Exploring Linkages Between Lean and Green Supply Chain and the Industry 4.0

Susana Duarte(✉) and Virgilio Cruz-Machado

UNIDEMI, Departamento de Engenharia Mecânica e Industrial,
Faculdade de Ciências e Tecnologia,
Universidade Nova de Lisboa, 2829-516 Caparica, Portugal
scd@fct.unl.pt

Abstract. A new paradigm with a considerable influence on the industrial value creation is begun to evolve. Industry 4.0 represents the development to the fourth industrial revolution. A new shift in business and technology trends is confirmed. With this new paradigm of high-tech industry, supply chains will develop into highly adaptive networks. Lean and Green supply chain management should have better opportunities to be performed, becoming more efficient and competitive. The aim of this study is to link the lean and green supply chain characteristics to the Industry 4.0. This paper has twofold: first, presents an overview of the phenomenon Industry 4.0 and the lean and green supply chain management. Next, a conceptual model is developed which incorporates the Industry 4.0 topics to the well-known lean and green supply chain. This paper provides an understanding of the role of lean and green paradigms in the new era of industrialization.

Keywords: Industry 4.0 · Lean paradigm · Green paradigm · Supply chain

1 Introduction

Today we face a new paradigm introduced by Germany in 2011, the Industry 4.0. This represents the beginning of the fourth industrial revolution and is driven by modern information and communication technology (ICT) [21,26,27]. By Industry 4.0 intends the optimization of value chains by implementing an autonomously controlled and dynamic production [21], through a full automation and digitalization processes. This paradigm is based on the idea that communication via internet allows a continuous exchange of information applying cyber-physical systems (CPS) [27,30]. The CPS provides the source for the creation of internet of things and services and their combination makes possible the Industry 4.0 [15,27]. CPS integrates networking, computation and physical processes and take them together to create a global value chain networked [15,27,30].

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According to [34] to establish the global value chain networks, the Industry 4.0 describes a production oriented CPS that integrates production facilities, warehousing and logistics systems and even social requirements. In addition, Germany Trade & Invest (GTAI) [15] mention that the industrial value chain, product life cycles and business information technology combination must integrate the processes from the product design to production, supply chain management, aftermarket service and training [15]. An intelligent factory is in development and is coined as smart factory. With this concept, others appear and are important for the establishment of implementation of Industry 4.0, as for example smart products, smart manufacturing and smart data.

The authors [27] mentioned that this implementation is still in progress. That's why it is important to understand the role of lean and green supply chain management in Industry 4.0. For example, the lean waste would be recognized with the smart factory implementation [28]. The resource efficiency which is a lean and green concept, are in the focus of the design of smart factories [27]. This study intends to understand if the Industry 4.0 allows the lean and green supply chains concepts become more important. That is, if it enables more easily the deployment of lean and green characteristics. A number of characteristics were presented on model, namely: (i) manufacturing, (ii) logistics and supply, (iii) product and process design, (iv) product, (v) customer, (vi) supplier, (vii) employee, (viii) information sharing and (ix) energy.

The remainder of this paper is organized as follows: in Sect. 2, a theoretical background on Industry 4.0 and lean and green supply chain are presented; in Sect. 3, a combination between lean and green supply chain and Industry 4.0 is developed; Finally, some concluding remarks are drawn.

2 Industry 4.0 Paradigm

The Industry 4.0 is considered the paradigm of the fourth stage of industrialization and describes a vision of future production [21,30]. The core idea of Industry 4.0 is the integration and application of information and communication technologies to implement Internet of Things and Services so that business process and engineering process are deeply integrated making an environment intelligent [28,34]. The concept of industry 4.0 which represents the integration of the virtual and physical worlds in a way that together create a truly networked environment and where intelligent objects communicate and interact with each other, is a Cyber-physical systems [15]. According to [19] the Industry 4.0 "will involve the technical integration of CPS into manufacturing and logistics and the use of the Internet of Things and Services in industrial processes. This will have implications for value creation, business models, downstream services and work organization."

The Industry 4.0 is represented by three features [19,30,34]: (i) horizontal integration across the entire value networks; (ii) vertical integration and networked manufacturing system; and (iii) end-to-end digital integration of engineering across the entire value chain or product life cycle.

The horizontal integration across the entire value network refers to the integration of the various systems used in the different stages of the manufacturing and business planning processes that involve an exchange of materials, energy and information both within a company as logistics, production, and marketing, and between several different companies; The idea is that information, material and money can flow easily among different companies creating new value networks as well as business models. This can result in an efficient ecosystem [19,30,34].

