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An investigation of lean and green supply chain in the Industry 4.0

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Abstract

Industry 4.0 is the new paradigm of the fourth industrial revolution; it embodies a smart industry by applying advanced information and communication systems, and high technology. These advancements evolved and assisted the supply chain to become a more adaptive network creating new opportunities for supply chain competitiveness. Management paradigms as lean and green can develop improvements in the supply chain. The integrative lean and green approach eliminates non-value added activities and at the same time reduces environment impacts and risks throughout the supply chain operations. This study is motivated by the lack of evidence how the lean and green supply chain should evolve to work efficiently in Industry 4.0 environment. The purpose of this study is to investigate whether Industry 4.0 can support the implementation of the lean and green supply chain. Based on literature review, a conceptualization of the relations between Industry 4.0, supply chain management and lean and green paradigms is presented. This paper provides an understanding of how this new industrial revolution incorporated lean and green supply chain paradigms.

Keywords

Industry 4.0, Supply Chain Management, Lean paradigm, Green paradigm

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1. Introduction

Companies worldwide are continuously trying to develop new and innovative ways to strengthen their brand image and achieve the best competitive advantage (Rao and Holt, 2005). Supply chain management is the management of the flow of material, information and cash between different companies, from the supplier to the manufacturer and customer. The supply chain activities have become a critical part of business processes. Therefore, supply chain must be seen as a system that needs continual improvement in their activities to achieve a product or service with a higher quality, in less time than ever before and above all, reducing cost. Also, companies want to be seen as the ones that responsibly conduct their business, being aware of the impact on environment provoked by supply chain activities (Zhu *et al.*, 2008; Mollenkopf *et al.*, 2010).

Exploring new paradigms as lean and green in supply chain context may change practices to obtain a more efficient and sustainable supply chain. The importance given to lean and green paradigms is rising. The lean paradigm improves quality and productivity by eliminating waste and at the same time reduces cost and time, satisfying customer needs; lean is focused on optimizing the processes of all the supply chain, searching for simplification and reducing activities that do not add value. The green paradigm aims to reduce environmental impacts while eliminating environmental waste in companies (EPA, 2007). The green paradigm focus on achieve profit and market share, by reducing environmental risks and impacts while improving ecological efficiency, within company and between companies (Zhu *et al.*, 2008). The integration of these two paradigms to achieve better performance in the supply chain is something that has more focus and attention by researchers. The compatibility of these two paradigms helps to streamline the value chain (Carvalho *et al.*, 2011).

However, there is a need to revolutionize how companies make things and deliver services today. The new industrial revolution, the Industry 4.0 comes to set a new course of new ways of creating customer value (Kagermann *et al.*, 2013). Through modern information and communication technologies in physical processes, is possible a better understanding of the customer needs and the quick sharing of the demand data throughout complex value chain (GTAI, 2014). Full automation and digitalization systems allow an individual customer-oriented adaptation of products or services that will increase the value added for companies and customers (Roblek *et al.*, 2016). Customers instead of choosing from a fixed product spectrum set by the manufacturer will be able to individually combine single functions and components and customize their products (GTAI, 2014). This paradigm involves an exchange of materials, information and energy both within a company and between different companies, through a flexible and reconfigurable system (Kagermann *et al*., 2013). There, it will change the value creation (Kagermann *et al.*, 2013). Industry 4.0 creates the intelligent industry that is coined as “smart”. It involves the combination of the industrial value chain, the product life cycles, and the business information technology; it must integrate the processes from the product and process design, production planning and manufacturing, and supply chain management.

The aim of this paper is to analyze the knowledge gap how these concepts interact, understanding the role of lean and green supply chains in the Industry 4.0. To respond to research objective, this paper is organized as follows: in section 2, a literature review on lean and green supply chain is presented; in section 3, a brief reviews literature on Industry 4.0; in section 4 a combination between lean and green supply chain and Industry 4.0 is developed; Finally, some concluding remarks are drawn.

2. Lean and Green Supply Chain

2.1 Supply chain management

Supply chain management is a vital subject between companies. The proper management of the supply chain means that the entire set of activities must be viewed as a single system. The objective is to guarantee a continuous flow between companies, to satisfy the customer needs with the right product or service, in the right quantities, at the right time, and at the right place at the lowest possible cost (Cruz-Machado, 2007).

Lambert and Cooper (2000) consider "members of a supply chain include all companies with whom the focal company interacts directly or indirectly through its suppliers or customers, from point of origin to point of consumption". The focal company is who rule the supply chain, provide the direct contact to the customer and design the product or service offered (Seuring and Muller, 2008). Companies are entities of the supply chain management considering the focal company, suppliers, and customers which are linked by information, material and cash flows (Kainuma and Tawara, 2006). Supply chain promotes interdependency between companies. Figure 1 shows a supply chain structure according to Lambert and Cooper (2000) and Anand and Kodali (2008).

