Lean Product Development for a Circular Economy: An Operations Management Perspective

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Abstract. For years, manufacturing companies have been working with developing and implementing lean thinking to continuously improve the management of their operations. Since lean thinking provides tools and approaches to solve problems enterprise-wide, there is an ambition among lean companies to use the lessons learned while applying lean, to develop and implement a more circular economy approach to their operations. However, extant research combining lean and circular economy concern mostly the business model level and there is a lack of research on how to bring circular economy thinking to the operations. Even though both lean thinking and circular economy emphasize the importance of designing products that can be manufactured in an efficient way, using as few resources as possible, and without waste, the extant literature combining these concepts refers mainly to the processes concerning the product's end of life. This paper deploys the 'by design' aspect of circularity through the lens of lean product development, a key element within the lean thinking concept.

Keywords: Circular economy · Lean product development

1 Introduction

The pressure on becoming sustainable challenges industry to shift existing business models and disrupt the way their operations are managed and performed. Even though business models and operations management (OM) models are deeply interrelated, they embody two different concepts. The first refers to how an organization realizes its revenues by capturing and delivering value to its customers. By contrast, OM refers to how an organization creates that value. OM includes the location where value adding activities are done, the information system supporting these operations, the network of

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contributing suppliers, as well as the management system that coordinates the overall value chain [1]. As such, OM entails a wider process of developing products that add value to the customer and society [2].

However, becoming sustainable implies to adapt or to change both the business and the operating models to deliver products that fit within the requirements imposed through the UN's sustainable goals. Among the tools developed for achieving these goals is the Circular Economy (CE) concept that aims at eliminating any types of waste from the design phase of a product throughout the manufacturing process, as well as its beginning of life to the end-life [3, 4]. Indeed, the concept of CE differs from the linear approach (i.e., produce-consume-dispose) by replacing the idea of 'throughput' with the idea of 'roundput' where resources are used but not used up [5] by the means of cyclical thinking [6].

In general, CE is considered a superior concept for achieving sustainability goals, but methods to implement CE in manufacturing operations are still scarce. Researchers have recommended combining lean thinking with CE to facilitate a better implementation of the latter [7–9]. Yet, despite these efforts, there is a lack of published work that provide viable results of the combination of these concepts towards sustainable OM [7]. In most extant research, CE has been introduced predominantly as a pathway for product life-cycle design and business model development while the CE concept in the context of OM has received a lesser amount of attention [10].

Furthermore, most research on lean and CE focuses on the waste reduction part of lean and on proposing models that combine lean (or green-lean) solutions with CE elements [7, 8]. Consequently, the focus is predominantly put on the direction of how to handle companies' current products but miss to introduce circularity at the product development phase from the OM perspective. This is rather interesting since CE is about products that are regenerative by design. Achieving that implies a radical change in the way products are designed and the way materials are selected and combined for each product. The challenges inherent in the required efforts might be solved by applying tools belonging to the Lean Product Development concept (LPD). To our knowledge, there is limited research where LPD is proposed as an approach to embrace when designing circular products. LPD was developed by Toyota as an integrated part of their OM system. They created each product by considering people, the whole manufacturing process as well as the technology needed for producing each new product. Such an approach allowed Toyota to focus on choosing the most appropriate materials, modularization elements, and other characteristics of a product while considering the constraints of the manufacturing line at theirs, as well as at suppliers' facilities [2].

With respect to a more holistic understanding of the topic, we derive this paper from theoretical and conceptual works to delineate potential opportunities of LPD within the context of CE. Thus, the following research question is posed: How can CE implementation benefit from LPD principles to realize more sustainable OM strategies?

2 Theoretical Background

2.1 Circular Economy

Among the most cited definitions of CE is the one provided by the Ellen MacArthur foundation who states that CE is "*an industrial system that is restorative or regenerative by intention and design*" [11]. The same organization identifies five pillars of the CE concept: 1) design out waste, 2) build resilience through diversity, 3) shift to renewable energy sources, 4) think in systems, and 5) think in cascade. Succinctly put, CE enables effective flows of materials, information, human resources, energy so that the natural and social capital can be rebuilt. The idea is to optimise systems rather than components, thus context is everything and, in order to provide productive and robust flows through continuous rebuilding of the capital stock, "design for fit" is an essential element [12].

While the concept of CE presents a great potential for achieving sustainable operations, the challenges for its adaptation and operationalization within most management styles of today, seem to remain unclear. An increasing number of new techniques, methods and models are being developed and most of these induce a complete change of the existing OM system. This requires investments in machines and materials as well as in upskilling the existent labor force. For most small and medium sized companies, it is rather challenging to accomplish such transitions due to higher capital and skills requirements [8]. In many aspects, the challenges are similar to those being aired with regards to lean thinking implementation.

