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Product-processes-supply chain structures alignment for mass customization scenarios. A literature review

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Resumen

In this era of temporary competitive advantage, both the coordination of the interdependencies among product, process, and supply chain design decisions, as well as the mass customization business strategy approach, have been identified as key drivers. The paper gives a comprehensive overview of the research advances achieved in the field of product-processes-supply chain structures alignment for mass customization scenarios by identifying and structuring key research issues as well as key research approaches to deal with them. Derived from this analysis, relevant uncovered research issues have been identified, suggesting this way promising further research lines.

Keywords: Mass Customization, Design for Supply Chain (DFSC), Three Dimensional Concurrent Engineering (3-DCE)

1. Introduction

As responsiveness and agility are becoming important competitive attributes in addition to quality, variety and price, this leads to many companies to simultaneously compete in the three domains of product, process, and supply chain to maximize the operational and supply chain performance (Fine, 1998, 2000; Fixson, 2005). On the other hand, Mass Customization (MC) is a business strategy to bring together, under the same production system, the competitive advantages of product "customisation" (economies of scope), and the efficiencies associated with "mass production" (economies of scale) (Davis, 1989; Pine, 1993; Tseng and Jiao, 1998). Quoting Pine (1993): "*Mass customisation denotes the ability to provide customised products and services at a comparable price and speed of equivalent standardised offerings*".

This paper gives a comprehensive overview of the research advances achieved in the field of product-processes-supply chain structures alignment for mass customization scenarios*. The paper is structured as follows. Section 2 presents the research method followed in order to develop the literature research. Section 3 introduces the key research problems/issues identified from the literature research, while section 4 presents the different approaches that have been found in the literature in order to deal with the former problems/issues. In section 5, a classification of the different approaches regards key problems/issues is presented. And finally, in section 6, main conclusions and future research lines are suggested.

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2. Research Methodology

The literature research has been conducted using different databases: Blackwell-synergy, EBSCO, Emerald, ISI Proceedings, ScienceDirect, SCOPUS, Web of Science. The databases were searched for a list of keywords as well as for important researchers in the field. As a result of this search, a preliminary list of 54 significant references (books, papers, thesis, etc.) was set. After analyzing them in detail, additional keywords considered as significant for this analysis were added. Final search keywords were the following: Mass Customization, Postponement, Design for Supply Chain (DFSC), Concurrent Engineering (CE), Three-dimensional concurrent engineering (3-DCE), Build to Order Supply Chain (BOSC), Supply Chain Configuration (SCC), Modular Supply Networks. Also, some of the previous references were eliminated and key new ones were added. In total, 15 key references, plus another 44 references considered as complementary, have been employed to develop the present state-of-the-art.

3. Research Problems/Issues

The analysis of the key references, as well as the complementary ones, has allowed the identification of three common generic research issues (Rungtusanatham and Forza, 2005) regards Product Families' Structure (PF) – Processes & Operations (P&O) – Supply networks (SN) alignment for Mass Customization Scenarios (MCS).

3.1. Research issue 1: Why should decisions with respect to product design, manufacturing process design, and supply chain design be coordinated?

This research issue is frequently the first one stated in the preliminary stages of a new paradigm building. Usually, based on a few empirical research studies, some authors start visualizing a new way of doing things that goes beyond the current practices and that can be a new source of competitive advantage for enterprises, as well as a new field for research development. The initial study in this stage generally follows a visionary perspective focused on theory and concepts building.

3.2. Research issue 2: What mechanisms allow product design, manufacturing process design, and supply chain design decisions to be coordinated?

Once the previous research issue has been demonstrated and assumed as relevant for the enterprise and academic communities, a second wave of research appears trying to place the new concepts and theories in the operational ground. To do so, new models-frameworks, methods and preliminary tools, are developed in order to generalize initial findings and apply them in broader enterprise operational contexts.

3.3. Research issue 3: What are the performance implications of coordinating product design, manufacturing process design, and supply chain design decisions?

The third research issue is specially focused on testing previously developed models-frameworks, methodologies and tools. This testing process can be developed following an empirical based perspective (case research, survey research, historical research, etc.) and/or modeling (i.e., optimization or simulation) approaches.

4. Research Approaches

This section reviews the main approaches existing in the literature analyzed that try to deal with the research issues identified above. From a research methodology viewpoint these approaches cover a wide spectrum of methods: theory building and theory-testing using either empirical-based (e.g., case research, survey research, historical research, etc.) and/or modeling (i.e., optimization or simulation) methodologies.

