The Interrelation of Lean and Green Manufacturing Practices: A Case of Push or Pull in Implementation

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Abstract--**Literature in the environmental sustainability field has underscored the importance of "Sustainability" as a driver of innovation. In this mindset firms seek new approaches of how companies deliver value to their customers, the impact on the environment of these value delivery activities, and the resulting societal welfare created by changing the way products and processes are created. As companies rethink their business models to facilitate sustainability, they also find themselves looking for new manufacturing approaches to meet the challenges of competition. In this environment, companies are implementing Lean manufacturing to improve organizational performance and are introducing cLean practices to achieve environmental sustainability. Therefore, the main goal of this study is to analyze how companies can integrate Lean and Green production principles in order to take advantage of their synergistic effects and reach competitiveness in accordance with the objectives of sustainable development.**

I. INTRODUCTION

Lean manufacturing and Green manufacturing are two well-known manufacturing approaches. Many organizations have implemented aspects of each approach, with the purpose of creating value through quality products and services and at the same time reducing manufacturing and/or environmental wastes [1][2]. There is, however, a need to understand if Lean practices can lead to environmental benefits and if environmental practices may lead to improved Lean practices. We identify studies where organizations that chose to implement one approach experienced positive outcomes in terms of organizational and/or environmental performance related with the other approach.

The purpose of this paper is to briefly examine and compare these two manufacturing approaches in order to understand their relationship using literature review as a research method. Understanding the Lean and Green relation is essential for organizations implementing these manufacturing systems since they can maximize their performance gains. A relational model is proposed to investigate the systemic impact of these practices on firm performance, and identify interaction pathways.

II. LITERATURE REVIEW

A. Lean Production

The term "Lean" has been promulgated to refer to manufacturing businesses that utilize an underlying set of manufacturing principles and practices that are expected to lead to a better state of operations. Originating in the automotive industry as a generalization of the practices observed in the Toyota Production System (TPS), Lean manufacturing seeks to eliminate all forms of waste or "muda" as a means to lower costs and reduce lead times, while maximizing production efficiency based on customer demand [3][4][5][6][7]. The literature on Lean suggests that production activities can be defined as either value-added (VA) or non-value-added (NVA) [6][8]. Value added activities are defined as activities that transform a product or service for which customers are willing to pay. Non-value-added activities are those activities for which the customer would not be willing to pay. Therefore the Lean manufacturing philosophy is based on a set of practices aimed to enhance the whole value chain within an organization [8][9] and eventually external to the organization [10]. To attain these objectives, five tenets of Lean are promulgated, namely value, value stream, flow, pull, and perfection, which aim to align production capabilities with customer demand rate, or takt time [8]. These tenets seek to guide the Lean transformation by specifying customer value by product, identifying the value stream for each product; making the value flow without interruption; letting the customer pull the value from the produce, and finally pursuing perfection as a reminder that the process of transitioning to Lean should never end. In this light, the improvement steps can be repeated to gain further improvements.

Within the concept of Lean thinking, waste is defined as everything that does not directly add value to a product based on customers' needs and requirements. In this framework, seven types of waste are recognized [6]: defects, inventory, overprocessing, waiting, motion, transportation and overproduction. Overproduction means producing over customer orders, producing unordered materials/goods; Waiting means hanging around, idle time (time when no value is added to the product); Transportation represents handling more than once, delays in moving materials, unnecessary moving or handling; Inventory is associated with unnecessary raw materials in stores, work in process (WIP), and finished stocks; Motion is the movement of equipment or people that add no value to the product; Overprocessing results from unnecessary processing or procedures (work carried out on the product which adds no value); and Defects appear when producing or reworking scrap. As a strategy developed for production performance, Lean manufacturing has expanded as a business practice and extended beyond manufacturing to succeed in service industries and product development operations with varying levels of success [11][12][13][14].