The vertical integration refers to the integration of the various information and physical systems at the different hierarchical levels, as for example the production management, manufacturing and execution, and corporate planning. This integration is inside a factory to create flexible and reconfigurable manufacturing system [19,30,34].

The goal of the horizontal and vertical integration is to deliver an end-to-end solution. The end-to-end solution refers to the digital integration of engineering across the entire value chain to support product customization: from the raw material acquisition to manufacturing product, and product in use and in the end of life [19,30,34].

Through these features, the Industry 4.0 expects to implement an environment more flexible, efficient, and sustainable. The idea is to individualize the customer requirements, as a customized product through a mass customization, improving productivity and achieving higher levels of quality with a manufactured profitably result [6,19]. Indeed, by applying advanced information and communication technologies and systems in the manufacturing and supply chain operations, the industry 4.0 addresses the smart factory [28]. Smart factory is designed according to sustainable and business practices, insisting upon, flexibility, adaptability and self-adaptability, learning characteristics, fault tolerance, and risk management [15]. Therefore, standards are essential to ensure the exchange of data between machines, systems and software and guarantee that product moves within a network value chain [6].

That is, high levels of automation come as standard [15]. Automation systems, manufacturing and product management are integrated and are the base of the smart factory [6]. Manufacturers can now add sensors and microchips to tools, materials, machines, vehicles and buildings to communicate with each other in real-time to make smart products [15].

According to [36], "products know their histories and their routes, and thereby not only greatly simplify the logistic chain but also form the basis for product life cycle data memories". Also, the products can be manufactured because smart factory is being supplied with energy from smart grids [30].

Not only smart factory and smart product were defined in this new industrialized era. Others concepts connected to them are considered in the literature. For their work development, Kolberg and Zuhlke [21] considered four different smart concepts to define the smart factory, namely, smart planned, smart product and smart machine, and smart operators. The authors [30] make mention of the smart grid, smart logistics and smart data. Sanders et al. [28] mention

Table 1. Concepts of Industry 4.0

Concepts	Description
Smart factory	Smart factory represents the key characteristic of Industry 4.0 [15]. The smart factory will be more flexible, dynamic and intelligent [27], where people, systems and objects communicate with each other [15]. The internet of things and services are the main enabler technology for a smart factory [15,29]
Smart manufacturing	Manufacturing will be equipped with sensors and autonomous systems which allow that operations can be optimized with a minimum employee's intervention [27,29]. It produces small-lot products of different types, more efficiently [34]
Smart product	A smart product is a product with sensors and microchips that allow communication via the internet of things with each other and with employees [27]. It holds the information about its requirements for the manufacturing processes and manufacturing machines [21,30]
Smart logistics	It is one of sustainable mobility strategies [15]. Smart logistics will use CPS for carrying the material flow within the factory and in the supply chain (between factories, customers and other stakeholders) [30]. The transport equipment is a part of smart logistics that is able to react to unexpected and autonomously should be able to drive between the starting point and the destination [30]. Distribution and procurement will increasingly be individualized [27]
Smart engineering	Includes product design and development, production planning and engineering, production and after sales service [29]
Smart data	Smart data is structured information of data that can be used for decision-making [30]
Smart machine	Machines and equipment will have the ability to improve processes through an intelligent decision-making, instead of being directly instructed [27,34]. The smart machines should have additional autonomy and sociality capabilities to adapt and reconfigure to different types of products [34]
Smart planner	Smart Planner optimizes processes in real-time [21]. Decentralized self-organization [27]
Smart operator	smart operator is an employee who supported by ICT, control and supervise ongoing activities [21]. Employees can be quickly directed to the right tool [6]
Smart customer	Customers' needs and behaviors are analyzed in real-time in way to provide them with new and more sustainable products and services [29]
Smart supplier	Based on factory needs it is possible to select the best supplier (which allows higher flexibility) and strengthen a sustainable relations with suppliers (by increase information sharing in real-time) [29]
Smart grid	Responsible to supply energy to a factory [30]. Energy management [15]
Smart energy	Monitor and provide feed-back on energy production and use [23]

others concepts as the smart systems, smart environment, smart machine and smart devices, and smart task. Table 1 compiles several concepts of Industry 4.0.