4.1. Research approaches to issue 1: Why

From a DFSC viewpoint, Famuyiwa and Monplaisr (2007) state that, for many manufacturing firms, the recent increase in competition in the marketplace due to globalization, increase demand in variety, and shorter product life cycles, has forced them to move from the traditional mass manufacturing world to the world of mass customization through flexibility and agility. In order to achieve agility, industries must adapt their product design and development processes to accommodate the rapidly changing needs of their customers. However, moving product from the initial design stage to its arrival at the customer requires many decisions on design and operations in the domains of product development, production-manufacturing and supply chain as the decisions made during the conceptual design stage have direct impact on over 70% of the production costs, even though the actual cost of the design phase accounts for only 6% of the total development cost (Shehab and Abdalla, 2001).

Regarding the relationship between the characteristics of orders and supply network models, Fisher (1997), based on the cases of Campbell Soup and Sport Obermeyer, and following too a DFSC perspective, distinguishes between functional products with foreseeable demand, and innovative products with unpredictable demand. For those belonging to the first group, the author assigns a physically efficient type of supply network, the aim of which is to maximize efficiency at the lowest cost possible, high levels of manufacturing level resources, a strategy of inventory minimisation and a reduction in lead times. As regards the second group, innovative products, Fisher (1997) recommends market responsive type supply networks. The aim of these ones is to respond quickly to a demand with a high degree of uncertainty for minimising stock-outs and obsolete inventories. For this, excess manufacturing capacity is required, as well as product parts and finished products broad buffers, aggressive investment in lead time reduction, supplier selection based on their speed, quality and flexibility, and a modular type design strategy which facilitates the postponement of customisation of the product as late as possible.

In a middle ground between the DFSC and 3-DCE approaches is placed the research of Petersen et al. (2005). In this research the authors argue that integrating suppliers into the new product development process has direct implications for manufacturing process design decisions and for supply chain configuration decisions. Based on this premise, a theoretical model is proposed in which the authors posit that higher product development team effectiveness can be achieved: (1) By carefully selecting suppliers and timing their involvement in the NPD process; (2) by involving selected suppliers in the establishment of technical performance metrics and targets that can affect manufacturing process design, and; (3) By engaging selected suppliers in assessing business performance goals and targets. Product development team effectiveness would, in turn, lead to better financial and design performance.

3-DCE concept was coined by Fine (1998: p. 133):"*When firms do not explicitly acknowledge and manage supply chain design and engineering as a concurrent activity to product and process design and engineering, they often encounter problems late in product development, or with manufacturing launch, logistical support, quality control, and production costs…"*. 3-DCE has its roots in concurrent engineering, which presumes that products and processes should be designed simultaneously, involving multi-functional teams early in the process, which may include suppliers and customers (Koufteros et al., 2001, 2002). Fine (1998) states that owing to the many demonstrated benefits of concurrent engineering, the adoption of concurrent engineering techniques has become commonplace enough that it no longer provides a source of competitive advantage. Thus, organizations are looking for the next level of breakthrough in improving performance.

In a more recent study, Fine et al. (2005) offers a quantitative formulation of 3-DCE problems through a weighted goal programming modeling technique that facilitates an assessment of trade-offs among potentially conflicting objectives. The weighted goal programming technique, in this context, seeks to minimize deviations from specified aspiration levels of various objectives (e.g., fidelity, costs, lead time, partnership, and dependency) deemed to be of strategic relevance to the product design, the manufacturing process design, and the supply chain design. The objective function is minimized by selecting an appropriate configuration out of a set of candidate configurations, with each configuration represented by the triplet of product version, product design, and assembly sequence and involving a set of elements participating in the configuration and a set of suppliers that can provide these elements. To demonstrate the utility of this methodological approach, the paper explores the issue of integrality vs. modularity in product and supply chain designs, asking specifically the question of whether or not integral (modular) product designs need to be accompanied by integral (modular) supply chain configurations.

