third is group technology, as least when applied to implement cellular manufacturing, because the hypothesis that cellular manufacturing improves mass-customization capability found empirical support in Tu et al. (2004a) and Liu et al. (2006). Finally, the positive effect of part standardization on mass-customization capability was supported by Wang et al.'s (2016) empirical results.

The remaining four enablers identified by Suzić et al.'s (2018a) review have not found support in theory-testing research. On the one hand, Peng et al. (2011) did not find a statistically significant effect of information technology-based product configuration on mass-customization capability (at $p < 0.10$). Likewise, Liao et al. (2013) did not find empirical support (at the same p value) for the hypothesis that postponement practices, including form postponement, enable mass-customization capabilities. Finally, concurrent product-process-supply chain design and product platform development have yet to be tested as predictors of mass-customization capability.

Table 1. *Prior theory-testing research on mass-customization enablers and their interdependencies (second-order constructs are bolded; first-order constructs that have not been tested individually in other studies are italicized)*

Reference	*Hypothesized enabler(s) of mass-customization capability*	*Hypothesized relationship(s) among the enablers**
Tu et al., 2001	**Time-based manufacturing practices** (second-order construct reflected by seven first-order constructs: *shop-floor employee involvement in problem-solving*, re-engineering set-ups, cellular manufacturing, preventive maintenance, quality assurance, *dependable suppliers* and *pull production*)	None
Tu et al., 2004a	(1) Re-engineering set-ups; (2) Preventive maintenance; (3) Cellular manufacturing; (4) Quality assurance (NOT supported)	None
Tu et al., 2004b	(1) Customer closeness; (2) **Modularity-based manufacturing practices** (second-order construct reflected by three first-order constructs: product modularity, process modularity and *dynamic teaming*)	(1) enables (2)
Liu et al., 2006	(1) Feedback to shop-floor employees; (2) Autonomous maintenance; (3) Cellular manufacturing; (4) Multifunctional employees; (5) High standards for recruiting; (6) Task-related training for employees; (7) Differentiated rewards and incentive systems; (8) Employee-contribution willingness; (9) Continuous improvement and learning; (10) Employee empowerment (NOT supported)	None
Huang et al., 2008	Effective process implementation (defined as process innovation capability)	None
Ahmad et al., 2010	(1) Product modularity; (2) Inter-functional design coordination	(1) enables (2)
Huang et al., 2010	**Organic structure** (second-order construct reflected by three first-order constructs: flatness, *decentralization* and employee multifunctionality), provided that the degree of product customization is high	None
Kristal et al., 2010	**Quality management** (second-order construct reflected by six first-order constructs: *small-group problem-solving*, *top management leadership for quality*, information and feedback, supplier involvement, customer focus and process management)	None
Peng et al., 2011	(1) Modular product design; (2) Configurator information technology (NOT supported); (3) Manufacturing information technology (NOT supported); (4) Supplier collaboration information technology	(1) enables (2)
Lai et al., 2012	(1) Internal integration; (2) Customer integration; (3) Supplier integration (NOT supported)	(1) enables (2); (1) enables (3)
Liu et al., 2012	Functional integration	None
Trentin et al., 2012	(1) **Self-containment of tasks** (second-order construct reflected by four first-order constructs: cellular manufacturing, employee empowerment, cross-functional training and autonomous maintenance); (2) **Environmental management** (second-order constructs reflected by three first-order constructs: supplier partnership, customer involvement and *external cooperation*); (3) Enterprise-wide information systems use (NOT supported); (4) **Use of lateral relations** (second-order construct reflected by three first-order constructs: coordination of decision making, integration between functions and *small-group problem-solving*)	None
Jitpaiboon et al., 2013	(1) Customer integration; (2) Operational performance	None
Liao et al., 2013	(1) Supplier segmentation, defined as 'the practice of applying modularity to a supply base' (p. 28); (2) Process modularity design; (3) Postponement practices (NOT supported)	None
Kortmann et al., 2014	Strategic flexibility	None
Wang et al., 2014	(1) Customization knowledge utilization; (2) Business process improvement	None
Zhang et al., 2014	(1) Organizational flatness (NOT supported); (2) Cross-functional coordination; (3) Cross-plant coordination (NOT supported); (4) Supply chain coordination; (5) Product modularity	(1) enables (2); (2) enables (5); (1) enables (3); (3) enables (5); (1) enables (4); (4) enables (5) (NOT supported)