Through the integration of the industry concepts and technologies it should be possible provide a customized or individualized product or service and at the same time be highly adaptive to demand changes [15]. These changes must be made on all stages of product life cycle: design phase, raw material acquisition phase, manufacturing phase, logistics and supply phase, and the use and end of

life phases [15,30]. Therefore, the requirements for design and operations of our factories become crucial for the success [36].

3 Lean and Green Supply Chain Paradigms

Nowadays, lean and green supply chain is an integrated approach; they have different objectives and principles but they complement each other [7,9,10,12–14,31]. Lean supply chain is about to increase value for customers by adding product or service features, with the elimination of waste or non-value steps along the value chain [11]. Green supply chain regards to reducing environmental impacts and risks while improve ecological efficiency of the organizations and their partners, and try to achieve corporate profit and market share objectives [35].

These two paradigms are often seen as compatible because of their joint focus on waste reduction [5]. Lean paradigm is concerning to the elimination of waste in every area of design, manufacturing, and supplier network and factory management [13]. The basic forms on the reduction and elimination of waste are [17]: production, waiting, transportation, unnecessary inventory, inappropriate processing, defects and unnecessary motions. One more waste is pointed by [31] as the unused employee creativity. Green considers ways to eliminate waste from the environment's perspective [11]. The waste generation have the form of [16]: Greenhouse gases, eutrophication, excessive resource usage, excessive water usage, excessive power usage, pollution, rubbish and poor health and safety. In their research [12] mention that the two paradigms have the same type of wastes: (i) inventory; (ii) transportation, and (iii) the production of by-product or non-product output. According to [5] the removal of non-value adding activities suggested by lean paradigm can provide substantial energy savings which integrates the principles of green paradigm.

The combination of lean and green supply chain practices have better results than the total from the implementation of each, but separately [12]. The two paradigms have similar characteristics. According to [4] both paradigm practice contribute for: (i) the increase of information frequency, (ii) the increase of the level of integration in supply chain, (iii) the decrease of production and transportation lead time, (iv) the reduction in the supply chain capacity buffers; (v) and the decrease of inventory levels. Another practice that contributes for the better employ and use of all tools is the involvement of the employees [12]. Both paradigms look into how to integrate product and process redesign in order to prolong product use, to allow easily the recycling or re-use of products, and to make processes with less wasteful [12]. In the supply chain both paradigms ask for a closed collaboration with partners [22]. In addition, waste reduction, lead time reduction, and use of techniques and approaches to manage people, organizations, and supply chain relations are synergies mention by [13].

Commitments must be made within factory, supplier network and customer, for the better deployment of lean and green practices in way to achieve the best supply chain efficiency. In the authors previous study [11] it was presented a table

Table 2. Lean and green paradigms characteristics in supply chain

Characteristics	Lean	Green
Philosophy focus	Long-term thinking [2]	Long-term thinking since environmental impacts affects the natural environment for many years [18]
Market focus	Serve only the current market segments with predictable demand [33]	Demands from at least some customer segments for more environmentally friendly practices [35]
Manufacturing focus	Lean manufacturing use Lean Automation [28]. Lean manufacturing focus on maximizing productivity by increasing output per unit of input, conserving resources, reducing waste, and minimizing costs [7]	Green manufacturing focuses on the environment and identifies waste as excessive use of resources or substances released to the air, water or land that could harm human health or the environment [24]
Product design focus	Product design sets the conditions for manufacturing: process and product development [18]; Eliminate waste, increase productivity and reduce cost [7]	Green design or Eco-design; Selection of low impact materials, reduction of materials usage, optimization of production techniques, improvement of distribution system, reduction of impact during usage, improvement of initial life time, and improvement of end of life system [18]
Inventory strategy	Minimizes inventory throughout the chain [4]	Reductions in inventory levels [4]
Supply focus	Inter-organizational involvement [22]. Close cooperation with all supply chain entities [18]	Inter-organizational collaboration involves activities to deploy green issues in supply chain entities [22]
Information sharing	Demand high levels of information sharing [22]	Information sharing is important for the successful implementation [22]
Employees	Employee involvement and empowerment [12]. The education and training of the employees to execute multiple tasks [2]	Involvement of employees [18]. The education of the employees concerning green issues [12]
Customer	Satisfying the customers by reducing costs and lead times [12]	Satisfying the customers by the implementation of green issues [12]
Processes	Focus on product [2]. Continuous improvement culture [24]	Focus on processes and products [18]. Process optimization through the implementation of green issues [31]

comparing the different characteristics between lean and green. Others important studies [3,4,12,18,22] were inspire for the development of a comparison between lean and green paradigms. Several lean and green supply chain characteristics are considered in Table 2.