Salvador et al. (2004), state that the BOSC approach has been adopted in several industries (consumer electronics, automobile, apparel…) in order to efficiently and effectively manage the increasing market volume and mix uncertainties. Building products to order (BTO), in a literal sense, means aligning the product creation and order fulfillment processes to specific customer ordering requirements, usually by adopting one or more approaches described in the Operations Management lexicon such as Assemble-to-Order, Make-to-Order, and/or Purchase-to-Order (Gunasekaran and Ngai, 2005; Svennsson and Barfod, 2002). BOSC attempts to reduce not only these risks but also the internal operational performance trade-offs that manufacturing firms typically face between being flexible in terms of production volume or being flexible in terms of production mix. Salvador et al. (2004) reports preliminary observations from a longitudinal case study (Lawn Mowers & Garden Tractors business unit of Deere & Company) in their transition towards becoming a BTO firm based on a BOSC.

4.2. Research approaches to issue 2: What Mechanisms

Following a DFSC approach, Feitzinger and Lee (1997), in a study at HP, discussed employing postponement strategy for the assembly of the power supply using a modular design. The authors state that the key to mass-customizing effectively is postponing the task of differentiating a product for a specific customer until the latest possible point in the supply network (a company's supply, manufacturing, and distribution chain). Companies therefore must rethink and integrate the designs of their products, the processes used to make and deliver those products, and the configuration of the entire supply network. By adopting such a comprehensive approach, companies can operate at maximum efficiency and quickly meet customers' orders with a minimum amount of inventory. They highlight three organizational-design principles that together form the basic building blocks of an effective mass-customization program.

Garg (1999) studied three product and process modular design alternatives, which differ in their number of supply chain stages and the sequence of some of the processes, for a new line of products at a large electronics products manufacturer. The author describes the application of Supply Chain Modeling and Analysis Tool (SCMAT) to identify the feasible set of product and process designs. Some of the analyses the tool could perform include: inventory-service level trade-offs, sourcing, location and transportation trade-offs, effects of capacity limitations, impact of lot sizes and designing products/processes for supply chain management.

Park (2001) presented a comprehensive model of integrated product platform and global supply chain configuration with experimental simulations. This model has ambitiously incorporated multiple platform strategies and included a large number of supply chain decision variables and parameters along the whole product lifecycle, from the front-end global market segmentation to product design and manufacturing stages to raw material sourcing and transportation, manufacturing plant location, and end-product distribution.

Kim et al. (2002) developed a mathematical model and a solution algorithm for assisting the manufacturer to configure its supply chain for a mix of multiple products sharing some common raw materials and/or component parts. The model evaluates how much of each raw material and/or component part to order from which supplier (contract) under such constraints as the supplier's capacity limit. They, however, did not use the model to investigate the impact of sharing common raw materials and/or component parts across multiple products although the model can be extended for this purpose (e.g. simply through a sensitivity analysis under different commonality levels).

Famuyiwa and Monplaisr (2007) proposed an integrated framework for making both product architecture and supply chain decisions concurrently during conceptual stage of product development. This integrated framework takes the form of a quantitative framework to aid product development engineers and managers in identifying the optimal modules considering multiple design and supply chain objectives. The optimization model incorporates decision variables so that one can examine the impact of modularity decisions on supply chain policy.

From a 3-DCE modular perspective, Camuffo (2000) examines some of the implications associated with modularization in design, manufacturing and organization supply chain. He defines modularity in design as defining the design boundaries of a product and of its components such that design features and tasks are interdependent across modules, modularity in manufacturing as designing manufacturing and assembly in order to reduce complexity in the main process by means of sub-assembly, while modularity in organization or supply chain means the organizational processes, governance structures and contracting procedures that are adopted or utilized to accommodate modular production. In the same line, Takeishi and Fujimoto (2001), proposes a conceptual framework that sees development/production activities as interlinked, multiple hierarchies of products, processes, and inter-firm boundaries.

Following a 3-DCE approach, Singhal and Singhal (2002) present an expert based approach to identify desirable product ideas that considers operations and marketing capabilities in a compatibility matrix. The approach takes into account the design of the supply chain, the product and the processes used to manufacture the product.

Also following a 3-DCE approach, Blackhurst at al., (2005), deployed a network based approach to develop and formalize the Product Chain Decision Model (PCDM), a high-level modeling methodology for describing the operation of a supply chain while considering decisions related to product design and manufacturing process design and the impact of such decisions on the supply chain. Moreover, by allowing for mathematical functions to be performed on the attributes describing the design and operation of the supply chain, PCDM effectively can be employed as a decision-making tool to support managers in conducting what if analyses before significant resources are committed to any particular product–manufacturing process–supply chain configuration.