B. Green Manufacturing

More recently, sustainability has become an important issue within businesses as a result of concerns over natural resources depletion, wealth disparity, and social responsibility [15]. In this regard, organizations are rethinking their products and processes implementing environmental management practices. This focus, has led to the concept of environmentally conscious manufacturing, also referred to as "Green Manufacturing" [16]. The concept of Green manufacturing has been seen as a new manufacturing paradigm that uses Green strategies and innovative techniques, including products/systems that consume less material and energy; new input materials; processes to reduce unwanted outputs; and programs to convert outputs into inputs (recycling) or new by-products (secondary product outputs) with the purpose of reducing environmental wastes when companies utilize resources to provide products or services to their customers. In this context, environmental waste has been defended as the unnecessary use of resources, or the release of a substance to the air, water, or land that could harm human health or the environment [1][17]. Different environmental metrics have been proposed to track environmental wastes, including but not limited to, energy use, materials use, solid waste, scrap, air emissions, wastewater discharges, hazardous waste, and water use [17].

Three different manufacturing approaches to reduce environmental wastes have been cited within the Green manufacturing filed. These approaches include pollution control, pollution prevention also known as cleaner production, and product stewardship. Pollution control is an "end of pipe" approach and is related to the methods to trap, store, treat, and/or dispose of pollution after it is created [18]. Pollution prevention is related with activities intended to eliminate emissions, affluent, and wastes. Viewed as a continuous improvement approach, pollution prevention may provide organizations advantages over their competitors when implemented; that is, pollution prevention may results in lower costs for raw materials and waste disposal as well as can help reduce cycle times by removing unnecessary steps in production and operations, which provide organizations benefits in terms of increased productivity, efficiency, and enhanced cash flow and profitability due to reductions in costs [18][19]. Finally, product stewardship extends the environmental perspective to the entire value chain, including other internal and external stakeholders such as R&D, product designers, and suppliers [18].

Within the Green manufacturing field, different authors have reviewed the literature to identify the perceived importance of Green manufacturing practices [15] [20]. Sezen and Cankaya [15] classified their review about Green manufacturing into two groups. The first group included studies focused on describing the concepts and frameworks for implementation, while the second group contained works that provided various analytical tools and models to realize Green manufacturing at different levels. Govindan et al. [20] showed the positive relationship between Green manufacturing and sustainability as well as its impact on operational performance.

C. Lean and Green relationship

Different authors have addressed the relation between Lean and Green manufacturing. For example, Lean and Green manufacturing have be seen as compatible or complimentary initiatives because of their joint focus on waste reduction, efficient use of resources, and emphasis on satisfying customer needs, at the lowest possible cost [21]. Lean manufacturing and environmental management practices are considered synergistic in terms of their focus on reducing waste and inefficiency [22]. There is a growing body of evidence to support the theoretical links between Lean manufacturing and environmental benefits, as shown in Table 1. The relationship between these two concepts arose from the hypothesis that when implemented, the focus of Lean for reducing non-value added activities helps directly or indirectly drive down the negative effects of different environmental wastes by producing less of them. One important fact about this relationship is that Lean can enhance the benefits of pollution prevention approaches. That is, according to the EPA [17], environmental wastes are embedded in or related to the seven Lean wastes. Therefore, by expanding Lean theory to consider environmental wastes as an 8th form of waste, Green manufacturing programs can maximize their gains when Lean methods are applied to specific pollution prevention activities. Table 2 provides examples of environmental wastes associated with the seven Lean wastes.

Lean and Green manufacturing also share the goal of enhancing performance indicators, as both approaches seek to improve quality and time as well as to reduce costs while generating value [1][2][3]. According to Deif [1] the use of Green manufacturing helps reduce material wastes and energy consumption which diminishes production costs and improves production time. It will also improve the quality of the production process which will in turn impact product quality. Similarly, Gupta and Jain [3] state that the main goal of a Lean manufacturing system is to produce products of higher quality at the lowest possible cost and in the least time by eliminating wastes.