4 Combining Industry 4.0 and Lean and Green Supply Chain

The future must become leaner in organization accurately in planning and technology [36]. The authors [21] mentioned that the paradigm Industry 4.0 solutions

not only can be integrated in lean manufacturing but can be beyond that improve lean manufacturing. Also Sanders et al. [28] considered that industry 4.0 and lean manufacturing can be integrated to achieve a successful production management. However, they are not mutually exclusive [28].

Definitely, several researches mention the benefits of the integration of lean and green in different stages of the company or the supply chain [1,9,12,13,20]. Kainuma and Tawara [20] studied the lean and green supply chain incorporating there cycling or re-use during the life cycle of products and services. It represents the different phases of a product life cycle, consisting in [20]: (i) the acquisition of the raw material, (ii) the manufacturing, (iii) the distribution, (iv) the retailer, (v) the use, (vi) the collection, (vii) the transportation, (viii) the dismantling and (ix) the decomposition.

Stock and Seliger [30] presented the opportunities for the realization of a sustainable manufacturing in the Industry 4.0. For them the life cycle (in the end-to-end solution) consists in different phases [30]: (i) the raw material acquisition, (ii) the manufacturing, (iii) the transport (between all phases), (iv) the use and the service phase, and (v) the end-of-life phase (containing the reuse, remanufacturing, recycling, recovery and disposal). In addition, the environmental/green dimension of the sustainability is better considered because the allocation of resources as products, materials, energy and water can be realized in a more efficient way [30]. The adoption of smart energy systems facilitates the energy use [23].

In fact energy models would assist the analysis of green factory designs, especially for evaluating alternatives during early design stages [25]. The design of lean and green supply chain, special in the early design stages for the products and the processes is a very important issue for the elimination of waste. In a lean and green environment [7] mention that "eliminating the use of toxics through product or process re-design could mean reduced worker health and safety risks, reduced risks to consumers and lower risk of product safety recalls and reducing process wastes in manufacturing often find more opportunities to reduce waste throughout the life cycle of the product, thereby having a possible domino effect on the entire supply chain". Industry 4.0 is in line with these ideas. According to [27], Industry 4.0 processes will change the entire supply chains, from suppliers to logistics and to the life cycle management of a product. It helps to streamline the process, with more transparency and flexibility.

Lean and green supply chain requires manufacturing technologies to make processes and products more environmentally responsible [22]. In addition they ask for a flexible information system [17]. The technology is a driver of the Industry 4.0 [15,34]. With smart technologies which include the use of electronics and information technologies [27] will help the implementation of a more efficient lean and green supply chain.

Also the collaboration with suppliers which is a lean and green characteristic is considered by Industry 4.0. Through a better communication mechanisms, with a high compatibility issues of hardware and software which should required

standardized interfaces, and synchronisation of data, allow that lean and green suppliers get better synchronisation with manufacturers [28,32].

The author [14] concludes that lean and green "is an effective tool to improve processes and reduce costs, by not only reducing non-value-added activities but also physical waste created by systems". Industry 4.0 is in line with this statement due this paradigm make all but in a better way, more sustainable, faster and efficient. According to [21] lean allows the organizations to be more standardized, transparent and having only the essential work which result in an organization less complex and support the installation of industry 4.0 processes and solutions. The green also support the implementation of the Industry 4.0 due it allows to reduce the negative environmental impacts.

The customer type is a concern in the lean and green supply chain. Of course that lean and green aim is to satisfy the customer needs, but this satisfaction is relative to: in the lean paradigm is based on cost and lead time reduction [9] and in the green paradigm is based on helping customers to being more environmentally friendly [13]. The Industry 4.0 will go to improve in this subject. It allows a better understanding of the customer needs and allows the immediate sharing of the demand data throughout complex supply chains [15]. According to [27] with the full automation and digitalization systems, it allows an individual customer-oriented adaptation of products that will increase the value added for organizations and customers. Customers instead of choose from a fixed product spectrum set by the manufacturer, they will be able to individually combine single functions and components and define their own product [15].

