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Reconceptualizing the effects of lean on production costs with evidence from the F-22 program

Tyson R. Browning [a,*], Ralph D. Heath [b]

[a] Neeley School of Business, Texas Christian University, TCU Box 298530, Fort Worth, TX 76129, United States
[b] Lockheed Martin Aeronautics Company, P.O. Box 748, Fort Worth, TX 76101, United States

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ABSTRACT

A central tenet in the theory of lean production is that the implementation of lean practices will reduce waste and thereby decrease costs. However, not all lean implementations have produced such results. Apparently, this effect is moderated by several factors, potentially even to the point of reversal. It is important to increase our understanding of how this might occur. In this paper, we explore how novelty, complexity, instability, and buffering affect the relationship between lean implementation and production costs. An interest in these factors drew us to study the case of Lockheed Martin's production system for the F-22, an extremely complex and innovative product. To build theory, we synthesize our empirical data from the case with other existing theory, such as theories of learning and complexity. Through this analysis, we develop a revised framework that reconceptualizes the effect of lean on production costs and use it to develop 11 propositions to direct further research. Included among these are propositions about how the timing, scale, and extent of lean implementation can regulate the benefits of lean. Furthermore, when the objective of lean is construed as the provision of value, we propose that this value is an emergent property of a complex process, different from the mere sum of the values provided by its constituent tasks. Therefore, the elimination of tasks will not guarantee cost reduction, and lean may provide even greater value by incorporating some aspects of agile manufacturing. Overall, we develop a fuller range of the effects of lean practices on production costs and illuminate how operations managers might control key variables to draw greater benefits from lean implementation.

1. Introduction

A central tenet in the theory of lean production is that the implementation of lean practices will reduce waste and thereby decrease costs. However, not all lean implementations have led to such results. Apparently, this effect is moderated by several factors, potentially even to the point of reversal. It is important to increase our understanding of how this might occur.

We believe that a key limitation of most past studies is that they have failed to consider the impact of environmental context or organizational contingencies, which can affect the relationship between lean practices and production cost reduction. For example, White et al. (1999) and Shah and Ward (2003) found that plant size had a significant effect on the implementation of lean practices. This shows that, regardless of establishing *what* lean is, it remains important to establish *how* best to become lean in varied contexts. Good theory must address both what and how (Handfield and Melnyk, 1998), yet lean implementation has so far received much less attention in the scholarly literature. According to Shah and Ward (2003), "There is

* Corresponding author. Tel.: +1 817 257 5069.
E-mail address: t.browning@tcu.edu (T.R. Browning).

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not only a lack of empirical attention given to contextual factors' relationship with lean practices, but there is also a paucity of theory to guide our expectations about the direction of possible effects." Reports of lean implementations in several industries led us to explore the effects of novelty, complexity, instability, and buffering on lean implementation. In an age of increasing product functionality, diversification, customization, and change, novel and complex products are becoming more common, and they account for a significant portion of the economic output of developed countries (Wallace and Sackett, 1996).

In this paper, we look deeper into the mechanisms by which lean affects production costs. An interest in novelty and complexity drew us to conduct an in-depth case study of Lockheed Martin's production system for the F-22, the most sophisticated aircraft ever produced in a flow shop. To build theory, we synthesized the empirical data with other existing theories of complexity and learning to develop a revised framework that reconceptualizes the effect of lean on production costs. This analysis led to 11 propositions which can be tested in future research. In brief, we propose that the timing, scale, and extent of lean implementation matter, and we discuss how. Also, when the objective of lean is conceptualized as the provision of value, we propose that this value is an emergent property of a complex process, different from the mere sum of the values provided by its constituent tasks. Therefore, the elimination of tasks will not guarantee cost reduction, and lean may provide even greater value by incorporating some aspects of agile manufacturing.

The remainder of the paper is organized as follows. Section 2 establishes the conventional expectations of lean production, as well as some of the problems, and presents our initial framework for investigation. Section 3 explains our research methodology and site selection, after which Section 4 summarizes the case study data. Section 5 builds theory through a synthesis of the empirical data with extant theory. Section 6 concludes.

