International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:10, No:3, 2016

A Reference Framework Integrating Lean and Green Principles within Supply Chain Management

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Abstract**—**In the last decades, an increasing set of companies adopted lean philosophy to improve their productivity and efficiency promoting the so-called continuous improvement concept, reducing waste of time and cutting off no-value added activities. In parallel, increasing attention rises toward green practice and management through the spread of the green supply chain pattern, to minimise landfilled waste, drained wastewater and pollutant emissions. Starting from a review on contributions deepening lean and green principles applied to supply chain management, the most relevant drivers to measure the performance of industrial processes are pointed out. Specific attention is paid on the role of cost because it is of key importance and it crosses both lean and green principles. This analysis leads to figure out an original reference framework for integrating lean and green principles in designing and managing supply chains. The proposed framework supports the application, to the whole value chain or to parts of it, e.g. distribution network, assembly system, job-shop, storage system etc., of the lean-green integrated perspective. Evidences show that the combination of the lean and green practices lead to great results, higher than the sum of the performances from their separate application. Lean thinking has beneficial effects on green practices and, at the same time, methods allowing environmental savings generate positive effects on time reduction and process quality increase.

Keywords**—**Environmental sustainability, green supply chain, integrated framework, lean thinking, supply chain management.

I. Introduction

IN the modern industrial production environment, an increasing number of companies applies *lean principles* to increase productivity and efficiency, minimising costs, idle time and wastes. On the other hand, a rising attention towards *green practices* appears to reduce landfilled waste, drained wastewater and pollutant emissions.

Lean Management (LM) scope is the minimisation of waste and the best use of the key resources justifying their adoption to create value to the final consumer. In particular, LM identifies seven types of waste to cut-off, i.e. overproduction, inventory, defects, transporting, inappropriate processing, excessive motion and, finally, waiting queues [1], [2]. To achieve its purpose, LM refers to a variety of practices and tools, such as 5S technique, Just in Time (JIT) and Pull management system, Total Quality Management (TQM), Poka Yoke approach, Cellular Manufacturing and clustering techniques, Value Stream Mapping (VSM) and Single Minute Exchange of Die (SMED) [1]-[3].

Green Management (GM) is the integration of environmental thinking into supply-chain management, including sustainable product design, low-carbon material sourcing and selection, green manufacturing processes, short-route delivery of the final products as well as end-of-life management and reverse logistics of the products at the end of their lifespan [4]. GM involves all the phases of a product life cycle, from the extraction of raw materials, through the design, production and distribution phases, to the use, post-use and disposal at the end of life [5]. Final scope of GM is to reduce the use of non-renewable resources, to eliminate toxic substances, to increase renewable energy penetration and to recover energy and matter from wastes. GM identifies seven main types of waste: excessive use of water, excessive use of energy, excessive use of resources, pollution, rubbish, greenhouse gas effects and eutrophication [1]-[2]. GM adopts dedicate practices and tools, such as Life Cycle Assessment (LCA), Design for the Environment (DfE), Cleaner Production (CP), Eco-efficiency, Eco-labels and Eco-design [1]-[3].

LM and GM share the common goal of waste elimination even if the waste they tackle is different. LM defines waste all the non-value added activities from the end-user viewpoint. GM focus is on the environmental externalities, so that it defines waste the extraction as well as the disposal of resources in higher quantity than those the nature is able to absorb. Environmental wastes represent an unnecessary or excessive use of resources, released in air, water or soil potentially threatening human health and contaminating the environment.

The current literature on industrial operative management focuses on such two topics separately. Few studies analyse the relationships between LM and GM. Even if they appear as ‘parallel universes’ [6], pioneering studies and the current practice show more than just a simply co-existence. The combination of LM and GM can lead to great results, higher than the sum of the performances from their separate application. In particular, LM has beneficial effects on GM and, at the same time, GM generates positive effects on time reduction and process quality increase. According to [7] and [8], “while lean practices can lead to environmental benefits, inversely environmental practices often lead to improved lean practices”. Starting from this background and the few contributions merging LM and GM, this paper revises the recent literature on the integration between LM and GM applied to supply chain management. Common points and differences between such two practices are discussed together

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with the tools and methodologies used by companies to greening their supply chain networks. In addition, an original reference framework integrates LM and GM in designing and managing logistic networks providing a rigorous logical path supporting the integration of the two practices. The proposed framework covers to the whole value chain, i.e. distribution network, assembly system, job-shop, storage system etc. pointing out the key performance indices (KPIs) for the lean perspective, the green perspective and the introduced integrated lean green perspective.