Another characteristic of lean and green supply chain is the employee involvement and empowerment [12]. According to [8] employee commitment and motivation, and employee empowerment and participation are elements of lean and green organization. Also [24] mention that connections between lean and green practices are shown through: (i) employee involvement, (ii) learning by doing, (iii) continuous improvement, and (iv) problem-solving tools. [36] mention that lean means reducing complexity, avoiding waste and strictly supporting the employees in their daily work. Also the reduction of environment impacts improves the health and safety of employees [31]. These aspects are in line of what is an employee in the four industrial revolution. Indeed, employees may find greater autonomy and more interesting or less arduous work [6]. Industry 4.0 needs employees not only with creativity and decision-making skills, encountered as a lean and green supply chain characteristic, as well as technical and ICT expertise [6].

There are in literature some studies that try to make the bridge between lean paradigm and green paradigm with Industry 4.0. [28] used 10 lean concepts in their research in way to validated for attainability through Industry 4.0 paradigm. Kolberg and Zühlke [21] described the lean automation and Industry 4.0 and give an overview of the links between them. [30] present an overview of sustainable manufacturing with the future requirements of Industry 4.0. Figure 1 illustrates an attempt to link lean and green supply chain characteristics to Industry 4.0 concepts.

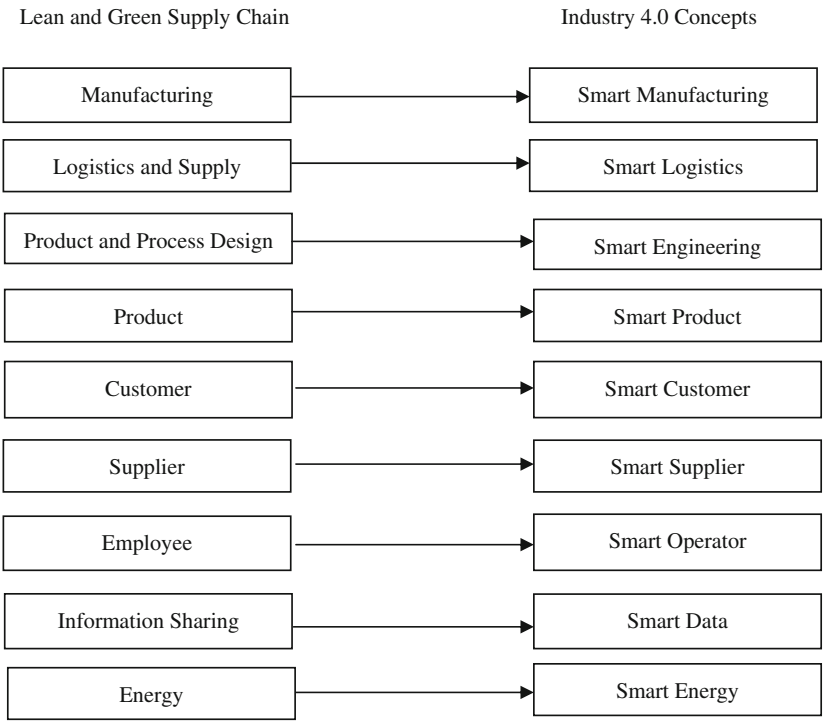

Fig. 1. Linking the lean and green supply chain characteristics to the Industry 4.0 concepts

5 Conclusion

Today, the term Industry 4.0 describes a vision of future of the supply chains. There is a strong conviction that the definition of lean and green supply chain will not disappear, it will be evolve and adapt to the new trends that the new industrial era will require. Lean and green supply chain is focussed on organization and in the flow of information, material and money between partners. That is, more directed to physical processes and less for virtual and technology. Even so there are in literature some examples that try to make the bridge between lean paradigm or green paradigm with Industry 4.0. This paper bridges the gap between the well-known lean and green supply chain management and the new era of industrial revolution.

A conceptual model was developed linking the lean and green supply chain characteristics to the Industry 4.0 concepts. Several characteristics were presented on model, namely: (i) manufacturing, (ii) logistics and supply, (iii) product and process design, (iv) product, (v) customer, (vi) supplier, (vii) employee, (viii) information sharing and (ix) energy. Those who understand the relationships between these two topics will have a greater chance of influencing their

supply chains into a source of competitive advantage and help in a better way on the deployment of the Industry 4.0 paradigm.

Future research is needed. Understand which lean and green characteristics are more important for the development of Industry 4.0 is required. It would be also beneficial to understand the priority between characteristics on the implementation of this new paradigm and in different entities in the supply chain. Industry 4.0 will be a step forward for the effectiveness and competitiveness of the lean and green supply chains.

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