Fixson (2005), following too, a 3-DCE approach, positions the product architecture as the mechanism for coordinating decisions across the three domains of product, manufacturing process, and supply chain and proposes a multi-dimensional assessment framework to operationalize the product architecture for discrete products.

4.3. Research approaches to issue 3: Performance Implications

Following a DFSC approach, Lee and Sasser (1995) studied the impact of employing principles of design for supply chain for new product development at Hewlett Packard (HP) Company, using a standard design for power supply units for HP printers that is applicable in both North America and Europe markets instead of using dedicated power supplies for each market. They developed an analytical model to quantify the complex impacts and benefits of cost drivers like, stock-outs, reconfigurations, manufacturing, logistics and inventory.

Salvador et al. (2002a) is perhaps one of the most comprehensive studies dealing with the mutual interactions between product platform strategies (product modularity and variety), production processes and supply sources. The study is based on a qualitative research design involving a multiple case study methodology to examine six product families belonging to six European companies. From the firm's perspective, a trade-off exists between product variety and operational performance, which includes, in this study, performance of its internal operations, as well as its component sourcing performance. To further the understanding of the interdependence among product, process, and supply chain design, this paper follows a DFSC approach and explores the implications of modularity in terms of such manufacturing characteristics as the level of product variety and the production volume of the final assembly process. Furthermore, the paper ties the decision to embed a specific type of modularity into the product family architecture to component sourcing decisions that relate to supplier selection and supplier location, with consequent implications for buyer–supplier relationships.

Salvador et al (2002b), also from a DFSC perspective, performed an empirical study on European firms in telecommunications, transportation vehicles and food processing equipment industries and explored how the firms supply chain should be configured when different degrees of customization are offered in order to achieve high operational effectiveness.

Thonemann and Bradley (2002), following too a DFSC approach, presented a mathematical model to analyze the impact of product variety on supply chain performance from several different perspectives. Their analyses showed that product variety has significant effect on supply chain lead-time especially when setup times are significant. It therefore becomes important to adjust the decision variables and parameters related to manufacturing processes and supply chains in order to improve performance under high product variety.

From a 3-DCE viewpoint, Huang et al. (2005) propose and apply an optimization model to understand the impact of platform products, with and without commonality, on decisions pertaining to supply chain configuration and the consequent performance of the configured supply chain. The proposed optimization model is solved heuristically using genetic algorithm and subsequently applied to two scenarios involving the case of a product family comprised of two notebook computer models. By comparing supply chain configurations and performance results between the two scenarios, the paper quantifies the supply chain cost benefits due to product platform commonality; identifies the impact on inventory levels at various stages of the supply chain; determines the capability requirements at procurement, assembly, and demand stages within the supply chain; and demonstrates, in this particular case, the insignificant effect on time-to-market from embedding commonality into the design of platform products.

Following also a 3-DCE approach, Su et al. (2005), applied queuing theory to evaluate time and form postponement structures in a supply chain. While the Time Postponement (TP) supply chain structure maps onto a "Make-to-Order" environment, the Form Postponement (FP) supply chain structure maps onto a hybrid "Make-to-Stock"-"Make-to-Order" environment. The performance of these two supply chain structures (i.e., total supply chain costs and customer waiting times) are compared and contrasted under varying product design (e.g., degree of product proliferation) and varying manufacturing process (e.g., process time variation, percentage of generic component coverage, system utilization rate) conditions. Based on these comparative results, the paper provides guidance as to which of the two supply chain structures to implement in light of specific product and manufacturing process conditions.

Saiz et al. (2006) research proposes a framework and a decision support simulation environment to gain understanding on how to design and manage demand driven responsive and efficient global SNs. For which, based on different network conditions (i.e. capacity constraints, suppliers lead times, internal processes lead times, inventory levels, means of transport, supplier location, manufacturing units, distribution centres...), and customised demand scenarios, alternative possible configurations can be identified from their global multi-plant network. The framework developed follows a 3-DCE approach, aligning product-processes-supply network structures for different mass customization scenarios.

In a similar line, ElMaraghy and Mahmoudi (2008) developed a comprehensive decision support model to concurrently determine the optimal product modularization scenario and the global supply chain configuration in a 3 echelon (suppliers, manufacturing facilities and distribution centres) global supply chain system considering the procurement costs, production, inventory and transportation costs along with the impact of changes in the global market currency exchange rates. The model combines the product design modular configuration problem (including modules make/buy options and the product modular structure alternatives) and the supply chain design configuration problem (including different locations for suppliers, manufacturers and distribution centres).