Reference	*Hypothesized enabler(s) of mass-customization capability*	*Hypothesized relationship(s) among the enablers**
Salvador et al., 2015	(1) Customer involvement; (2) **Endowment of flexible manufacturing resources** (second-order construct formed by five first-order constructs: multifunctional employees, setup time reduction, product modularity, line flow production and *flexible suppliers*); (3) **Product management tools** (second-order construct formed by three first-order constructs: product configurator, *product data management system* and *business intelligence applications*)	(1), (2) and (3) have a positive complementary effect on mass-customization capability (MCC) (NOT supported: Each pair of the three enablers has a synergistic effect on MCC, provided the remaining enabler is at a low level)
Wang et al., 2015	(1) Customer orientation; (2) Competitor orientation; (3) Innovation orientation; (4) Customization knowledge utilization	(1) enables (4); (2) enables (4); (3) enables (4)
Zhang et al., 2015a	(1) Cognitive capital; (2) Relational capital (NOT supported)	None
Zhang et al., 2015b	(1) Knowledge acquisition from customers; (2) Knowledge acquisition from suppliers (NOT supported); (3) Knowledge application	(1) enables (3); (2) enables (3); (1) enables knowledge assimilation, which enables (3); (2) enables knowledge assimilation, which enables (3)
Wang et al., 2016	(1) Standardization; (2) Innovation	(1) enables (2); (1) and (2) mutually reinforce their positive effects on MCC
Zhang et al., 2017	(1) Human capital; (2) Social capital; (3) Structural capital (NOT supported); (4) Process innovation	(1) enables (3); (3) enables (4); (2) enables (3); (3) enables (4); (1) enables (4); (2) enables (4) (NOT supported)
Morita et al., 2018	(1) **Product development capability** (second-order construct reflected by four first-order constructs: customer involvement in new product development, manufacturing involvement in new product development, supplier involvement in new product development and *front-end loading in new product development*) (NOT supported); (2) **Supply chain capability** (second-order construct reflected by four first-order constructs: lead time focus, *JIT focus*, quality focus and *demand stability focus*)	(1) enables **product modularity**; (1) and (2) mutually reinforce their positive effect on MCC (NOT supported)
Sandrin et al., 2018	**Coalignment of high-involvement (HI) practices** (second-order construct reflected by four first-order practices: power-HI, *information-HI*, rewards-HI and knowledge-HI), provided that the degree of product customization surpasses a certain threshold value	None explicit (They implicitly show that the four HI practices have a synergistic effect on MCC, which effect is contingent on the degree of product customization)
Zhang et al., 2019	Product modularity	None
Qi et al., 2020	(1) Agile practices (construct measured by the following items: flexible workforce, integrating manufacturing and design process, customer support, customer process integration and supplier process integration); (2) Lean practices (construct measured by the following items: quality management practices, cost reduction programs, manufacturing lead-time reduction programs and processing technologies) (NOT supported)	None
Zhang et al., 2020	Assimilation of big data analytical intelligence	None
Liu et al., 2023	**Operational innovation capability** (second-order construct reflected by two first-order constructs: product innovation and process innovation)	None
Zhang et al., 2023	(1) Learning goal orientation (positively moderated by competitive intensity); (2) Performance goal orientation (negatively moderated by competitive intensity)	None

**In the column 'Hypothesized relationship(s) among the enablers', the covariation of the constructs that underlie a valid, reflective, second-order construct is excluded.*

While half of the enablers identified by Suzić et al.'s (2018a) review still await empirical corroboration, many of the enablers proposed by the analyzed set of theory-testing studies are not mentioned by the mass-customization implementation guidelines reviewed by Suzić et al. (2018a). For example, none of those guidelines mentions variables capturing the abilities of an organization to understand its customers, as well as to share information and collaborate with them, such as Tu et al.'s (2004b, p. 150) customer closeness ('the practice of keeping close contact with customers, to communicate with customers effectively, and to understand customers' individual needs'), Lai et al.'s (2012, p. 444) customer integration ('involves mainly customer information sharing, customer partnership, and customer involvement in product design and delivery'), Salvador et al.'s (2015, p. 619) customer involvement ('the extent to which a manufacturer engages in interactions with its customers to understand and respond to their needs and to receive feedback on quality and delivery'), Wang et al.'s (2015, p. 5281) customer orientation ('A firm focusing on customer orientation is able to understand its target customers') and Zhang et al.'s (2015b, p. 1277) knowledge absorption from customers ('the processes of knowledge acquisition from customers, knowledge assimilation, and knowledge application').