Hence, while CE is rich in concepts and approaches, examination of pragmatic steps toward implementation often falls short [3]. Thus, to achieve a favourable integration of CE with OM, companies must identify specific meanings relevant to the manufacturing domain [10]. For that, there is a need to apply a form of system thinking across the whole life cycle of the product. A systematic approach can predict and avoid creating environmental problems by addressing and eliminating the root causes of these problems from the design phase [13]. To incentivize that, there is also a need for tangible design and engineering targets that can function as environmental key performance indicators [14].

2.2 Lean Product Development

Within OM, lean thinking is acknowledged as one the most successful paradigms for managing operations and in many cases implies a high beneficial impact on sustainability [15]. According to [16], understanding lean thinking requires a close look at every step in the value creation process, beginning with the process of developing and engineering the product and then continuing along the entire manufacturing chain until the customer is reached. Another perspective on lean thinking is provided by [17] who emphasizes the view of lean as a socio-technical system based on systematic routines that underlines scientific reasoning at all organizational levels.

Lean thinking as a concept was first introduced in the 1980's to describe a manufacturing system that transformed the traditional logic of mass production following a longitudinal study of the automotive industry [18]. A lean approach is capable of manufacturing a broad range of products in relatively low volumes at competitive costs

[18]. LPD seeks to enhance value and reduce cost from a product perspective [19]. As such, LPD practices can be described as 13 principles that together can help organizations design better products by " *appropriately integrating people, processes, tools, and technology to add value to the customer and society*" [2].

According to [2], the thirteen principles of LPD are: 1) Establish customer-defined value to separate value-added activity from waste. 2) Front-load the product development process while there is maximum design space to explore alternative solutions thoroughly. 3) Create a leveled product development flow. 4) Utilize rigorous standardization to reduce variation and create flexibility and predictable outcomes. 5) Develop a chief engineer system to integrate development from start to finish. 6) Organize to balance functional expertise and cross-functional integration. 7) Develop towering technical competence in all engineers. 8) Fully integrate suppliers into the product development. 9) Build in learning and continuous improvement. 10) Build a culture to support excellence and relentless improvement. 11) Adapt technology to fit your people and processes. 12) Align your organization through simple, visual communication. 13) Use powerful tools for standardization and organizational learning. These principles are grouped under three categories: process (principles 1 to 4), people (principles 5 to 10), and technology (principles 11 to 13) [2].

Adding to these principles, Toyota developed tools and guiding rules that can be applied when implementing each of these principles (for a detailed description, see [2]). To exemplify, among of the tools developed to support decision making in the design and engineering process while considering a holistic view of the entire value chain is the one called Obeya. This tool facilitates the process of making decisions through direct communication and information sharing, team integration, and maintaining partnerships [20]. The term defines systematic meetings with specialists from each department within the company. Each of these specialists brings specific knowledge to the process of developing a new product. Succinctly put, LPD is a holistic approach to manufacturing products through an integrative process where quality is built in, while waste is eliminated starting at the design and engineering phase [2].

Still, the implementation of lean thinking is perceived by many as a concept that does not concern for the environment since its focus is on improving the business processes. Meanwhile, several other authors do agree that lean thinking alongside improving business performance, also contributes to improving the environment [7, 9, 21]. The latter studies have indeed concluded that holistic frameworks are essential in deepening our understanding of how to jointly use lean while being environmentally and socially responsible [21]. This is also in line with E. Deming's ideas of modifying or replacing industrial processes to consume fewer resources and eliminate any form of waste [14].

3 Method

This paper is based on a literature study in two main domains: CE and LPD. Literature studies represent an essential element of any research as they: 1) enable mapping, summarizing, and evaluating the knowledge base relevant for a studied topic, and 2) provides guidance for future studies to address knowledge gaps [22]. To better understand the phenomenon under investigation, a literature review was carried out using

the search terms: 'lean product development and circular economy' in several different styles within the following scientific databases: Science Direct, Google Scholar, and Web of Science. From an initial collection of 139 articles, non-peer-reviewed papers, theses, foreign texts, and duplications were removed. As such, 48 articles proceeded to be reviewed in full. Among these, several articles consider LPD as a tool towards sustainability at the business model level e.g., [14, 23] while CE is mentioned as an element within the sustainability approach. Other articles bring LPD as a supporting tool for knowledge exchange or learning within and among organizations aiming to become circular e.g., [24, 25]. However, none of the reviewed articles provide research about the applicability of LPD's principles and tools as an OM supporting model in the process of implementing CE.

4 Discussion

For most companies, implementing a CE involves radical changes of the business and the operating models. This is partly due to CE being applied as a disruptive and innovative economic model that relates to government policy, businesses, and consumers. At its core, CE is restorative and regenerative by design, structure, and objective. Through CE, products, components, and materials are designed to continuously add, recreate, and sustain value at all times. As such, CE challenges the existing business models and forces a rethinking of the many various aspects of OM and product utilization across the entire value chain [3]. To achieve circularity, products must be designed with the disassembly process in mind leading in this way to more predictable material recovery rates while generating more value and less waste [26]. Most of the articles combining lean and CE assume the elimination of waste as one of the main connecting principles. However, real circularity can be achieved only by designing the product in a way that eliminates any form of waste along the whole value chain.