5. Analysis

The mechanisms found in the literature that allow product design, manufacturing process design, and supply chain design decisions to be coordinated, cover an spectrum of models-frameworks, methods-methodologies, and tools (Table 1).

Table 1. PF-P&O-SN alignment for MCS literature matrix.

Research Issues	RESEARCH APPROACHES Models and Frameworks	 Methods and Methodologies	 Tools	DOMAINS* P	 P&O	 SN	 P for MC	 P&O for MC	 SN for MC
Research Issue 1 **Why should decisions with respect to product design, manufacturing process design, and supply chain design be coordinated?**	Framework that relates product orders characteristics with Supply Chain Configurations: Fisher (1997)			✓		✓			
	Set of benefits of taking account of supply chain considerations in the design and process engineering stages: Nielsen and Holmstrom (1995)			✓	✓	✓			
	3-DCE framework: Fine (1998)			✓	✓	✓			
	Theoretical model regards the effect of integrating suppliers into the new product development process and its implications for manufacturing process design decisions and for SCC decisions: Petersen et al. (2005)			✓	✓	✓			
	Build-To-Order (BTO) strategy: Holweg and Frits (2001)						✓	✓	✓
	Observations about how to become a BTO firm based on a BOSC: Salvador et al. (2004)						✓	✓	✓
			Quantitative formulation of 3-DCE problems through a weighted goal programming modeling technique that facilitates an assessment of trade-offs among potentially conflicting objectives: Fine et al. (2005)	✓	✓	✓			
Research Issue 2 **What mechanisms allow product design, manufacturing process design, and supply chain design decisions to be coordinated?**	Integrated quantitative framework for making both product architecture and supply chain decisions concurrently during conceptual stage of product development: Famuyiwa and Monplaisr (2007)			✓		✓			
	HP postponement model: Feitzinger and Lee (1997)						✓	✓	✓
	Conceptual framework that interlink product-processes-supply chain structures following a modular perspective: Takeishi and Fujimoto (2001)						✓	✓	✓
		Expert based approach to identify desirable product ideas that considers the design of the supply chain, the product and the processes used to manufacture the product: Singhal and Singhal (2002)		✓	✓	✓			

*Domains: P-Product; P&O - Processes and Operations; SN - Supply Network; MC - Mass Customization

Table 1 (cont). PF-P&O-SN alignment for MCS literature matrix.

Research Issues	RESEARCH APPROACHES Models and Frameworks	 Methods and Methodologies	 Tools	DOMAINS* P	 P&O	 SN	 P for MC	 P&O for MC	 SN for MC
(cont.) Research Issue 2 What mechanisms allow product design, manufacturing process design, and supply chain design decisions to be coordinated?		Product Chain Decision Model - modeling methodology and simulation tool for designing coordinating decisions across product design, manufacturing process design, and supply chain design: Blackhurst at al. (2005)		✓	✓	✓			
		Assessment framework that positions the product architecture as the mechanism for coordinating decisions across the three domains of product, manufacturing process, and supply chain: Fixson (2005)					✓	✓	✓
			Simulation tool for integrated product platform and global supply chain configuration development: Park (2001)	✓		✓			
			Supply Chain Modeling and Analysis Tool (SCMAT): Garg (1999)	✓	✓	✓			
Research Issue 3 What are the performance implications of coordinating product design, manufacturing process design, and supply chain design decisions?	Framework that relates soft and hard mass customization with product structure and SCC: Salvador et al. (2002a, 2002b)						✓		✓
			Tool (mathematical model) to analyze the impact of product variety on manufacturing processes and supply chain performance: Thonemann and Bradley (2002)	✓	✓	✓			
			Tool (mathematical model and a solution algorithm) for assisting the manufacturer to configure its supply chain for a mix of multiple products sharing common parts: Kim et al. (2002)				✓	✓	✓
			Quantitative tool (based on queuing theory) for evaluating time and form postponement structures over SCC and SC performance: Su et al. (2005)				✓	✓	✓
			Tool (optimization model) to understand the impact of platform products on decisions pertaining to manufacturing processes and supply chain configuration and the system performance: Huang et al. (2005)				✓	✓	✓
			Decision support simulation environment to evaluate the effect of aligning product-processes-supply network structures for different MCS over several performance metrics: Saiz et al. (2006)				✓	✓	✓
			Decision support tool (optimization model) to concurrently determine the optimal product modularization scenario and the global supply chain configuration: ElMaraghy and Mahmoudi (2008)				✓	✓	✓

*Domains: P-Product; P&O - Processes and Operations; SN - Supply Network; MC - Mass Customization

From the analysis of the matrix above, two uncovered research issues can be stated:

- Which are the keys to success and potential pitfalls of PF-P&O-SN strategies alignment development, for MCS, in real industrial companies' implementations?
- Which are the best methods and tools, in real industrial companies' implementations, to improve the PF-P&O-SN strategies alignment for MCS?