The reminder of this paper is organised as follows: the next Section II revises the literature on the topic. Section III presents the original framework for integrating LM and GM within supply chain management. Finally, Section IV concludes this paper with final remarks and future research opportunities.

II. Literature Review

Due to the growing interest towards the integration between LM and GM, in the recent years several authors are focusing their attention on this theme. The most of them stress the necessity of a simultaneous implementation of such two approaches, leading to production efficiency and environmental saving.

This Section is organised as follows: Section II *A* analyses the main overlaps and synergic effects generating by the concurrent implementation of LM and GM. Section II *B* presents the differences existing between the two approaches. Finally, Section II *C* concludes the literature review, first, presenting the major tools and methodologies used by companies to greening their lean supply chain networks; afterwards three evaluation drivers are introduced to classify contributions on LM and GM.

A. Lean and Green Synergic Effects

Galeazzo et al. [9], through the examination of three pollution prevention projects undertaken by two manufacturing plants of two large multinational firms, analyse the opportunity of concurrently implementing LM and GM underlining their synergic effects. Using two types of pollution prevention technologies, examples are given of how the two practices can be applied either sequentially either simultaneously, producing sequential and reciprocal interdependencies. According to the authors, the involvement of external suppliers is another important element to develop reciprocal interdependences and an efficient and simultaneous implementation of LM and GM, together with the collaboration between operational and environmental managers, sharing their skills and creating new ones. Dües et al. [1] analyse a relevant number of works in the field of LM and GM to understand if LM is synergic to GM, if GM is synergic to LM and to identify opportunities to use their lean frameworks in greening their processes. The study proves that synergic effects between the two practices exist. A synergy is when 1+1=3, meaning that the integration of the practices produces great results, higher than the sum of the performances from their separate application. Brasco Pampanelli et al. [3] introduce an integrated approach between LM and GM named “Lean&Green Model”. The model combines environmental sustainability and LM within production cells. Its purpose is the minimisation of production wastes and the reduction of the process environmental impact. A kaizen approach improves mass and energy flows in a manufacturing environment. Results show that the model reduces the use of resources from 30 to 50% and the total cost of mass and energy from 5 to 10%. Bergmiller and McCright [10], after examining the distinctive features of several lean companies, find that lean firms including elements of Green Operations Systems will have stronger lean results than those that do not include green elements. This further confirms that synergies and interdependences between the two practices exist. In particular, the application of gm Systems and Green Waste Reducing Techniques, in addition to commitment, collaboration and employee involvement, lead to both lean and green positive results.

A parallel research stream investigates on the extension of lean and green borders to include a social dimension. Studies are about the integration of the social and environmental dimensions within the traditional performance metrics. This means that LM and supply management are determinants of the environmental performances and ease the adoption of environmental best practices [11]. Environmental and social dimensions affect the profits obtained by the implementation of lean actions. Verrier et al. [2], after an analysis of 21 Alsatian industries, introduce a repository for LM and GM collecting lean indicators, green indicators and green intention indicators to link lean and green knowledge on the industrial context.

B. Lean and Green Differences

Despite LM and GM share a number of similarities, some differences exist. Johansson and Sundin [12] investigate if lean and green are “two sides of the same coin”. Through a review of 102 journal publications, it proves that the main differences concern the goals, the value construct and the waste construct. About the goals, the main goal of LPD is the creation of value for the end consumer by eliminating waste and unnecessary actions in the product development process. The main purpose of GPD is to ensure the development of products that have minimal negative impacts on the environment. About the value construct, in LPD, value is created by the generation of effective information which can leads to a product that is attractive for customers. In GPD value is associated to the development of a product environmentally benign. About the waste construct, in LPD waste is associated with the activities that are non-value adding. GPD considers waste to be of a physical nature. The main idea is to minimise the amount of waste going to recycling, incineration and landfill. The analysis leads to the conclusion that LPD and GPD diverge looking at the goals they want to reach.