It is noteworthy that both approaches share waste reduction as an objective, with the added benefit of bringing savings to organizations. Few studies have found negative interactions between Green and Lean manufacturing, but they may exist. In the case of Green manufacturing, organizations may require, in some cases, the use of less harmful raw materials. These materials could be costly, increasing production costs. Similarly, Lean manufacturing can result in negative environmental impacts when more Greenhouse gases (GHG) are emitted due to changes in supply chain management due to just-in time (JIT)materials delivery [23][24].

TABLE 1. JOURNAL ARTICLES ASSESSING LEAN AND GREEN MANUFACTURING

Article	Author(s)	Publication title	Finding(s)
1	[36]	Lean and Green: the move to environmentally conscious manufacturing	Found that a relationship between Lean supply chain members facilitate the adoption and spread of environmental practices and innovations.
2	[48]	Case study: Honda of America Manufacturing, Inc.: Can Lean production practices increase environmental performance?	Highlighted that waste minimization through Lean manufacturing motivate environmental activities
3	[44]	Lean and Green? an empirical examination of the relationship between Lean production and environmental performance	Found that Lean production is complementary to waste reduction and pollution reduction
4	[24]	Lean, Green, and the quest for superior environmental performance	Found evidence to support the link between Lean practices and resource efficiency and environmental performance
5	[31]	Using Kaizen to Reduce Waste and Prevent Pollution	Found that Lean manufacturing supplies the organization with the tools necessary to accomplish its pollution prevention goals
6	[28]	Lean and Green: doing more with less	Highlighted that Lean and Green thinking have a great deal in common, both challenging the way resources are currently used and promoting initiatives designed to “do more with less”
7	[47]	Perfect Complements: Synergies between Lean Production and Eco-Sustainability Initiatives	Found that Lean manufacturing produces substantial resource productivity improvements that contribute directly to environmental performance gains.
8	[32]	Use the supply relationship to develop Lean and Green suppliers	Found evidence suggesting that environmental practices may be developed as part of a close relationship in a low transaction cost manner as a direct and indirect feature of any Lean transformation
9	[16]	Do Green supply chains lead to competitiveness and economic performance?	Provided a literature review about Lean production and Green supply chain
10	[39]	En-Lean: a framework to align Lean and Green manufacturing in the metal cutting supply chain	Presented a case study to illustrate the relation between Lean and environmental performance
11	[49]	Mediated effect of environmental management on manufacturing competitiveness: An empirical study	Highlighted that firms with closer supplier partnerships and solid continuous improvement practices are more likely to develop a proactive environmental Management program, which enhances competitive advantage through cost savings, quality improvement, and process/product innovation
12	[30]	Lean Manufacturing for Sustainable Development	Showed Lean manufacturing system provides a competitive strategy to achieve sustainable development
13	[43]	Green, Lean, and global supply chains	Examined the relationship among Green, Lean, and global supply chain strategies and revealed drivers, barriers, converging, and contradictory points across the three strategies
14	[40]	A case study of Lean, sustainable manufacturing	Found Lean and Green manufacturing can have a more significant, positive impact on multiple measures of operational performance when implemented concurrently rather than separately
15	[38]	Lean, agile, resilient and Green: divergencies and synergies	Provided links between Lean, agile, resilience and Green paradigms and the supply chain performance. Identified synergies and divergences between the paradigms
16	[41]	Tools and techniques for enabling sustainability through Lean initiatives	Provided strategies/techniques that enable an organization to acquire environmental performance using Lean initiatives
17	[22]	Impact of Lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms	Explored the relationships between Lean manufacturing practices, environmental management, and business performance
18	[45]	Lean to Green supply chain management: a case study	Suggested a strong correlation between Lean and Green supply chains
19	[46]	Model of efficient and sustainable improvements in a Lean production system through processes of environmental innovation	Demonstrated that costs, income, social responsibility and sustainability can be improved when environmental innovation is applied, when the production system is transformed into a Lean system
20	[37]	Lean management and supply management: their role in Green practices and performance	Found that the impact of Lean management, and to a lesser extent supply management, on environmental performance is mediated by environmental practices
21	[34]	Assessment of Lean and Green strategies by simulation of manufacturing systems in discrete production environments	Studied the effect of Lean and Green strategies inside a manufacturing system through a case study. The implementation of both strategies resulted in reductions in production costs