The former research issue could mainly refer to the models and frameworks research approach domain, while latter would be specially related with the methods, methodologies and tools research approach domains.

6. Conclusions

The insights derived from the literature review encourage the initial research assumption that the correct alignment of product design, process design, and supply chain design can help organizational profitability for different customization scenarios. Nevertheless, most of the research presented, just cover partial steps in the research methodology, or treat the PF-P&O-SN alignment for MCS in a biased way:

- Many papers have been identified focussed on the development of frameworks to deal with the PF-P&O-SN alignment, but without a further theory-testing validation. In fact, the fewer that have covered these two methodological steps, just approach the theory-testing step by limited case research, with the consequent lack of generalization possibility.
- Another set of papers focus on modelling (simulation and optimization) tools to help managers improve their decision making process, that lack a comprehensive previously developed and justified PF-P&O-SN alignment framework.
- Finally, many key references deal with the PF-P&O-SN alignment issue without taking into consideration MCS.

Therefore it has been found a lack in the literature of a systemic PF-P&O-SN alignment for MCS approach, and a systematic methodological research approach, that fully cover the process from theory building (framework or conceptual models) towards theory-testing, with multi-case studies for a general empirical validation, as well as modeling (i.e., simulation or optimization) methodologies and tools to give insights and understanding about the implications of changes over the behavior of the PF-P&O-SN complex systems under different MCS. A systemic and systematic approach like that could aid managers very much in their decision making process to globally improve the PF-P&O-SN system performance for different MCS.

References

Amaro, G., Hendry, L., Kingsdam, B. 1999. Competitive advantage, customisation and a new taxonomy for non make-to-stock companies. *International Journal of Operations & Production Management*, 19(4), pp. 349-371.

Banker, R.D., Datar, S.M., Kekre, S., Mukhopadhyay, T. 1990. Cost of product and process complexity. In: Kaplan, R.S. (Ed.), *Measures for Manufacturing Excellence*. Harvard Business School Press, Boston, MA, pp. 269–290.

Bopana, K.G., Chon-Huat, G., 1997. A hierarchical system of performance measures for concurrent engineering. *Concurrent Engineering: Research and Application* 5 (2), 137–143.

Brown, S.L., Eisenhardt, K.M. 1995. Product development: past research, present findings, and future directions. *Academy of Management Review* 20 (2), 343–378.

Camuffo, A. 2000. *Rolling Out a World Car: globalization, outsourcing and modularity in the auto industry*. IMVP Working Paper, available at: http//imvp.mit.edu/papers.

Chang, K.H., Silva, J., Bryant, I., 1999. Concurrent design and manufacturing for mechanical systems. *Concurrent Engineering: Research and Application* 7 (4), 290–308.

Child, P., Diederichs, R., Sanders, F., Wisniowski, S., 1991. The Management of Complexity. *Sloan Management Review* 33 (1), 73-80.

Da Silveira, G., Borenstein, D., Fogliatto, F.S. 2001. Mass customization: Literature review and research directions. *International Journal of Production Economics*, Vol. 72, pp. 1-13.

Davis, S. 1989. From future perfect: Mass customizing. *Planning Review*, 17 (2), pp. 16-21.

Ellram, L.M., Tate, W.T., Carter, C.R. 2007. Product-process-supply chain: an integrative approach to three-dimensional concurrent engineering. *Intemational Joumal of Physical Distribution & Logistics Management*, Vol. 37 No. 4, pp. 305-330.

ElMaraghy, H.A., Mahmoudi, N. 2008. Concurrent Design of Product Modules Structure and Global Supply Chain Configuration. In, *Supply Chain,Theory and Applications*, Book edited by: Vedran Kordic, ISBN 978-3-902613-22-6, pp. 558, February 2008, I-Tech Education and Publishing, Vienna, Austria.

