Interaction between Lean and Green Supply Chain Management: experiences from the automotive sector

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Abstract: Lean Management (LM) is a business and operations strategy embraced by several industries, to minimize waste in manufacturing and supply chain, increasing productivity, efficiency and continuous improvement actions. The Lean Supply Chain Management (LSCM) looks at streamlined, highly efficient systems able to offer finished products at the pace customer's demand. During the last decades, the rising concern around the environmental burdens of industrial processes made sustainability performances critical issues for companies. The greater attention to sustainability by society and users and the regulations introduced by institutions and policy makers led companies to adopt sustainable strategies in manufacturing and supply chain activities. The integration between LSCM and Green Supply Chain Management (GSCM) is a hot stream of research, looking for convergences and gaps faced by companies belonging to different sectors in the joint implementation of LSCM and GSCM. This working paper follows this research stream, discussing interactions in the current and potential implementations of lean and green principles within supply chain management. The automotive sector is focused, presenting industrial case histories and best practices, showcasing the adoption of lean strategies fostering green practices.

Keywords: Lean Supply Chain Management, Green Supply Chain Management, Sustainability

I. INTRODUCTION

The concept of Lean Management (LM) arose from the study of Japanese manufacturing techniques applied to the automotive industry, particularly in the Toyota Production System [1], and it is adopted by many businesses to remain competitive in the increasingly global market [1, 2, 3, 4]. LM focuses on cost reduction by increasing productivity and efficiency though continuous improvement actions and waste minimization in manufacturing and supply chain. LM considers as a waste everything that does not directly contributes to add value to a product under the perspective of customers' needs. To reduce and, where possible, to eliminate the considered wastes, LM refers to a variety of practices and tools, such as 5S methodology, Just in Time (JIT), Total Quality Management (TQM), Total Productive Maintenance (TPM), Kanban, Value Stream Mapping (VSM), Cellular Manufacturing and Single Minute Exchange of Die (SMED) [5, 6, 7]. This approach is extended to the company's entire supply chain to reach a Lean Supply Chain Management (LSCM) looking for a streamlined, highly efficient system, able to offer finished products at the pace customer's demand [8]. The increasing deterioration of the environment, e.g., low availability of raw material resources, overflowing waste sites, and increasing levels of pollution, rises attention and concerns towards the sustainability of production activities [9]. In this context, the increased pressure from community and the presence of environmentally conscious customers led to the introduction of rigorous environmental regulations by institution and policy makers, forcing the manufacturers to adopt ecologically responsive practices [10, 11, 12]. Since in a global supply chain companies may be responsible for the performance of their suppliers [13], Srivastava [9] defined the Green Supply Chain Management (GSCM) as the integration of the environmental thinking into Supply Chain Management, spanning from the product design and raw material sourcing, through manufacturing

phases, to the delivery to the users and the end-of-life management [14]. According to Bortolini et al. [5], the green approach focuses on reducing the use of non-renewable resources, eliminating toxic substances, increasing renewable energy penetration and recovering energy and matter from wastes. Common green practices and tools regard internal environmental management, Life Cycle Assessment (LCA), Eco-design, Eco-efficiency, green purchasing and cooperation with customers [5, 15]. Hence, Cruz Machado [14] highlighted that many research analyse LSCM and GSCM separately, as lean and green professionals operate in 'parallel universes' [16] despite other evidences show that lean significantly improves environmental performance [17, 18]. Overall, the current research and industrial practice show that lean concept is beneficial for green practices and the implementation of green practices in turn has a positive influence on existing lean business practices [5, 6]. The integration of these paradigms results in benefits for both. Because of lean programming is reaching a point of total consensus and standardization, lean systems can provide the structure and broad acceptance green systems lack, while green techniques will enhance lean efforts [19]. Starting from this background, this paper addresses two main research questions (RQ):

RQ1 – "Is there convergence between lean and green concepts and their main practices?"

RQ2 – "How lean strategies fosters green practices in the automotive industry?"

While the first RQ is mainly answered through the similarity and dissimilarity analysis provided in Section 2, the second RQ focuses on the automotive sector and requires practical insights. For this purpose, Section 3 collects and analyses case histories showcasing the adoption of lean strategies fostering green practices during their joint implementation in automotive industries.