TABLE 1. JOURNAL ARTICLES ASSESSING LEAN AND GREEN MANUFACTURING - CONTINUE

Article	Author(s)	Publication title	Finding(s)
22	[25]	Green as the new Lean: how to use Lean practices as a catalyst to Greening your supply chain	Provided evidence suggesting that Lean is beneficial for Green practices and the implementation of Green practices in turn also has a positive influence on existing Lean business practices
23	[21]	Modelling Lean and Green: a review from business models	Identified the models that should influence the Lean and Green culture
24	[29]	Lean and Green product development: two sides of the same coin?	Compared the Lean product development (LPD) and Green product development (GPD) concepts through a literature review. Found that the concepts share a number of similarities that indicate a synergistic relationship
25	[26]	Lean and Green in action: interdependencies and performance of pollution prevention projects	Found that Lean and Green practices may be implemented either sequentially or simultaneously, generating sequential or reciprocal interdependencies, respectively
26	[23]	Lean Management, Supply Chain Management and Sustainability: A Literature Review	Evaluated the state-of-the-art of research between Lean Management, Supply Chain Management and Sustainability
27	[35]	Sustainable manufacturing-Greening processes using specific Lean Production tools: an empirical observation from European motorcycle component manufacturers	Showed that implementation of Lean tools such as 5S, cellular manufacturing, Single Minute Exchange of Die (SMED), and Total Productive Maintenance (TPM) in general, brings benefits to environmental management.
28	[27]	Lean and Green – a systematic review of the state of the art literature	Provided a review of the existing literature on Lean and Green, aimed at providing guidance on the topic, uncovering gaps and inconsistencies in the literature, and finding new paths for research
29	[33]	Integrating and implementing Lean and Green practices based on proposition of Carbon-Value Efficiency metric	Proposed a methodology to integrate Lean and Green practices. The results clearly demonstrate that companies can achieve quantitative benefits by integrating and implementing Lean and Green practices.
30	[42]	Lean and Green strategy: the Lean and Green House and maturity deployment model	Developed a Lean and Green maturity model in order help organizations to manage their Lean and Green performance

TABLE 2 EFFECT OF 7 LEAN WASTES REDUCTION ON ENVIRONMENTAL PERFORMANCE
(INFORMATION TAKEN FROM[41])

Lean Waste	Impact	Benefit
Overproduction	Overproduction leads to excessive consumption of raw materials and energy resources in making unwanted parts; excessive hazardous materials resulting in extra emissions and waste disposal.	If organizations do not overproduce they consume fewer raw materials, use less energy to operate, and eliminate the risk associated with not selling the excess inventory and eventually disposing of it as waste.
Overprocessing	Overprocessing leads to additional consumption of parts and raw materials per unit of production, increased waste, energy usage, and emissions.	Improving processing to just what is needed allows organizations to cut down on waste and lower their environmental footprint.
Waiting	Waiting leads to damage of potential materials components; energy waste from heating, cooling, and lighting during production time.	Reducing waiting can cut down on production downtime, which means organizations have less wasted energy.
Transportation	Transportation leads to extra energy usage and emissions for transport.	Minimizing transportation reduces the energy used and the costs associated with the product.
Inventory	Inventory adds waste from deterioration of work in process (WIP) products as well as from the replacement of damaged WIP by alternate materials.	By having less product inventory sitting around, organizations can use their plant space more efficiently (saving heating and cooling demands) whilst also consuming less packaging and raw materials. Lower levels of inventory also reduce the risk of waste due to obsolescence and undiscovered defects.
Defects	Defects leads to consumption of raw materials and energy in making defective parts, recycling for defective components, space for rework	Minimizing product defects means organizations are using fewer raw materials to manufacture products, which equals less energy consumption.
Motion	Motion requires more space increasing heating, cooling, and lighting demands. It can also increase the time to produce a product resulting in increased energy requirements.	Reducing any effort of lifting things unnecessarily or the needing to walk an excessive distance back and forth to find tools or complete a task means organization will use less energy.