Famuyiwa, O., Monplaisr, L. 2007. *An Integrated Framework Matching Product Architecture with Supply Chain Design Policies*. OCLC's Experimental Thesis Catalog.

Feitzinger, E., Lee, H.L. 1997. Mass Customization at Hewlett-Packard: The Power of Postponement. *Harvard Business Review*, January-February, pp. 116-121.

Fine, C.H. 1998. *ClockSpeed: Winning Industry Control in the Age of Temporary Advantage*. Perseus Books Reading, Massachusetts.

Fine, C.H. 2000. Clockspeed-based Strategies for Supply Chain Design. *Production and Operations Management*, Vol. 9, No. 3, Fall, pp. 213-221.

Fine, C.H., Golany, B., Naseraldin, H. 2005. Modeling tradeoffs in three-dimensional concurrent engineering: a goal programming approach. *Journal of Operations Management* 23, pp. 389–403.

Fisher, M.L. 1997. What Is the Right Supply Chain for Your Product?. *Harvard Business Review*, March-April.

Fixson, S.K. 2005. Product architecture assessment: a tool to link product, process, and supply chain design decisions. *Journal of Operations Management* 23, pp.345–369.

Forza, C., Salvador, F., 2002. Product configuration and inter-firm co-ordination: an innovative solution from a small manufacturing enterprise. *Computers in Industry* 49 (1), 37-46.

Garg, A. 1999. An Application of Designing Products and Processes for Supply Chain Management. *IIE Transactions*, 31, 417-429.

Gilmore, J.. Pine II, J. 1997. The four faces of mass customization. *Harvard Business Review*, 75 (1), pp. 91-101.

Graves, S.C., Willems, S.P. 2001. *Optimizing the supply chain configuration for new products*. Working Paper, Leaders for Manufacturing Program and A.P. Sloan School of Management, MIT.

Gunasekaran, A. 2005. The build-to-order supply chain (BOSC): A competitive strategy for 21st century. *Journal of Operations Management* 23, 419-422.

Gunasekaran, A., Ngai, E.W.T. 2005. Build-to-order supply chain management: a literature review and framework for development. *Journal of Operations Management* 23, 423–451.

Gunasekaran, G., 1998. Concurrent engineering: a competitive strategy for process industries. *Journal of the Operational Research Society* 49, 758–765.

Hart, C.W.L. 1995. Mass customization: conceptual underpinnings, opportunities and limits. *International Journal of Service Industry Management*, Vol. 6 No. 2, pp. 36-45.

Holweg, M., Frits, K.P. 2001. Successful Build-to-Order Strategies Start with the Customer. *Sloan Management Review*, 43: 73-82.

Huang, G.Q., Zhang, X.Y., Liang, L. 2005. Towards integrated optimal configuration of platform products, manufacturing processes, and supply chains. *Journal of Operations Management* 23, pp.267–290.

Hult, G., Swan, K., 2003. A Research agenda for the nexus of product development and supply chain management processes. *Journal of Product Innovation Management* 20, 333–336.

Jiao, R.J., Huang, G.G.Q., Tseng, M.M., 2004. Concurrent enterprising for mass customization. *Concurrent Engineering: Research and Application* 12 (2), 83–88.

Joglekar, N., Rosenthal, R., 2003. Coordination of design supply chains for bundling physical and software products. *Journal of Product Innovation Management* 20, 374–390.

Kim, B., Leung, J.M.Y., Park, K.T., Zhang, G., Lee, S. 2002. Configuring a manufacturing firm's supply network with multiple suppliers. *IIE Transactions* 34, 663–677.

Koufteros, X., Vonderembse, M. and Doll, W. 2001. Concurrent engineering and its consequences. *Journal of Operations Management*, Vol. 19, pp. 97-115.

Koufteros, X., Vonderembse, M. and Doll, W. 2002. Integrated product development practices and competitive capabilities: the effects of uncertainty, equivocality, and platform strategy. *Journal of Operations Management*, Vol. 20 No. 4, pp. 331-55.

Lampel, J., Mintzberg, H. 1996. Customizing customization. *Sloan Management Review*, vol. 38, pp. 21-30.

Lee, H. 1998. Postponement for mass customization: satisfying customer demands for tailor-made products. *International Journal of Strategic Supply Chain Alignment: Best Practice in Supply Chain Managemen*t, 77-91.