Reviewing the existing research that combines lean thinking and CE implemented at the OM level proved to show a lack of published work on this particular topic, also in line with the conclusions of [7]. At the same time a contrasting difference between lean and CE is, according to [8], that lean focuses on the immediate and effective usage of the resource within a specific process, while CE takes a more holistic approach from systems perspective, as to enhance the value of the resource even after the ended life cycle of the product. Yet, this analysis lacks to consider the systematic approach provided by LPD where people, processes, and technology are integrated towards a holistic view of the entire value chain.

Nevertheless, there is a large gap on the literature combining LPD and CE. The literature on CE accentuate that companies should focus on the design phase, if not, companies can risk missing out the cost-and environmental benefits that can be reaped from disassembly, reuse, refurbish, or remanufacture each element of the product to be disposed. Without such effort, there will always be a poor rate of circularity within the whole OM process. It is here LPD can provide valuable insights and methods. LPD argues that many of the attributes of a product are established during the design phase and the decisions taken at the early design stage therefore determine the scale of the environmental impacts. Sutherland et al. [13] capture the essence of this idea:

'a poor design, from an environmental standpoint, cannot really be remedied during manufacturing'. Thus, in order to succeed with CE in OM, companies need to include circular targets in the design and development of each new product.

LPD aspires to provide a system and structure to enable people to bring their best selves and contribute to making great products that are design efficient from both a financial and environmental perspective. One of the LPD principles refers to adapting technology to fit company's people and processes (principle 11). Applying this principle could reduce the amount of investment needed for implementing CE as without focusing on the people dimension, no transformation of product development will be able with regards to the business model aimed at. LPD emphasizes the collaborative aspects of developing a product and by using tools like Obeya rooms it gives the possibility of including issues connected to the end-of-life of the product within the design and engineering phase. Extending the number of participations in the product development process with specialists that address this part of the value chain will create better opportunities at the OM level and uncover uncaptured value within the existing business model. Since product development is a team sport, it takes effective collaboration to meet the targets, which are supported through having compatibility before completion and using Obeya rooms effectively.

Table 1 provides a tentative framework that depicts the applicability of the LPD within the five CE principles. The first five LPD principles resonate well with the first principle of circularity, which is design out waste. This can be done through building CE competence at both design and production levels while considering customers' requirements. Building resilience through diversity, the second CE principle, can be accomplished through developing people and by involving suppliers to be part of developing circular products (cf. Principles 6–9). Such approach is also necessary when applying a systematic thinking throughout the whole OM process so that the company can effectively adapt its processes and technology to support a circular model. The third and fifth CE—shift to renewable energy sources and think in cascade - can be added as desirable elements of the entire OM process that needs to be redesigned and improved continuously. Yet, this type of association needs to be tested in lean companies who are willing to apply LPD tools when implementing CE.

Implementing CE at the operational level in a company, is, like for lean, dependent on the level of understanding at the leadership level, the context of the implementation, and the level of training among the employees. There is no "one-solution fits all" type of approach and each company should first ensure at least a basic level of training of its people through continuous improvement possibilities. This literature-based study has found that while LPD in itself might appear agnostic to circular thinking, it is a system that could be effectively used to support adaptation of CE by using the tools developed for a successful LPD implementation. A circular product can be achieved through a close collaboration among all stakeholders including both the ones at the beginning of life as well as the ones dealing with the product after its lifecycle was completed.

Table 1. LPD and CE principles

	LPD Principles	CE Principles
1	Establish customer-defined value to separate value-added activity from waste	1) design out waste,
2	Front-load the product development process while there is maximum design space to explore alternative solutions thoroughly.	
3	Create a leveled product development flow	
4	Utilize rigorous standardization to reduce variation and create flexibility and predictable outcomes	
5	Develop a chief engineer system to integrate development from start to finish	
6	Organize to balance functional expertise and cross-functional integration	2) build resilience through diversity 3) shift to renewable energy sources
7	Develop towering technical competence in all engineers.	
8	Fully integrate suppliers into the product development.	
9	Build in learning and continuous improvement.	
10	Build a culture to support excellence and relentless improvement.	
11	Adapt technology to fit your people and processes.	4) think in systems 5) think in cascade.
12	Align your organization through simple, visual communication.	
13	Use powerful tools for standardization and organizational learning.	

5 Concluding Remarks

An important aspect of CE is to understand what customers consider valuable in regards to the final product and to include sustainable aspects as well as circularity aspects [14] from the design phase throughout the whole OM process.

Collaboration across departments and stakeholders create an understanding of the environmental implications of decisions at the design stage with clear roles and responsibilities for execution. Promoting a culture of sustainable development that integrate product development with circularity can become a key objective in lean companies. Part of a successful implementation of CE lays in training engineers in the principles, strategies, tools, and methods of CE so that these become a part of their professional development not just a constraint. LPD tools may be the missing holistic approach that most lean companies can use in becoming circular.

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