III. RESEARCH METHODOLOGY

To understand the relationship between Lean and Green manufacturing, we used literature review as a research method. Different keywords such as "Lean manufacturing" "Green manufacturing", "pollution prevention", and/or clean production (sometimes written as "cLean" to highlight the use of Lean) were used. The procedure to perform the literature review was based on the use of databases to find peer-reviewed journal articles that contained at least a key word related with both, Lean and Green manufacturing. The search results showed that 30 articles from 1996 to 2016 have been published to address the connection between Lean and Green, with the majority being published in the last 10 years. A summary of the journal articles that have explored the Lean and Green relationship is presented in Table 1.

IV. RESULTS

From the 30 articles appropriate to this work, we observed that the Lean and Green concepts are fairly well established within both the academia and the industry. In addition we noted that companies reducing the seven types of wastes identified within the Lean culture also reported positive environmental results from this reduction. Many of these gains were studied by Dües et al. [25] who analyzed both concepts and provided evidence of the areas where they overlap. They suggest that Lean is beneficial for Green practices and the implementation of Green practices in turn also has a positive influence on existing Lean business practices. A generalization of their findings is presented in Figure 1, where both concepts overlap on creating value for the customer, improving waste elimination, and involving of supply chain actors in order to achieve business success. Galeazzo et al. [26] in a more recent work also found that Lean and Green practices may be implemented either sequentially or simultaneously, generating sequential or reciprocal positive interdependencies.

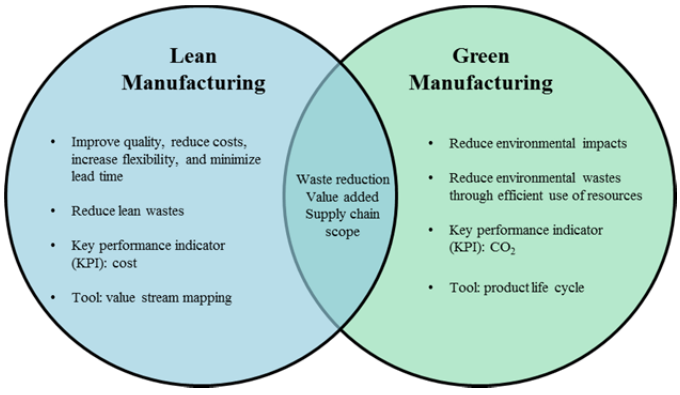

Figure 1 Lean and Green philosophies (Adapted from [25])

In assessing the relationship between Green and Lean, Rao and Holt [16] provide a literature review about Lean production and Green supply chain. Garza-Reyes [27] also presented a review of the existing literature on Lean and Green, aimed at providing guidance on the topic, uncovering gaps and inconsistencies in the literature, as well as new paths for research. Simons and Mason [28] highlight that Lean and Green thinking have a great deal in common, both challenging the way resources are currently used and promoting initiatives designed to "do more with less". Similarly, Johansson and Sundin [29] point out that from a Lean perspective, when a waste is minimized, it provides benefits from a sustainability perspective since inefficiencies lead to increased environmental burdens. Supporting this view, Upadhye et al. [30] state that Lean manufacturing systems provide a competitive strategy to achieve sustainable development goals.

