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The impacts of lean production on the complexity of socio-technical systems

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A R T I C L E I N F O

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A B S T R A C T

Although lean production (LP) is widely deemed as a means for influencing the complexity of socio-technical systems, empirical evaluations of this impact have not adopted an explicit complexity theory perspective, nor have they accounted for the multidimensional nature of complexity. This paper presents an investigation of the lean impacts on attributes of complex socio-technical systems (CSS) from several sectors. The assessment was based on a survey with 326 respondents. LP impacts on five bundles of complexity attributes were evaluated, namely: number of elements; interactions; diversity; unexpected variability; and resilience. The analyzed systems were firstly classified into manufacturing and services. Then, a cluster analysis divided each group into high and low lean adopters, based on their adherence to lean principles. Next, ANOVA tests were performed to check for differences in the intensity of complexity attributes between high and low lean adopters. Results indicated that LP in CSS tends to: (i) reduce the number of employees; (ii) reduce diversity of behaviors and beliefs; (iii) reduce disruptions due to information and human-related problems; (iv) increase richness and frequency of interactions; (v) increase functional diversity of elements; and (vi) increase resilience. While impacts (i), (ii) and (iii) reduce complexity, the others imply in its increase, suggesting that LP can be an effective way of balancing complexity attributes. Also, the framework for data analysis can be used for assessing lean impacts on the structure and functioning of socio-technical systems of different natures, thus supporting the understanding of lean systems from a complexity perspective.

1. Introduction

One of the reasons for the academic and industrial interest in Lean Production (LP) is its contribution for the removal of unnecessary complexity from socio-technical systems, which is a form of waste (Saurin et al., 2013). Farrokhi et al. (2015), for example, describe a lean intervention that reduced the number of instruments in an operating room from 197 to 58, decreasing unnecessary diversity and, therefore, unnecessary complexity.

While less emphasized by literature, lean can also benefit from complexity and even increase it in some dimensions. For example, just-in-time supply chains make systems tightly-coupled, which increases interactive complexity, as well as efficiency (Christopher, 2012; Perrow, 1984). Indeed, relationships between lean and complexity are not trivial, and there are many nuances to be explored (Van Der Krogt et al., 2010). The case reported by Gopinath and Freiheit (2012), for example, highlighted how different sources of waste were highly interconnected to the point that it was not possible to eliminate one source without creating undesired side-effects. In fact, even the key lean concepts of value and waste are not clear-cut in complex socio-technical systems (CSS), since there are multiple clients which may have partially overlapping and partially conflicting requirements (Bishop et al., 2014; Browning and Heath, 2009; Johansson and Osterman, 2017).

Furthermore, earlier studies that considered lean as a way of reducing complexity used this term in a loose manner, without commitment to complexity theory (Godinho Filho and Barco, 2015; Lian and Van Landeghem, 2007). Previous studies focused on one or two attributes of complexity, disregarding the multidimensional nature of this concept (Elmaraghy et al., 2014; Soliman and Saurin, 2017). Thus, there is a paucity of empirical evidence collected and analyzed within a complexity theory framework, to sustain generalizable claims about the relationships between lean and complexity. This drawback can be due to the lack of a framework for assessing the said relationships, which can offer high-order insights and a new account of why and how LP works, in terms of mechanisms of systems functioning.

Hence, two complementary research questions (RQ) are addressed by this study, as follows: RQ1: how to analyze the impacts of LP on the complexity of socio-technical systems; and RQ2: what are the lean production impacts on complexity? We are assuming that the investigation of these questions is a desirable requirement for future studies that intend

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to go deeper in the investigation of the detailed mechanisms linking lean and complexity. In order to address RQ1 we developed a framework for analyzing the impacts of LP on five bundles of complexity attributes, which account for complexity manifestations in four sub-systems of socio-technical systems (i.e. social, technical, work organization, and external environment).

As for the RQ2, based on the said framework, we conducted a survey with 326 respondents from both manufacturing and service systems, checking for differences in the intensity of complexity attributes between high and low lean adopters. Results pointed out lean that has a mixed impact on the complexity attributes, and that the proposed framework articulates the lean impacts on both social and technical dimensions, which are usually analyzed separately in lean research. The theoretical and practical implications of these findings are discussed based on the empirical data collected in the survey.

2. Theoretical background and hypothesis development

2.1. Lean principles adopted as a basis in this study

Lean production has its roots in the Toyota Production System (TPS), which emerged from decades of experimentation and trial and error (Fujimoto, 2001). As such, there is a consensus that managerial and behavioral principles are the keys of the TPS, rather than visible artifacts such as *kanban* cards, *andons* and *poka-yoke* devices (Liker and Hoseus, 2008; Spear and Bown, 1999). Thus, in our empirical study, we adopted one of the most well-known accounts of those principles, which was proposed by Liker (2004). These principles are divided into four groups, also known as the 4P's of the TPS (Table 1).

