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Connecting product design, process and supply chain decisions to strengthen global supply chain capabilities

Erika Marsillac [a,*], James Jungbae Roh [b,1]

[a] Old Dominion University, Norfolk, VA 23529, USA
[b] Rowan University, 201 Mullica Hill Rd., Glassboro, NJ 08028, USA

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ABSTRACT

The importance of product design as a main determinant of process design has been emphasized in operations management literature for decades, but the direct and indirect impacts of product design on process and supply chain activities is a research area that has received less attention to date. This multiple case study addresses this research gap by assessing how and why changes in product design shape process and supply chain practices and in particular, how these changes influence global supply chain behavior and capabilities.

Utilizing a 3DCE theory base, multiple manufacturing case studies are compared and contrasted to examine the interrelationships and dependencies among product, process and supply chain behaviors and capabilities. Product design changes were found to alter the scope and scale of process and supply chain modifications in specific ways that alter firms' competitive product design customization capabilities and competencies; flexible, advanced process technologies; and collaborative supplier practices.

This study contributes to operations management literature by providing a rich empirical analysis of operations system interplay. The study develops substantive research propositions and a 3DCE theoretical framework that may be used to drive future operations management research and in addition, provides managerial insights that can be used to strengthen supply chain capabilities in a global and dynamic context.

1. Introduction

Previous research in operations management has emphasized the emergent importance of product design, particularly as a large determinant of the total cost of producing and delivering products (Child et al., 1991; Hong and Roh, 2009). Perceived as essential in today's competitive and dynamic business environment, product design bears a strategic role, and can determine the direction and competitive advantage of a firm for years to come (Kilsun and Chhajed, 2000; Hong et al., 2011).

In the early stages of product development research, Hayes and Wheelwright (1979a, 1979b) developed a product process matrix to illustrate how product design can stimulate and determine process design. Many firms, and even government agencies such as the US Department of Defense, have subsequently used this matrix or similar principles to integrate product design and process selection, and to encourage cross-functional cooperation among operational, marketing, finance and engineering areas (DoD, 1998). Complementary research has expanded on this integrative perspective through the concept of three-dimensional concurrent engineering (3DCE), which describes certain overlapping responsibilities found among product, process and supply chains (Fine, 2000), but gaps in knowledge and research still exist.

Operations management research has separately addressed the influence of product design on supply chain type (Beamon, 1998; Christopher and Towill 2001; Lee, 2002; Christopher and Peck, 2004; Wang et al., 2004; Vonderembse et al., 2006; Kristianto et al., 2012), and the connections between product characteristics on supply chain strategy (Fisher, 1997; Vonderembse et al., 2006; Selldin and Olhager, 2007; Droge et al., 2012), but the majority of the research has addressed the individual associations *between* product and process, and *between* product and supply chain. Although valuable, by focusing on the individual linkages achieved, such as through product architecture or supplier integration (Fixon, 2005; Petersen et al., 2005; Rauniar et al., 2008), research on the simultaneous associations among product, process and supply chains has been addressed less frequently (Forza et al., 2005; Rungtusanatham and Forza, 2005; Marsillac and Roh, 2012).

This paper intends to address this research gap by utilizing a 3DCE theory base to examine the influences *among* product design, process and supply chain activities, determine how these influences develop and evolve, and in particular, explore how these changes influence global supply chain behavior and capabilities. This research contributes

* Corresponding author. Tel.: +1 757 683 3662; fax: +1 757 683 5639.
E-mail addresses: emarsill@odu.edu (E. Marsillac), Roh@rowan.edu (J.J. Roh).
[1] Tel.: +1 856 256 5430; fax: +1 856 256 4439.

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to operations management literature by using case study methodology to comprehensively examine four illustrative companies and their product, process, and supply chain activities. Assessments from within and across companies suggest the existence of integrative principles that may be used to strengthen firm's global supply chain capabilities. Study findings offer insights leading to a number of theoretical propositions and a framework of product/process/supply chain influences and behaviors.

2. Literature review

This paper begins by providing a brief overview of the underlying theoretical foundation that can support and integrate product, process and supply chains for global supply chain capabilities, that of three-dimensional concurrent engineering (3DCE). Following this overview, critical concepts are defined and reviewed, specifically: Product design, manufacturing processes, and supply chains, and the links between and among these concepts. The four illustrative case studies are then described and examined (both within each case and across all cases), with interrelationships and dependences among product design, process, and supply chain decisions elucidated. From this analysis, several propositions and a research framework are developed for future research. The paper then ends with a discussion of managerial implications and a section devoted to conclusions and future research directions.