2. Background of lean production

2.1. Theory

While stemming from the roots of the mass production concepts developed in the U.S. by pioneers such as Samuel Colt and Henry Ford (Chase et al., 2006, p. 471; Flanders, 1925; Ford, 1926; Womack et al., 1990), lean production (hereafter, just "lean" for short) is broadly considered to have emerged from the innovations in the Toyota Production System (TPS) in Japan since the 1940s (Fujimoto, 1999), especially the just-in-time (JIT) delivery of materials between work stations to minimize work-in-process (WIP) inventories. While several historical reviews of lean are available (e.g., Hines et al., 2004; Holweg, 2007; Hopp and Spearman, 2004), a commonly accepted specification of the "theory of lean" in the scholarly literature is not. Therefore, we review the literature to isolate the theoretic tenets underpinning lean.

We begin by noting that the mere definition of lean varies widely. Various authors have equated or differentiated the TPS, JIT, and lean. Sugimori et al. (1977) wrote the first paper in English about the TPS, emphasizing JIT production and the use of good thinking by all employees to continuously improve performance. Several books and papers on JIT and the TPS emerged in the 1980s (e.g., Hall, 1983a,b; Monden, 1983; Ohno, 1988; Schonberger, 1982a,b,c; Shingo, 1989). According to Hopp and Spearman (2004), Ohno (1988) described the TPS as designed for continuous flow and based on two main principles: autonomation (best practices and standard work) and JIT (*kanban* and level production). Autonomation gives rise to practices pertaining to visual control, mistake proofing, and housekeeping (or "5S"—sort, straighten, sweep, standardize, and self-discipline), while JIT drives change-over reduction. Sohal et al. (1989) and Waters-Fuller (1995) provided reviews of the literature on JIT, and Fullerton et al. (2003) found a significant relationship between the implementation of JIT practices and improved financial performance at the firm level.

The term "lean production" was first used by Krafcik (1988) and popularized by Womack et al. (1990). To some, lean is just a repackaging of JIT. For example, according to Hopp and Spearman (2004), Womack et al. (1990) "freshened JIT by recasting it as 'Lean Manufacturing.'" Gaither and Frazier (2002, p. 464) equated lean with "the philosophies and approaches embodied in JIT." Krafcik (1988) and McLachlin (1997) viewed lean and JIT as closely related. Meanwhile, other authors such as Chase et al. (2006) equated lean instead with the TPS and considered it a compilation of many practices, of which JIT is only one. Some others have an effort to distinguish JIT and lean—e.g., "The major difference between JIT and lean production is that JIT is a philosophy of continuing improvement with an *internal* focus, while lean production begins *externally* with a focus on the customer" (Heizer and Render, 2006, p. 641, emphasis in original).

Despite these differences, there is much stronger agreement that the salient characteristic of lean, JIT, and the TPS is an emphasis on the *reduction of waste* (Brown and Mitchell, 1991; Chase et al., 2006; Hines et al., 2004; Monden, 1983; Ramarapu et al., 1995; Schonberger, 1982a; Sugimori et al., 1977). "Most sources describe the essence of lean production as waste reduction" (Hopp and Spearman, 2004). Ohno's "main focus was to reduce cost by eliminating waste" (Holweg, 2007). This emphasis on waste reduction drove practices such as inventory reduction (e.g., Hall, 1983a,b), process simplification (e.g., Hall, 1983a; Schonberger, 1986), and the identification and elimination of non-value-adding tasks (e.g., Blackstone and Cox, 2004), for which Womack and Jones (2003, p. 20) classified tasks into *three types*:

1. Those that add value (by directly transforming the product into the form desired by its user),
2. Those that do not add value but are necessary with current production methods ("Type 1 *muda*"), and
3. Those that do not add value and are unnecessary ("Type 2 *muda*" or "obvious waste").

Some authors have given prominence to other key practices in their definitions of lean, such as respect for people (e.g., de Treville and Antonakis, 2006; Sugimori