Lee, H.L., Sasser, M.M. 1995. Product Universality and Design for Supply Chain Management. *Production Planning and Control*, 6, 3, 270-277.

McCutcheon, D.M., Raturi, AS., Meredith, J.R., 1994. The customization-responsiveness squeeze. *Sloan Management Review* 35 (2), 89-99.

Nielsen, N.P.H., Holmstrom, J. 1995. Design for Speed: a Supply Chain Perspective on Design for Manufacturability. *Computer Integrated Manufacturing Systems*, 8, 3, 223-228.

Pahl, G., Beitz, W., 1996. *Engineering Design. A Systematic Approach*. Springer, London.

Park, B.J., 2001. *A framework for integrating product platform development with global supply chain configuration*. GIT PhD Dissertation, Georgia.

Petersen, K. J., Handfield, R. B., Ragatz, G. L. 2005. Supplier integration into new product development: coordinating product, process and supply chain design. *Journal of Operations Management* 23 (2005) 371–388.

Petersen, K.J., Handfield, R.B., Ragatz, G.L. 2005. Supplier integration into new product development: coordinating product, process and supply chain design. *Journal of Operations Management* 23 (2005) 371–388.

Pine II, B.J. 1993. *Mass Customization: The New Frontier in Business Competition*. Harvard Business School Press, Boston, Massachusetts, USA.

Pine II, B.J., Victor, B., Boynton, A.C. 1993. Making mass customization work. *Harvard Business Review*, September–October, pp.108-116.

Rungtusanatham, M., Forza, C. 2005. Coordinating product design, process design, and supply chain design decisions. Part A: Topic motivation, performance implications, and article review process. *Journal of Operations Management* 23, pp. 257-265.

Saiz, E., Castellano, E., Besga, J.M., Zugasti, I., Eizaguirre, F. 2006. Global and flexible supply networks modelling and simulation. Blecker, Thorsten and Wolfgang Kersten (Eds.) *Operations and Technology Management II: Complexity Management in Supply Chains. Concepts, Tools and Methods*. Erich Schmidt Verlag, Berlin.

Salvador, F., Forza, C., Rungtusanatham, M. 2002a. Modularity, product variety, production volume, and component sourcing: theorizing beyond generic prescriptions. *Journal of Operations Management* 20, pp.549–575.

Salvador, F., Forza, C., Rungtusanatham, M. 2002b. How to mass customize: Product architectures, sourcing configurations. *Business Horizons*, July-August.

Salvador, F., Rungtusanatham, M., Forza, C., Trentin, A. 2004. *Build-to-order is not that easy: adding volume flexibility to mass customization*. IE Working Paper WP04-16 04 / 05.

Shehab, E. M., Abdalla, H. S. 2001. Manufacturing cost modeling for product development. *Robotics and Computer Integrated Manufacturing* 17, 341-353.

Singhal, l., Singhal, K. 2002. Supply chains and compatibility among components in product design. *Journal of Operations Management*, Vol. 20, pp. 289-302.

Spira, J. 1996. Mass customization through training at Lutron Electronics. *Computers in Industry*, 30 (3), pp. 171-174.

Su, J.C.P., Chang, Y.-L., Ferguson, M. 2005. Evaluation of postponement structures to accommodate mass customization. *Journal of Operations Management* 23, pp.305–318.

Sun, J., Zhang, Y.F., Nee, A.Y.C., 2001. A Distributed multiagent environment for product design and manufacturing planning. *International Journal of Production Research* 39 (4), 625–645.

Svensson, C., Barfod, A. 2002. Limits and opportunities in mass customization for ‘‘build to order’’ SMEs. *Computers in Industry* 49, pp.77–89.

Takeishi, A., Fujimoto, T. 2001. Modularization in the Auto Industry: Interlinked Multiple Hierarchies of Product, Production, and Supplier Systems. *International Journal of Automotive Technology and Management*, 1(4).

Thonemann, U.W., Bradley, J.R. 2002. The effect of product variety on supply-chain performance. *European Journal of Operational Research* 143, 548–556.

Tseng, M.M., Jiao, J. 1998. Design for Mass Customization by developing Product Family Architecture. *Proceedings of ASME Design Engineering Technical Conferences (DETC'98)*, DETC98/DFM-5717, September 13-16, Atlanta, Georgia, USA.

Wu, T., O'grady, P. 1999. A Concurrent engineering approach to design for assembly. *Concurrent Engineering: Research and Applications* 7 (3), 231–243.