Our choice for Liker's principles is due to three main reasons: (i) their broad view of what a lean system looks like; (ii) their high abstraction level, which makes them meaningful in different contexts; and (iii) their clear links with most (if not all) practices commonly associated with a lean system - e.g. pull production is obviously associated with L3, while the same holds true for visual management and L7. Furthermore, some of the principles cover philosophical and cultural aspects of lean, which have been more and more recognized as a key for successful implementation. The same principles have been previously adopted by Shang and Sui Pheng (2012) and Dombrowski and Mielke (2013), among others.

Table 1
Liker's principles of the Toyota Production System.

Perspective	Principles
Philosophy	L1. Base your management decisions on a long term philosophy, even at the expense of short-term financial goals
Process	L2. Create a continuous process flow to bring problems to the surface
	L3. Use “pull” systems to avoid overproduction
	L4. Level out the workload
	L5. Build a culture of stopping to fix problems, to get quality right the first time
	L6 Standardized tasks and processes are the foundation for continuous improvement and employee empowerment
	L7 Use visual control so no problems are hidden
	L8 Use only reliable, thoroughly tested technology that serves your people and process
People and partners	L9 Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others
	L10. Develop exceptional people and teams who follow your company's philosophy
	L11. Respect your extended network of partners and suppliers by challenging them and helping them improve
Problem solving	L12. Go and see for yourself to thoroughly understand the situation
	L13. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly
	L14. Become a learning organization through relentless reflection and continuous improvement

Source: Liker (2004).

2.2. Attributes of complex socio-technical systems

Complexity science represents a paradigm shift from reductionism, which assumes that systems can be understood by the sum of its parts, to holism, which stresses the understanding of emergent phenomena, which arises from interactions and exhibits new properties that do not exist in the parts (Manson, 2001). In fact, complexity science has profound philosophical implications, since its ontology is focused on the abstract interactions between elements (e.g. how people, process and technologies interact to produce a desired output) rather than only the internal structure of those elements (e.g. the tools or equipment that transform inputs to outputs) (Heylighen et al., 2007).

According to Walker et al. (2010), there are three approaches to complexity. The first, referred to as the attribute view, is the most used one and it assumes the complexity of a system can be described through attributes such as number of parts and interconnections, change and dynamism (Azadegan et al., 2013). The second approach is focused on defining measures of complexity (e.g. computational equivalence), which corresponds to the amount of data necessary to reproduce the system (Manson, 2001). The third view assumes complexity as an emergent characteristic of socio-technical systems (Cilliers, 1998).

In this study, the attribute view was adopted. This perspective is relevant for the purpose of this study, since we are interested in analyzing the impacts of LP on multiple dimensions of complexity, rather than on specific metrics or one or two characteristics. Attributes of CSS commonly described in literature are nonlinear interactions (Perrow, 1984; Snowden and Boone, 2007), adaptive capacity (Kurtz and Snowden, 2003; Stacey, 2000), openness to environment (Cilliers, 1998), feedback loops (Cilliers, 1998; Érdi, 2008; Perrow, 1984), large number of elements (Carayon, 2006; Cilliers, 1998; Johnson, 2010), and emergent properties (Érdi, 2008; Sweeney, 2006). Saurin and Gonzalez (2013) compiled attributes from several studies into four categories (or meta-attributes), as shown in Table 2. These categories were adopted in

Table 2
Attributes of CSS and examples.

Attributes	Examples in socio-technical systems
A large number of elements	- High number of people, parts, procedures, materials, flows. - Many external partners
Dynamically interacting elements	- People, materials, information and technologies interacting in a nonlinear fashion - Operations with little slack (tightly coupled system). E.g. just-in-time, processes arranged in continuous flow, etc.
Wide diversity of elements	- Social diversity: age, instruction level, nationality, language, culture, etc. - Technical diversity: many technological levels; equipment from different manufacturers; a myriad of supplies and raw materials, procedures, etc. - Functional diversity: roles played by workers, mix of products made by the same machine, etc. - Organizational diversity: hierarchical levels, sectors, departments, subsidiaries, business types; management styles, etc.
Unexpected variability	- Internal variability: absenteeism, machine breakdown, quality of materials, uncertainty of measures, workarounds, etc. - External variability: demand fluctuation, economic crisis, politics, currency exchange, strikes, natural disaster, terrorism, war, etc.
Resilience	- Ability of the system to adjust performance and sustain required operations under expected and unexpected conditions - Slack of resources (in the form of stocks, time, money, people, area, cognitive capacity, etc.) to cope with variability - Adaptive capacity to reorganize the system and to create slack

Source: Adapted from Saurin and Gonzalez (2013).