The replenishment frequency is the main point of collision between LM and GM. According to JIT principles, the minimisation of inventory level comes from daily deliveries.

Frequent travels imply high emissions, in contrast to the green principles so that, from this perspective, a lean supply chain is not necessarily green. Globally, a short-range lean supply chain may be green, but as distances increase, lean and green go in conflict. In this case, trade-offs and opportunities for the network optimisation are mandatory [13].

The last difference analysed in this study is the type of final consumer target of lean and green paradigms. Lean customer is driven by achieving cost and lead-time reduction, whereas green customer is driven by its green belief and satisfied when the products are environmental friendly [1].

C. Tools and Methodologies

A strong issue for the joint implementation of LM and GM is the identification of useful tools and methodologies. Aguado et al. [14] try to tackle this issue through a model about efficient and sustainable improvements in a lean production system with environmental innovations. In particular, the study uses an easy application based on Eco-Indicator 99 (EI99) to quantify the sustainable improvements of a lean system and, finally, explains how to use the information from the application to implement a standardized process. By applying this model, companies can reach good results in terms of cost reduction, reduction of material and energy consumption, low emissions, income improvement, social and environmental responsibility.

Looking at the major tools and methodologies used in the field of LM, GM and the existing lean tools used for greening supply chains, some elements occur. In particular, VSM, Safety Standards, 5S/6S technique, Cellular Manufacturing, JIT/Pull Systems and Kaizen are the major lean tools used in lean-green supply chains. In this study, in the light of the future research opportunities, VSM appears to be the most interesting technique. VSM looks at the identification and minimisation of wastes, often neglecting environmental performances [15]. Faulkner and Badurdeen [16] introduce an innovative methodology for evaluating sustainability performances, called Sus-VSM (Sustainability-Value Stream Mapping). Sus-VSM allows the evaluation of water usage, energy consumption, raw material usage and other societal aspects, such as ergonomics. This tool plays an important role in the identification of opportunities for sustainability improvements in a company. Brown et al. [17] confirm the great applicability of Sus-VSM, proposing three operative case studies, and underline the great utility of this tool in evaluating sustainability performances varying the manufacturing system configuration. Several contributions prove the importance of VSM and Sus-VSM as tools to map the “as-is” state of a manufacturing system and to suggest improvements for a future state. As example, Rosenbaum et al. [18] introduce an application in the field of sustainable civil engineering. With reference to the construction of a hospital, improvements are in the service level and in the environmental performances during the structural work stage. This case study confirms the tool effectiveness in reducing costs, improving quality and minimising the environmental impact generated by construction projects, linking construction and environmental wastes.

To overcome the limits of traditional lean strategies, other methods as discrete event simulation or mathematical optimisation are of interest to get social, environmental and production advantages [19].

The review of the literature highlights three evaluation drivers to classify contributions on LM and GM:

- Addressed KPI, i.e. the parameter of interest for the analysis;
- Investigation strategy, i.e. the approach used to develop the analysis;
- Post-investigation method; i.e. the method used to provide a clear evidence of the effectiveness of the proposed approach.

Table I summarises the literature review on the topic. It shows that cost is the most widely considered KPI since it crosses both LM and GM. A growing awareness towards green topic is rising in the recent years. Finally, lean aspects are often investigated through rules-of-thumb and examples rather than through optimisation or sub-optimisation methods. Studies investigating the relationship between LM and GM from a qualitative point of view exist [20]-[23]. On the contrary, few contributions tackle this issue from a quantitative perspective.

Studies proposing a rational approach to integrate LM and GM from such a perspective are encouraged.