Soltero and Waldrip [31] found that Lean manufacturing provides the organization with the tools necessary to accomplish its pollution prevention goals. Simpson and Power [32] found evidence suggesting that environmental practices may be developed as part of a close relationship, in a low transaction cost manner, as a direct and indirect feature of any Lean transformation. Ng et al. [33] proposed a methodology to integrate Lean and Green practices. The authors suggest that companies can achieve quantitative benefits by integrating and implementing Lean and Green practices. Diaz-Elsayed et al. [34] studied the effect of Lean and Green strategies inside a manufacturing system through a case study. The implementation of both strategies resulted in reductions in production cost. Chiarini [35] showed that the implementation of Lean tools such as 5S, cellular manufacturing, Single Minute Exchange of Die (SMED), and Total Productive Maintenance (TPM) in general, brings benefits to environmental management. The effect of Lean wastes reduction on environmental performance is presented in Table 2. That is, for example, minimizing product defects means organizations are using fewer raw materials to manufacture products, which is equals to less energy consumption. Similarly, improving processing to just what is needed allows organizations to cut down on waste and lower their environmental footprint.

In a research study performed by Florida [36] the author found that a relationship between Lean supply chain members facilitates the adoption and spread of environmental practices and innovations. Following this research path, Hajmohammad et al. [37] found that the impact of Lean management, and to a lesser extent supply management, on environmental performance, is mediated by environmental practices. Carvalho et al. [38] presented links between Lean, agile, resilience and Green paradigms and the supply chain performance. The authors identified synergies and divergences between the paradigms.

In terms of firm performance, Yang et al. [22] found a positive relationship between Lean manufacturing practices and environmental management on business performance. Sawhney et al. [39] presented a case study to illustrate the relation between Lean and environmental performance.

Similarly, Miller et al. [40] found Lean and Green manufacturing can have a more significant, positive impact on multiple measures of operational performance when implemented concurrently rather than separately. Rothenberg et al. [24] found evidence to support the link between Lean practices and resource efficiency and environmental performance. Vinodh et al. [41] provided strategies intended to enable an organization to acquire environmental performance using Lean initiatives. In order to help organizations manage their Lean and Green performance, Verrier et al. [42] developed a Lean and Green maturity model.

In other work, Mollenkopf et al. [43] examined the relationship among Green, Lean, and global supply chain strategies and revealed drivers, barriers, converging, and contradictory points across the three strategies. Martínez-Jurado and Moyano-Fuentes [23] provided evidence where Lean and Green practices connect within the supply chain. The authors found that Lean and Green practices share the objective of waste elimination, although waste is defined in a different way by each concept. King and Lenox [44] also found that Lean production is complementary to waste reduction and pollution reduction. In addition, Jasti et al. [45] suggested a strong correlation between Lean and Green supply chains.

Other authors have suggested that when an organization achieves sustainable improvements in a Lean production system, including processes of environmental innovation, they may create a competitive advantage [46]. In this context, companies that continually implement Lean practices expect to improve environmental performance through good housekeeping practices, such as general waste reduction and minimizing hazardous waste, reducing lead times, material and staff costs, and simultaneously increasing production activity and enhancing quality [21]. Larson and Greenwood [47] support this point of view, finding that Lean manufacturing produces substantial resource productivity improvements that contribute directly to environmental performance gains. In this regards, Maxwell et al. [48] highlight that waste minimization through Lean manufacturing motivates environmental activities as well as Yang et al. [49] point out that firms with closer supplier partnerships and solid continuous improvement practices are more likely to develop a proactive environmental management program. Together they enhance competitive advantage through cost savings, quality improvement, and process/product innovation.

IV. DISCUSSION

The overall debate among the articles presented in the previous section section is focused on the potential benefits of implementing Lean and Green practices to achieve gains in organizational and environmental performance within an organization's operations and processes.

In general, the articles suggest that the adoption of Lean and Green practices has a positive effect not only on organizational performance, but also on environmental performance. This positive opinion is derived from the perspective of waste elimination, where the reduction in any of the Lean wastes may lead to lower environmental wastes, shows the complementarity of the concepts. In addition, the synergy between Lean and Green manufacturing was also evidenced, supporting the fact that when implemented together, organizations may achieve greater benefits. From the supply chain side, the adoption of Lean and Green practices in operations/processes and supply chains can contribute to the achievement of corporate profit and market share through the reduction of costs and environmental risks [38]. These findings highlight that the implementation of Lean manufacturing practices help organizations to obtain environmental benefits in terms of environmental wastes reduction. The findings also suggest that the relationship between Lean and environmental waste is governed in some cases by a push process, where Lean implementation has resulted in tools being pushed into use for Green gains. Evidence of the opposite, where Green implementation pulls the use of Lean tools, did not appear in the literature, other than a theoretical postulate.