The reminder of this paper is organized as follows: Section 2 reviews the literature concerning the integration of lean and green practices, Section 3 presents three automotive case histories evaluating the environmental benefits obtained by the implementation of lean practices. Section 4 discusses the main aspect of the presented case study, while Section 5 concludes the paper with final remarks and future research opportunities.

II. RESEARCH CONTEXT

The growing interest towards the join integration of lean and green management practices led several authors to focus on this stream of research. An analysis of the main similarities is presented in Section 2 *A*, while section 2 *B* presents the main divergences between the two paradigms.

A. Lean and green similarities

In the recent years, several authors are focusing their attention on the integration between lean and green principles, finding several similarities suggesting they can be naturally complementary [18, 20] and beneficial in reaching production efficiency and environmental saving [5]. According to Tice et al. [18] both lean and green paradigms rely on a continuous improvement philosophy supported by performance measurement and sharing the same focus on waste elimination. Despite lean practices target wastes increasing the product cost for customers, while green wastes focus on the inefficient use of resources, the waste reduction techniques proposed by both paradigms are often similar [6, 19]. Dües et al. [6] presented the green wastes as an extension to lean wastes that enhance opportunities for further waste elimination in the entire supply chain. Following this waste-focused interpretation, Bergmiller and McCright [19] justified further research about the integration of these paradigms into a single Zero Waste Operation system. In addition, both paradigms seek to foster an organizational culture that empowers employees to solve problems and take action to improve organizational performance [18, 19, 21] with the important endorsement and commitment of top managers [15]. The high level of employee involvement required in the company is also reflected on the entire supply chain level, where a close collaboration with suppliers and partners enables the sharing of information and best practices and leads to a more integrated supply chain [6]. Overall, the main overlaps between lean and green paradigms are the waste reduction focus and techniques, the people involvement both as employees and managers [22] and the supply chain relationship. Based on these similarities, one of the current streams of research is evaluating how the adoption of one paradigm affects the other and the results of the joint implementation of green and lean initiatives. As a powerful business model, the adoption of lean production practices significantly improves environmental performance [18] and the study by Sabadka [23] summarized the positive implications and benefits of the principal lean tools, e.g., 5S, TPM, Cellular Manufacturing, Kanban and others, in a waste reduction direction. According to King and Lenox [17] LM reduces the cost of environmental management and increases the

likelihood that companies will adopt advanced environmental management systems. Bergmiller and McCright [19] study confirmed that the implementation of one program may ease the implementation of the second one. The presence of lean programs eases the adoption of green practices because of the many green elements included in lean programs. In the same way, evidence collected by the researchers suggest that green practices can help companies to become leaner, supporting the conclusion that synergic effects between the two practices exist [5, 6, 15, 19, 24]. Synergies result when the combination of the practices lead to great results, higher than the sum of the performance from their separate application, and according to Bergmiller and McCright [19] "only when both paradigms are implemented simultaneously, lean and green can unfold their full potential and bring greater benefits than when implemented separately".

B. Lean and Green divergences

Beyond the above-described similarities, lean and green paradigms show some divergences and gaps. Johansson and Sundin [22] conducted a systematic review addressing the "green thinking is thinking lean" assumption and concluded that one of the main differences between lean and green concepts concerns their goal. The overall goal of the lean paradigm is the creation of value for customers through cost reduction, production flexibility and unnecessary actions elimination in the product development process. Green paradigm, instead, focuses on the ecological and sustainable impact of operations [6, 12] with the key goal of ensuring the development of products that have minimum negative impact on the natural environment [22]. Although some research highlighted that a lean environment can be considered, to some extent, green because of the mutual focus on waste elimination [6], what is considered as a 'waste' reflects a deep difference. Lean paradigm strongly links waste to non-value adding activities from the end-user viewpoint, resulting in seven types of waste: overproduction, inventory, defects, transporting, over-processing, motion and waiting [6]. Green paradigm considers waste to be "of a physical nature and product-related", generated by industry at all stage of production, product use and disposal and their amount going to recycling, incineration and landfill should be minimized [22]. This different waste paradigm is evident also in the different seven main types of green wastes, i.e., excessive use of water, excessive use of energy, excessive use of resources, pollution, rubbish, greenhouses gas effects and eutrophication, that are environmental externalities representing excessive use of resources potentially threatening human health and contaminating the environment [5, 7]. According to Dües et al. [6], a further difference regards the type of customer targeted by the two paradigms, as the lean customer is attracted by cost and time reduction while the green customer chooses products to help them being more environmentally friendly. Overall, according to Bortolini et al. [5] and to Dües et al. [6], the main point of collision between lean and green practices is related to the replenishment practices. Through the adoption of pull systems with small batches and the JIT delivery technique, the lean paradigm aims at getting the minimization of inventory level through a frequent replenishment of raw material or semi-finished product. However, the frequent travels result in high CO_2 emissions, leading a lean supply chain to conflict with the green principles as the distances between suppliers and the company increase. To reduce the environmental harm of JIT technique, opportunities for the network and routing optimization, e.g., selecting nearby suppliers that could share truckloads, are necessary to manage the difficult lean-green trade-off in the supply chain management [12]. Moreover, the small batch size production recommended by lean practices may lead to greater production of waste created during the cleaning activities and the disposal of unused process material [6, 17]. Finally, Ng. et al. [25] and Duarte and Cruz Machado [15] stated that the combination of green and lean practices involves considerable investment, not affordable for companies with limited resources.