Table 2. *An overview of mass-customization enablers*

Category	*Mass-customization enabler(s)*	
	Enablers from Suzić et al. (2018a)	*Other enablers from theory-testing research*
Product-related	Parts standardization; Product modularization; Product platform development	Product development capability
Process-related	Process modularity	Pull production; Re-engineering set-ups; Preventive maintenance; Autonomous maintenance; Process innovation
Both product and process-related	Group technology; Form postponement	Postponement practices (including logistics postponement, too)
Information technology-related	Information technology-based product configuration	Manufacturing information technology; Supplier collaboration information technology; Enterprise-wide information systems use; Product data management system; Business intelligence applications
Organization design-related		Organizational flatness; Decentralization; Small-group problem-solving; Inter-functional integration; Cross-plant coordination; Dynamic teaming (the practice of using modular structures to reorganize manufacturing teams quickly and link them to necessary resources in response to product design or manufacturing process changes); Structural capital (disciplined methods and codified knowledge); Task-related training for employees; Multifunctional employees; Shop-floor employee involvement in problem-solving; High (employee) involvement; High standards for recruiting; Employee-contribution willingness; Human capital; Social capital (knowledge that emerges from interactions among employees); Differentiated rewards and incentive systems
Quality management-related		Quality assurance; Top management leadership for quality; Feedback to shop-floor employees; Continuous improvement and learning
Customer-related		Customer closeness; Customer integration; Customer involvement; Customer orientation; Knowledge absorption from customers
Supplier-related		Dependable suppliers; Supplier integration; Supplier segmentation (modular supply base); Flexible suppliers; Knowledge absorption from suppliers
Supply chain-related		External cooperation; Supply chain coordination; Relational capital (the trust and commitment between a supplier and a customer); Cognitive capital (the common objectives and values, and shared language and codes between a supplier and a customer); JIT focus
Others	Concurrent product-process-supply chain engineering	Operational performance; Strategic flexibility; Customization knowledge utilization; Competitor orientation; Innovation orientation; Learning goal orientation; Performance goal orientation; Demand stability focus; Assimilation of big data analytical intelligence

The picture of mass-customization enablers that emerges from the comparison of our results with those of Suzić et al. (2018a) is summarized in Table 2.

Coming to the relationships among mass-customization enablers, the mainly 'sequential logic' that Suzić et al. (2018a, p. 865) derived from the body of knowledge on mass-customization implementation guidelines still awaits empirical corroboration. Out of the 30 theory-testing studies analyzed here, only 11 posit hypotheses on the relationships among mass-customization enablers and only Peng et al.'s (2011) hypothesis that product modularity positively affects product configurator information technology overlaps with one of the precedence relationships found by Suzić et al. (2018a), the one from product modularity to information technology-based product configuration.

While the mainly sequential logic that dominates the literature on mass-customization implementation guidelines remains untested, other hypotheses concerning the relationships among mass-customization enablers have been supported empirically, as observed in the previous section. One of these hypotheses seems to challenge the sequential logic mentioned above. This is the case of Salvador et al.'s (2015, p. 618) complementary hypothesis involving three different 'resource types' that enable mass-customization capability: customer involvement, the endowment of flexible manufacturing resources and the use of product management software applications. This hypothesis was not supported by their data, as they found that: 'When the level of one resource type is low, the two remaining resource types exhibit a strong bivariate complementarity effect on mass customization capability. Conversely, when one resource type is at a high level, the complementarity effect on mass customization capability of the two remaining resource types disappears and is replaced by a cancellation [i.e., a negative interaction] effect' (Salvador et al., 2015, p. 618). Since the endowment of flexible manufacturing resources is conceptualized in their study as a second-order formative construct with five first-order constructs, of which one is product modularity, and the use of product management tools is conceptualized there as another second-order formative construct with three first-order constructs, of which one is the use of a product configurator, their finding could lead one to conclude that product modularity and information technology-based product configuration should be implemented jointly, rather than in a sequence, provided customer involvement is low.