2.1. Theoretical foundation

Three dimensional concurrent engineering (3DCE) was first introduced by Fine in the late 1990s in his seminal tome *Clockspeed* (Fine, 1998). 3DCE advocates the concurrent integration of product design into process and supply chain design, which is a departure from previous operations management foci of solely product and process. By concurrently addressing and balancing the needs of product, process, and supply chain, improved operational performance is encouraged and the entire system can be harmonized (Ellram et al., 2007; McKay and de Pennington, 2001). System harmony, in addition to yielding fiscal benefits, provides an opportunity for enhanced environmental benefits, an important cost/benefit/impact equilibrium that is unfortunately somewhat rare in today's global marketplace (Ellram et al., 2007, 2008).

Although recognized as an operations management theory with valuable potential applications, research on 3DCE and its applications remains nascent and its practical application is not yet widespread (Fine, 2000; Ellram et al., 2008; Ellram and Stanley, 2008). The simultaneous and dual-directional integration of design ideas in product, process and supply chains has been found to be challenging with few successful implementations of the theory in practice, e.g. Intel, Chrysler (Fine, 2000, Ellram et al., 2007; Caniato et al., 2012) (Fig. 1).

When addressing product, process and supply chain design, development and activities, 3DCE can be used as a unique theoretical lens to examine the influences of each area on the others, to help determine how those influences develop and evolve, and most importantly explore how those influences can be leveraged to improve global supply chain behavior and capabilities. To examine this effectively, a solid and shared understanding of the foundational elements of 3DCE, i.e. product, process and supply chains, and their potential interactions, must be presented.

2.2. Product design/development

Krishnan and Ulrich (2001) define product development as "a deliberate business process involving hundreds of decisions".

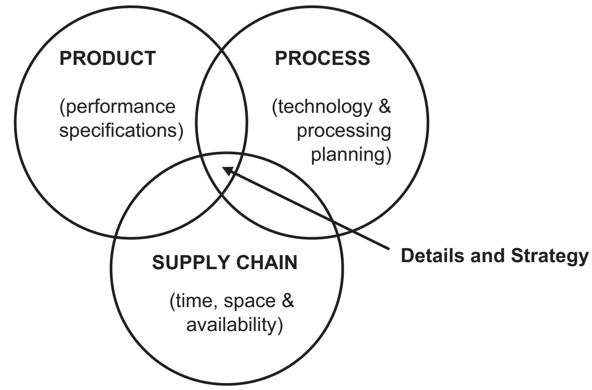

Fig. 1. 3DCE product, process and supply chain responsibilities (adapted from Fine, 2000).

This sum of multiple decisions focuses on developing a tangible, physical product, or developing an intangible service product. Krishnan and Ulrich (2001) focused their attention chiefly on the development of a tangible, physical product, and to simplify a complex subject, this paper will similarly focus on the role of product as a physical good.

Multiple perspectives of product development exist due to the fact that the product development process spans a broad range of decision areas (Hong et al., 2011; Hong and Roh, 2009; Rauniar et al., 2008; Petersen et al., 2005). Krishnan and Ulrich (2001) advocate for a operations management perspective of product development, which they define as including "…a sequence of development and/or production process steps", critical success factors of "supplier and material selection (and) design of production sequence", and decision variables that may include "development process sequence and schedule (and) point of differentiation in production process" (Krishnan and Ulrich, 2001, p. 3). Again to simplify a complex subject, this paper will similarly focus on the operations management perspective of product development.

2.3. Manufacturing processes

Manufacturing processes have changed as production has evolved from traditional craft systems to more modern industrial manufacturing infrastructures (Skinner, 1985). Throughout this evolution, process design has taken on greater prominence. Process design commitments are long-term, significant, capital intensive, and can determine the direction of a firm for years to come. They can help a firm develop sustainable competitive or first mover advantages, or instead shackle a firm to an inappropriate and unprofitable manufacturing future. In order to be successful, process design demands a coordinated strategy and integration of multiple areas of the firm (Hayes and Wheelwright, 1979a, 1979b).

Process goals have shifted through time, and as technology has advanced. For example, many traditional process priorities have changed or been replaced by new priorities, e.g. a traditional process emphasis on high volume has evolved to a process emphasis on faster time, or a traditional process emphasis on increased standardization has been replaced with an emphasis on increased flexibility and product variety (Skinner, 1985; Doll and Vonderembse, 1991). Even the role of manufacturing has changed, from that of a back-up, secondary player to that of a lead player, replacing the narrative of a silo mentality with one accentuating a more integrative, global approach. Within this evolution, researchers have recognized that former process expectations are no longer effective, so they must be modified. These