In conclusion, synergies result from the simultaneous implementation of lean and green practices even if trade-off and balance of divergent goal and investments is required [5], answering RQ1. Since its origin in the automotive sector, LM concept remains strongly connected to the automotive industry, now moving towards a greater use of renewable energy sources and a "greening" of manufacturing processes [23]. The depth and variety of automotive manufacturers' investments reported by Sabadka [23] are indicative of the high levels of lean and green implementation in the automotive industry [15]. According to Caldera et al. [26], most of the lean and green models were developed in companies in the automotive industry that is considered the most concerned with environmental issues and where lean principles and tools are more developed [27]. Thus, a focus on case histories and best practices in this reference sector

is presented in the next section, addressing RQ2 by providing some consideration about the practical application of the literature theories to industrial contexts and allowing a deeper understanding of the integration between green and lean paradigms.

III. CASE STUDIES

This section aims to analyse the interactions between lean and green practices throughout the supply chain by collecting case studies from the automotive sector available in the literature. The case studies were collected by exploring Scopus database using the following search string: TITLE-ABS-KEY ("lean" AND "green" AND ("case study" OR "empirical observation") AND ("automotive" OR "motorcycle")). A total of 28 papers resulted from the investigation. Subsequently, an analysis of the resulting papers was carried out, looking for applications in the automotive industry context that attested to practical implications of the synergy between lean and green practices. The case studies were expected to present both lean and environmental effects obtained through the application of the different practices. A total of 3 papers were then selected complying with the requirements.

A. Green effects by applying lean tools in five motorcycle components producers

Chiarini [28] analysed how LM tools helped to reducing environmental impact at five component suppliers in the motorcycle industry. The selected companies had similar products, production processes and sizes so that the effects obtained were comparable. Moreover, they operated in the European Union (EU) area, so they were all subject to the same EU environmental legislation. In each company, five lean tools were implemented over the period of one year in similar areas or machines, and environmental improvements were measured using the same parameters over the following six months. The implemented lean tools and the overall environmental effect evaluated are discussed below and summarised in Table I.

The application of the 5S methodology, which aims to optimise working standards through the management of cleanliness and order at workstations, took the form of the following activities, with related green benefits:

- the companies introduced highly visible and identifiable bins, generating a reduction of mistakes during the separate collection of wastes;
- the companies introduced a new standardized drip tray for solvent and oil containers. This led to a drastic reduction in the leakage from the workplace to the floor. Moreover, it reduced the quantity of rags used in cases of leakage, which are garbage that needs to be collected and treated.

The implementation of similar working cells following the Cellular Manufacturing principles, which involve the creation of work cells that perform work on similar products, in the different companies led to a decrease in the distances travelled between stations for material handling. As a result, energy consumption by electric trucks decreased.

On the other hand, concerning SMED activities, which have the final goal reducing setup time, there were no major environmental benefits. Indeed, it was assumed that the decrease in setup times can generate a reduction in energy consumption during the machines' standby time, no data were available to support this hypothesis.

TPM is a lean tool that aims to improve the efficiency of production processes through the maintenance of machines. The application of the TPM resulted in two main activities: operators started autonomous daily maintenance of the machine (lubrication, cleanliness of the filters, inspection of the instrumentations on the machine, etc.), while engineers collected data and drew up a plan for maintaining the machines and replacing components. The collateral effects of these practices were a dramatic reduction of leakage from the machine to the floor and a reduction of the atmosphere emissions in terms of dust and fumes.