4. DISCUSSION AND CONCLUSION

The analysis of the selected papers and the comparison of their results with those of Suzić et al. (2018a) make three fundamental contributions. One is a much richer picture of the enablers of mass customization than the literature on mass-customization implementation guidelines had offered. While that body of literature has focused almost only on product- and/or process-related enablers, a whole bunch of non-technological enablers still await to be incorporated into mass-customization implementation guidelines. The challenge of implementing mass customization extends beyond technology and there is ample room for future research that aims to include other dimensions of this challenge—from organization design issues (e.g., Sandrin et al., 2014) to customer- and supplier-related aspects (e.g., Grosso et al., 2017; Coletti et al., 2023; Sandrin, 2023)—into mass-customization implementation guidelines in order to give better aid to the companies that pursue a mass-customization strategy.

The second contribution of the present literature review lies in its showing that prior theory-testing research has paid relatively little attention to the interplay of mass-customization enablers. On the one hand, the mainly sequential implementation process that Suzić et al. (2018a) derived from their review of the literature on mass-customization implementation guidelines remains untested. On the other hand, scattered results from prior theory-testing research seem to challenge that process, suggesting synergistic benefits that a sequential process would inevitably delay. In summary, there is ample room for future research to investigate how the numerous enablers of mass customization interact to contribute to mass-customization capability, especially when more than two enablers are considered. While this work may be statistically challenging datawise and is unlikely to be accomplished in a single study, more research is definitely needed to provide practitioners with a more comprehensive and more empirically grounded picture of the relationships among mass-customization enablers.

The third fundamental contribution of our work is represented by some mixed findings that we highlight and that await reconciliation. For example, information-technology product configuration is among the most cited enablers by the literature on mass-customization guidelines (Suzić et al., 2018a; Suzić et al., 2018b), but Peng et al. (2011) did not find empirical support for the hypothesis that product configurators improve mass-customization capability. Similarly, Liao et al. (2013) did not find support for the hypothesis that postponement practices—comprising both form postponement and logistics postponement—improve mass-customization capabilities, even though the 'power of [form] postponement' to implement mass customization has been heralded by Feitzinger and Lee (1997, p. 116) and acknowledged by several mass-customization implementation guidelines (Suzić et al., 2018a; Suzić et al., 2018b). These unexpected findings suggest the necessity of delving into the effects of these variables on mass-customization capability from a more nuanced perspective than the universalistic one, according to which an effect is assumed to be universal across the reference population. For example, a conceptual work has recently argued that different types of mass-customization strategy require different types of form postponement (Trentin and Salvador, 2023).

A more nuanced perspective could also explain mixed findings on the role of lean production on mass-customization capability. Lean production was mentioned among mass-customization 'processes and methodologies' since the first literature review on mass customization appeared in 2001 (da Silveira et al., 2001) and, indeed, many of the building blocks of lean production identified by Shah and Ward (2007), such as involved customers, low setup, flow (i.e., cellular manufacturing), involved employees (meant as cross-trained workers) and preventive maintenance, have repeatedly been found as having a statistically significant positive effect on mass-customization capability. However, other building blocks of lean production, such as controlled processes, pull (production) and involved employees (meant as suggestion involvement), while captured by first-order components of second-order constructs (cf. Tu et al., 2001; Kristal et al., 2010; Salvador et al., 2015), have yet to be tested individually for their positive effects on mass-customization capability. In addition, theory-testing research results on the effect of supplier-related building blocks of lean production are inconclusive, with some hypotheses supported (e.g., Liao et al., 2013) and others not (e.g., Lai et al., 2012). Finally, Qi et al. (2020) did not find empirical support for the hypothesis that lean practices, taken as a whole, improve the implementation of servitization through mass-customization capability. In fact, Sandrin et al.'s (2018) results on the effect of high (employee) involvement on mass-customization capability suggest that the degree of product customization could play a role in moderating the effect of lean practices and, thus, could reconcile the seemingly contradictory findings that an implicitly universalistic perspective produces.

6. ACKNOWLEDGEMENTS

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