III. Reference Framework for Lean and Green Supply Chain Management

The aim of this section is to collect the evidences of the literature providing a logical path supporting the integration of LM and GM. Fig. 1 presents a conceptual framework for integrating LM and GM in the design and management of logistic networks. It illustrates and organises the main concepts, analytical approaches and output. At first, LM and GM are analysed separately (top and bottom blocks). For each perspective, the correspondent set of tools and methodologies and the most relevant KPIs is specified. The integrated lean and green perspective completes the framework (central block) to clarify the practices to apply at the different stages of the supply chain. Some of them are for a single stage, others cross several stages of a supply chain (sourcing, production, distribution).

A. Lean Perspective

In the lean perspective, some tools and methodologies as Kaizen, JIT, VSM, TQM and SMED fit to all the supply chain stages. On the contrary, Kanban Management System (KMS) is for sourcing and production stages, only, while 5S and Poka-Yoke are for the sole production phase. According to the LM, the most relevant considered KPI’s are the service and quality levels, the process reliability, the inventory level and the costs.

TABLE I
LITERATURE REVIEW AND CONTRIBUTION CLASSIFICATION

No.	Optimisations Kpi's			Investigation strategy			Post-investigation methods		Reference
	Stock	*Emission*	*Cost*	*Optimising*	*Sub-optimising*	*Rule-of-thumb*	*Qualitative example*	*Numerical example*	
1		x	x			x		x	[2]
2		x	x			x		x	[3]
3		x	x			x		x	[9]
4			x		x			x	[10]
5	x	x	x			x		x	[11]
6	x	x	x			x	x		[12]
7	x	x				x		x	[13]
8		x	x			x		x	[14]
9	x	x	x			x	x		[15]
10		x	x			x		x	[16]
11		x	x			x		x	[17]
12	x	x	x		x			x	[18]
13			x			x	x		[21]
14	x	x	x			x		x	[22]
15	x			x				x	[24]
16	x	x	x		x	x		x	[25]
17			x			x		x	[26]
18	x	x	x			x	x		[27]
19	x	x	x			x	x		[28]

B. Green Perspective

Multiple tools match the efforts of a company that decides to invest in reducing pollution and environmental emissions. Some of these fit to in all the supply chain stages, such as LCA, DfE and Eco-labels, others are tailored to the production phase, e.g. CP, Eco-efficiency and Eco-design. According to ISO 14040 standards, the most considerable green KPIs refer to the damage categories (Human health, Ecosystems, Resources) and to the impact categories ($CO_{2\text{-eq}}$ emissions, Climate change human health, Ozone depletion, Human toxicity, Photochemical oxidant formation, Particulate matter formation, Ionising radiation, Climate change Ecosystems, Eutrophication, Acidification, Ecotoxicity). Such KPIs are a standard measure of the supply chain environmental impact.

C. Integrated Lean Green Perspective

Looking for some tools to integrate LM and GM, Sus-VSM seems to be an interesting technique. Other possibilities deal with the use of optimisation trade-off methods, discrete event simulation and, finally, practical rules-of-thumb.

As discussed within the literature review, the lack of quantitative methods makes the definition of specific KPIs hard. The next step will be the definition of a rational procedure to investigate the link existing between the two practices to define specific performance parameters simultaneously optimising lean, green and economic aspects

IV. CONCLUSION

The increasing sensibility towards LM, in terms of service level, product quality, costs and inventory level, and GM, in terms of environmental emission reduction, suggests the adoption of integrated approaches in the design and management of logistic networks. In this sense, the concurrent implementation of LM and GM is a new challenge for competitiveness. However, in this field, few contributions exist in literature, especially adopting quantitative optimal models.

This paper revises this topic starting from a literature review analysing studies and research works in the field of LM and GM. Evidences are collected into a conceptual framework joining the two approaches. This framework integrates lean, environmental and economic issues looking at the whole supply chain or at parts of it. Synergies result from the simultaneous implementation of LM and GM even if trade-off and balance of divergent goal is required. Starting from this scenario future research opportunity deal with the development of operative models of industrial interest to optimally design and manage the supply chain reaching lean and green targets.