Overall, to map and identify the environmental improvements in the processes, the companies successfully used a specific type of VSM, named Environmental VSM. This tool requires a data box under each process symbol that contains the environmental impacts of the process and was developed in each company before applying lean tools and after, to compare the improvements achieved over the time.

TABLE I. ENVIRONMENTAL EFFECTS CAUSED BY THE APPLICATION OF LEAN TOOLS [28]

Lean tool	Environmental effects
5S	Reduction of the mistakes during the separate collection of garbage
	Reduction of greased and solvent rags as a waste

	Reduction of leakage on the floor
Cellular Manufacturing	Reduction in electricity consumption by trucks
SMED	No relevant effects observed
TPM	Relevant reduction of oil leakage on the floor
	Reduction of dust and fume emissions
VSM	Mapping and identifying environmental impacts in the processes

B. Influencing first-tier suppliers in the automotive supply chain

The case study described by Avezedo et al. [29] concerns the influence a Portuguese automaker had on its most important suppliers. The company, in fact, was located within an industrial park, where it rented space to first-tier suppliers, following the LM principle of close collaboration with suppliers. The companies located in the industrial park were required to comply with certain policies and practices, both lean, such as Just-In-Sequence (JIS) deliveries directly to the automaker's assembly line, and green, as the adoption of reusable packaging. The Authors investigated how the policies imposed by the automaker drove suppliers to improve their sustainability performances by conducting interviews and collecting relevant data about CO2 emissions and wastages. The results obtained are listed below and shown in Figure 1.

Green practices, i.e., mandate for first-tier suppliers to have environmental management systems, monitoring suppliers' environmental performance, using green purchasing guidelines and sourcing from environmentally responsible sources, using reusable packages to deliver materials, had obviously a positive effect on suppliers' sustainability, while the effects obtained by adopting lean practices were:

- JIS and deliveries directly to the point of use involved frequent deliveries of small quantities from the first-tier suppliers to the automaker assembly line, leading to higher energy consumption and CO2 emissions. For this reason, the Portuguese company tried reducing distances by promoting the installation of foreign suppliers in the industrial park;
- geographical concentration was requested to reduce the level of inventory and the lead time. However, as mentioned before, lower distances between suppliers and the automaker generated a decrease in CO2 emissions for the transportation of materials;
- using Electronic Data Interchange (EDI) to share structured business data and product data between the automaker and supplier's information systems made the implementation of JIS possible, but also made scrap rate reduce, since suppliers knew exactly what they need to produce, avoiding the production of non-selling components and reducing the number of rejected materials or parts mislabelling;

	Performance / *Upstream SCM practices*	**Economic**			**Environmental**			**Social**		
		Operational cost	Inventory cost	Environmental cost	Business wastage	Green image	CO2 emissions	Corruption risk	Supplier screening	Local suppliers
Green	Mandate for first-tier supplier to have environmental management systems			↓	↓	↑	↓		↑	
Green	Monitoring supplier's environmental performance			↓	↓	↑	↓		↑	
Green	Using green purchasing guidelines and sourcing from environmentally responsible sources			↓	↓	↑	↓	↓	↑	
Green	Using re-usable packaging to deliver materials	↓	↓	↓	↓	↑				
Lean	Just-in-sequence	↓	↓	↓	↓	↑	↑			
Lean	Deliveries directly to the point of use	↓	↓	↓	↓	↑	↓			↑
Lean	Geographical concentration	↓	↓	↓	↓	↑	↓			↑
Lean	Using EDI to share information	↓	↓		↓					
Lean	Single sourcing	↓								

Legend: ↑ the practice contributes to increase the performance measure value; ↓ the practice contributes to decrease the performance measure value;

Figure 1:The effect of Green and Lean upstream SC practices on sustainable development of suppliers [29]

- a single sourcing policy was used with the first-tier suppliers to manage the supplier capacities and to ensure JIS delivery. Therefore, the single sourcing practice contributed to increasing the utilization rate of resources, reducing cost and business wastage.

C. *Perception of the Lean and Green synergy in a Brazilian automotive assembler*

Sobral et al. [30] conducted studies on the environmental benefits gained through LM in a company located in Brazil, part of an international group, which assembled automotive vehicles. LM practices have been in place at the company since 2007. The adoption of LM led the organization to create an intranet portal, through which it makes available all the lean-related tools in use at the company.