Relating these activities, we can now propose a starting point for modeling interactions of Lean and Green. The Lean literature promotes the removal of all non-value adding activities (NVA) from manufacturing processes in view of improving processes performance. The reduction of these activities has shown to have a positive effect on performance indicators such as quality (Q), time (T), and cost (C), which enhance firm value creation (V_C) as shown in Equation 1. Knowing that NVA generate manufacturing wastes (W_m) as shown in Equation 2, and that these wastes comprise Lean wastes (W_L) and environmental wastes (W_E), we can see through simple substitution that value creation is function of both Lean and environmental wastes as shown in Equation 3. Since some environmental wastes are associated with Lean wastes, Equation 3 can be expanded to show the operational impact ($W_{L_{OI}}$) and the environmental impact ($W_{L_{EI}}$) of Lean wastes (Equation 4). This final equation illustrates the relationship between the two concepts in terms of how they share waste elimination. Together they provide greater value creation, and by a push process Lean may help reduce environmental wastes. This supports the notion that Lean may enhance pollution prevention approaches.

$$\downarrow \mathrm{NVA} = (\uparrow \mathrm{Q} \downarrow \mathrm{T} \downarrow \mathrm{C}) = \uparrow V_C \quad (1)$$

$$\downarrow W_m = (\uparrow \mathrm{Q} \downarrow \mathrm{T} \downarrow \mathrm{C}) = \uparrow V_C \quad (2)$$

$$\downarrow (W_L) + \downarrow (W_E) = (\uparrow \mathrm{Q} \downarrow \mathrm{T} \downarrow \mathrm{C}) = \uparrow V_C \quad (3)$$

$$\downarrow \left(W_{L_{OI}} + W_{L_{EI}}\right) + \downarrow (W_E) = (\uparrow \mathrm{Q} \downarrow \mathrm{T} \downarrow \mathrm{C}) = \uparrow V_C \quad (4)$$