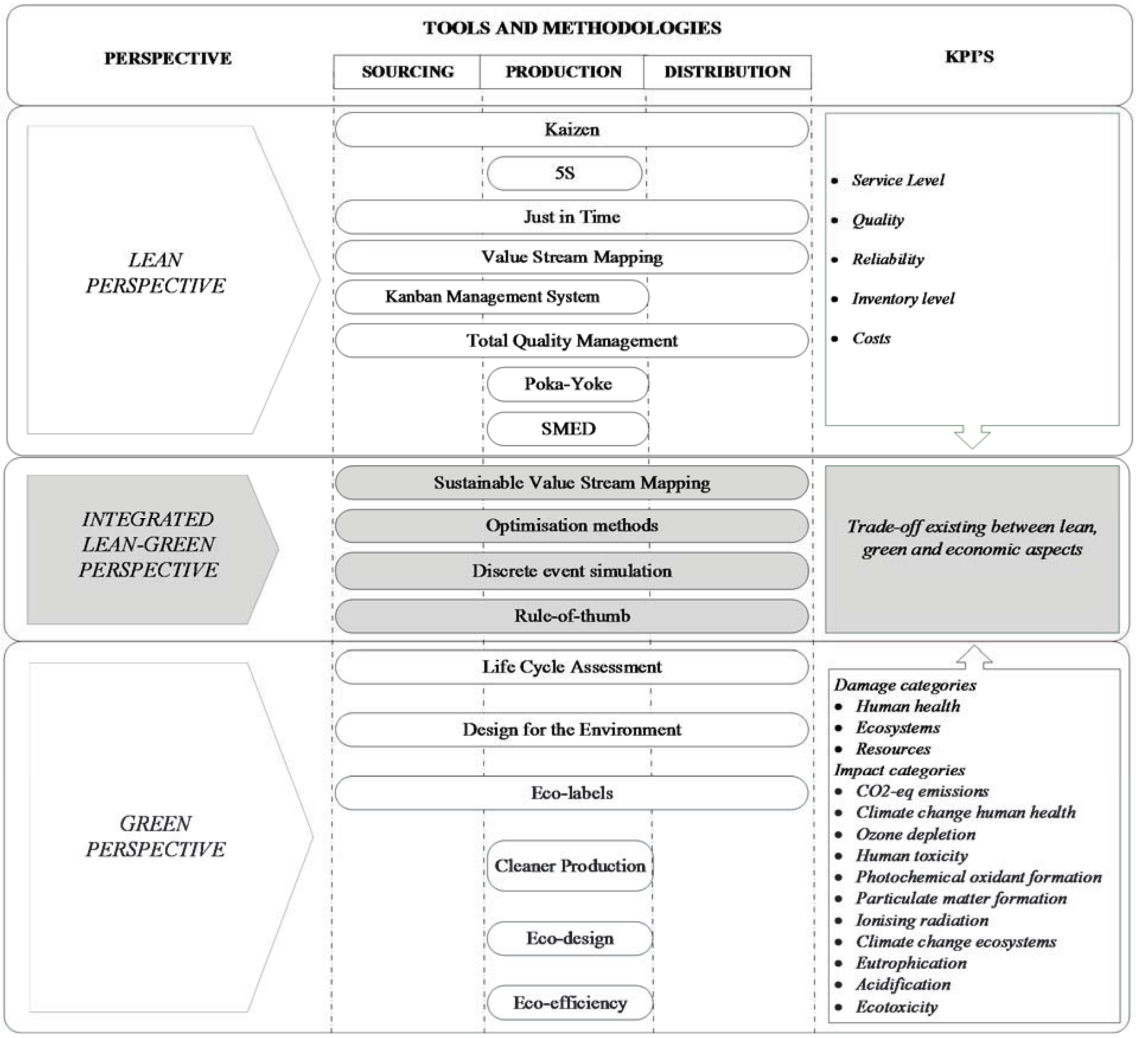

Fig. 1 Reference Framework

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