The study was carried out by using direct observation, collecting data and interviewing key employees. The objective was to gather employees' perceptions of the adoption of lean practices and the relationship with sustainability, and to compare those results with what was directly observable in the field and from the data.

The interviewees noted how LM is relevant to sustainability in terms of the efficient use of resources and reduction of waste generation. In this sense, the company's intranet portal contains a dataset of all Kaizen and continuous improvement actions that contributed to achieving an environmental benefit. Training on LM issues provided to operators also had a positive impact on their proactivity and involvement in sustainability. Furthermore, key personnel observed that the application of lean practices indirectly created some green benefits. In the past, some materials remained in storage for a long time and consequently required a protective layer of oil. Following the implementation of JIT, the use of oil was eliminated with a saving on water used to clean parts. A further example provided is when the VSM tool allowed to identify the excessive use of glue that led to the consumption of water to clean certain products.

However, it appeared that the synergy between lean and green was not fully understood by the employees interviewed. Managers of the production and environmental areas stated that they usually work separately instead of collaborating. Furthermore, several tools that could also be useful to achieving sustainability goals, such as TPM and 5S, were never mentioned in the interviews. Finally, VSM is never used in the analysed company in the form of Environmental VSM for the identification of green improvements.

IV. DISCUSSION

The analysis of the collected case histories addresses the second RQ, showing how the adoption of lean practices and tools, e.g., 5S, JIT, JIS, VSM and TPM, in the automotive industry effectively generated positive results on the environmental performance of the considered companies. Specific tools, such as the Environmental VSM, are implemented to evaluate the environmental impacts of the industrial processes, proving the rising importance of GM for automotive companies. In fact, all the three companies under analysis proved to be concerned not only about operational and financial performances, but also about the environmental aspects of their production activities. Because the sustainability of the business processes depends on all the supply chain management practices, the second case study assessed how the green policies imposed by the company to its suppliers helped to reducing the total supply chain CO2 emissions and wastes.

However, while the first and second automotive companies fully understood the synergic results coming from the joint implementation of lean and green practices, in the last case company the two concepts were not fully exploited, obtaining partial results.

V. CONCLUSIONS

In the current industrial context, Lean Management (LM) and Lean Supply Chain Management (LSCM) are adopted by many businesses to increase productivity and efficiency inside the company and throughout its supply chain to remain competitive in the increasingly global market. However, driven by the rising attention and concerns around the environmental burdens of industrial processes, many companies developed and adopted sustainable strategies in manufacturing and supply chain activities. The joint implementation of lean and green principles in the supply chain management is a new challenge for companies' competitiveness and for researchers, analyzing convergences and gaps between LSCM and Green Supply Chain Management (GSCM). This working paper follows this research stream, highlighting the main similarities and differences between lean and green paradigms. Three case histories from the automotive industry are presented, providing a practical application of the literature theories to a

relevant industrial context and analyzing the existence of synergies and divergences between the two paradigms resulting from their joint implementation.

In particular, the first case study considered the experiences collected by five European component suppliers in the motorcycle industry, clearly highlighting how the application of lean tools can generate environmental benefits. Furthermore, it presented the application of a tool that considers both lean and green critical issues and improvements, the Environmental VSM. The second case study presented how the LM principle of close collaboration with suppliers can improve the level of sustainability of the supply chain. In fact, it described the effects on the environmental performance of the supply chain of the application of lean policies required by a Portuguese automaker to its first-tier suppliers. Some lean practices, such as geographical concentration of the suppliers and information sharing along the supply chain, generated some green advantages, while JIS caused an increase in CO2 emissions, as it requires frequent deliveries. The last case study analyzed the perception of the key employees in a Brazilian automotive assembler about the synergy between lean and green practices. They identified several examples where the two philosophies went hand in hand, nevertheless, they did not seem to have a full awareness of the potential of this synergy. In fact, they did not consider certain lean tools, such as TPM practice, as useful for sustainability as well. Furthermore, the managers of the production and environmental areas did not cooperate in the performance of their tasks.

Overall, the case studies showed several positive interactions between LSCM and GSCM, highlighting at the same time a few examples where the two approaches diverged. Furthermore, it was noted that companies are sometimes unaware of these synergies. Further research should focus on the field analysis of the effectiveness of the synergy between LSCM and GSCM, evaluating both the effects of lean practices on the environmental performance and the application of tools joining both the approaches.

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