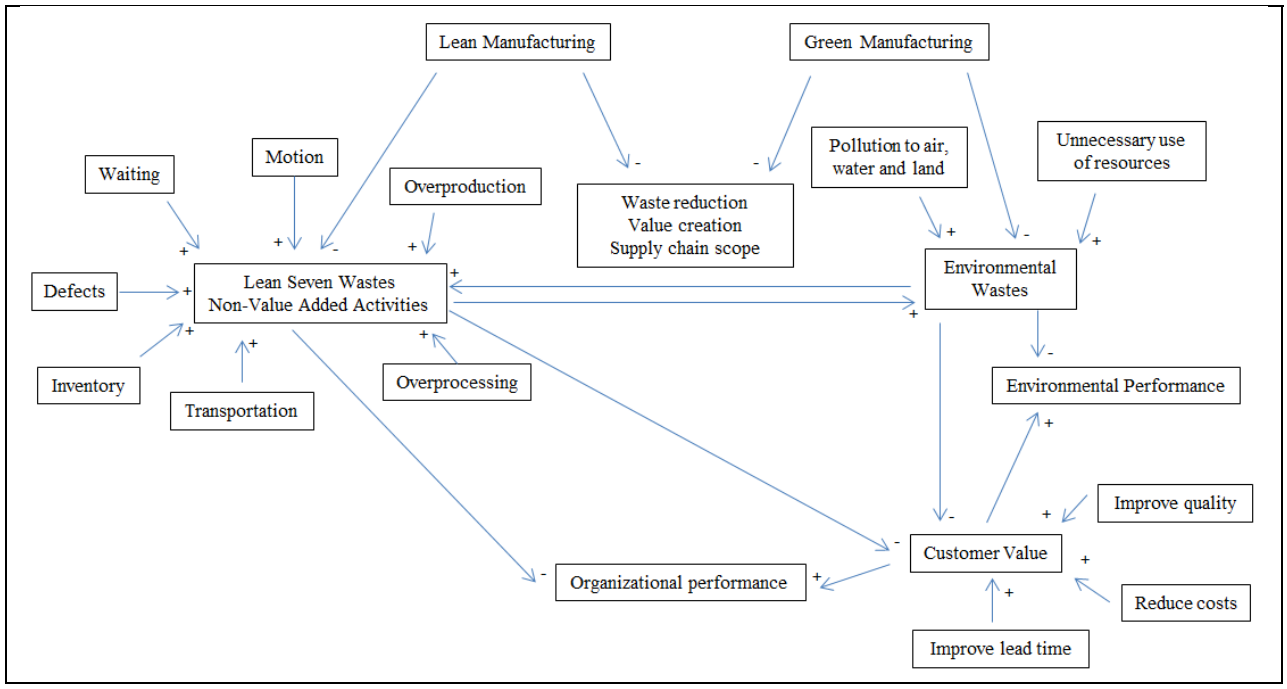

Figure 2 Lean and Green system dynamics model

To see the effects of the removal of NVA activities or waste reduction on organizations' performance a systems dynamics model is presented in Figure 2. Using a causal relation diagram approach, we can look at the influence of Lean and environmental wastes reduction on value creation. Value creation can be measured as the number of value adding activities (VA) and the number of NVA as shown in Equations 5 to 7.

$$V_C = VA + NVA \tag{5}$$

$$V_C = (VA) + (W_m) \tag{6}$$

$$V_C = (VA) + (W_L + W_E) \tag{7}$$

Equations 5 to 7 are easily transformed into a discrete event case (Equations 8 to 10), by considering the m value-adding activities and the n non-value adding activities as each having individual activity cycle times.

$$V_C = \sum_{i=1}^{m} VA_i + \sum_{j=1}^{n} NVA_j \tag{8}$$

$$V_C = \sum_{i=1}^{m} VA_i + \sum_{j=1}^{n} W_{m_j} \tag{9}$$

$$W_m = (W_L + W_E) = \left[w_{1_L} + w_{2_L} + w_{3_L} + w_{4_L} + w_{5_L} + w_{6_L} + w_{7_L} + w_{8_E}\right] \tag{10}$$

We see from Equation 9 that improving processes efficiencies by removing the 8 wastes, transportation, overprocessing, overproduction, defects, inventory, motion, waiting, and pollution, implies improvement in Q, and T, as well as reductions in C, and, thus, gains in value creation. This value creation process translates into organizational and environmental performance gains.

V. CONCLUSION

The findings of the literature review show that a variety of authors have researched the relationship between Lean and Green manufacturing during the last few decades. The majority of the studies that found a relation between Lean and Green manufacturing are highly optimistic in their findings, based on varying levels of evidence that Lean and Green manufacturing practices have in fact a positive contribution in the improvement of environmental and organizational performance.

Three types of relationship between Lean and Green manufacturing were observed from the review. The first relation indicates that Lean and Green manufacturing complement each other since both concepts share objectives such as waste reduction, value creation, and supply chain scope. The second relationship is related with the synergy between the two concepts; different authors stated that when combined together organizations achieved greater performance gains. The third relationship is the push interrelation between Lean and environmental wastes reduction; that is, when Lean wastes are reduced, environmental wastes can be directly or indirectly reduced as

well.

The causal relation model developed based on the literature review illustrates these relationships. The equations developed based on these relations show that organizations can maximize their performance gains when performance indicators are improved through Lean and environmental wastes reductions. However, the model is neither complete nor exhaustive, and offers a starting point for further developing a theory for optimizing firm performance through Lean and Green implementation.

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