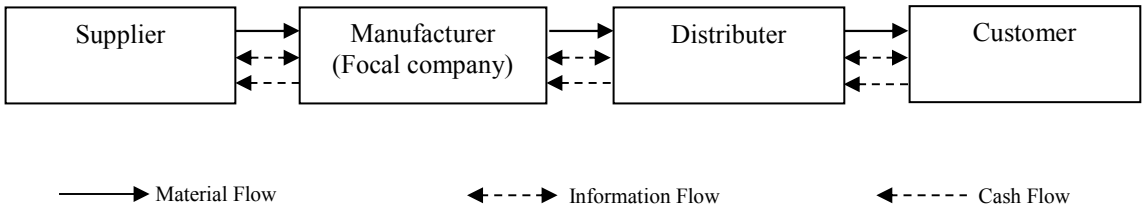

Figure 1. Supply chain structure

As a result, the supply chain definition comprises issues as cost, time and quality. However, several features may affect the supply chain activities. Examples are the customized customer demand, the design of products and services, the protection of the ecological environment, innovation-technology and globalization (Mollenkopf *et al.*, 2010; Carvalho *et al.*, 2011). Supply chains need to answer to customer demand and conventional management practices are not enough to ensure the long-term business success. Therefore, companies must develop solutions to improve the supply chain (Mollenkopf *et al.*, 2010). These requirements can be improved with the lean and green supply chain paradigms.

2.2 Lean and green paradigms supply chain

Lean paradigm and green paradigm are being deployed on supply chain activities, at the same time. Lean is a philosophy that strives to identify and eliminate all non-value added activities involved in any process flow, with the aim to achieve improvements (Govindan *et al.*, 2015). This paradigm is being implemented in a large number of companies all over the world (Chiarini, 2011). Initially, this management system was developed to reduce waste in production processes and to improve the product quality (Jasti and Kodali, 2015; Verrier *et al.*, 2016). Now, lean is about a number of initiatives considering on almost every aspect of processes (Duarte and Cruz-Machado, 2011). The lean asks for space reduction, workforce reduction, increased capacity utilization, higher system flexibility and use of standard components (Pettersen, 2009). Lean requires a climate of innovation, an infrastructure to support it, and a complete management commitment (Wyton and Payne, 2014). It extends beyond the limits of a company, from the suppliers to the customers (Jasti and Kodali, 2015). Indeed, lean seeks to eliminate all form of waste along the supply chain (Venkat and Wakeland, 2006). The authors, Mollenkopf *et al.* (2010) highlight that lean supply chain management literature are already well developed.

Green is a critical management paradigm since it intends to reduce environmental impacts and risks and at the same time achieve organizational profit and market share objectives (Azevedo *et al.*, 2012). The green paradigm has root in environmental management (Srivastava, 2007). Green supply chain management adopts environmentally friendly initiatives which can be deployed to decrease the environmental impact (Karagullea, 2012). This can be through reduction of green waste as energy, water, emissions to air, solid waste and hazardous waste (EPA, 2007), through the pollution prevention (Jaggernath, 2015) or a more efficient use of all resources (Mohanty and Prakash, 2015). According to Jaggernath (2015) green initiatives should be considered in the initial phase of product design

and raw material acquisition, continue throughout the various manufacturing stages, the delivery and distribution of the product to the customer and the dispose of the end use product. The scope of green supply chain ranges from initiatives implemented through reduce, reuse and recycle, and rework, return, remanufacturing and reverse logistics (Srivastava, 2007). The green supply chain also asks for collaboration with customer and suppliers for environmental objectives (Zhu *et al.*, 2008). Implementing green practices can enable the maintenance of business (Jaggernath, 2015).

The integration of these two paradigms is possible due to their high compatibility. Both paradigms have characteristics that can be integrated. It can originate synergies for supply chain improvement. Table 1 presents several lean and green supply chain characteristics, resulting of the author´s previous work.

Table 1. Lean and Green paradigms supply chains characteristics
(Adapted from: Duarte and Cruz-Machado, 2011 and Duarte and Cruz-Machado, 2017A)

Characteristics	Lean paradigm	Green paradigm
Philosophy	Long-term thinking.	Long-term thinking since environmental impacts originating from industrial activities affects the natural environment for many years.
Organizational Structure	Use of flat hierarchy.	Cross-functional collaboration for environmental improvements.
Market	Serve only the current market segments with predictable demand.	Demands from at least some customer segments for more environmentally friendly practices.
Manufacturing focus	Maintain high average utilization rate. Realize improvements in productivity and product quality through waste elimination.	Green manufacturing use appropriate material and technologies. Realize improvements in productivity and environmental performance as pollution prevention, production process modernization, materials substitution and waste minimization.
Product design Strategy	Maximize performance and minimize cost.	Eco-design or green design; development of products that are more durable, energy efficient, avoid the use of toxic materials and which can be easily disassembled for recycling.
Information Sharing	Highly desirable.	Highly desirable.
Stakeholders	Close cooperation with all stakeholders in the supply chain. Strategic alliance (trust and partnership) with suppliers. Inter-organizational involvement.	Green supply chain brings all supply chain entities benefits (dissemination of green to partners). Green purchasing. Inter-organizational involvement.
Inventory strategy	Generates high turns and minimizes inventory throughout the chain.	Reduced product dimensions; making products foldable for storage and transport. Introduce remanufactured or re-used parts in the material inventory.
Product life cycle	Long; standard products have long life cycle times.	The product life cycle is influenced by the design for environmental issues, the improvement of processes and having an efficient reverse logistics system in place.
Employee involvement	Employee involvement and employee empowerment. Effective management of human resources. Employees' training to perform multiple tasks.	Positive motivations among internal employees. Educating employees concerning green issues.
Processes	Process optimization. Achieving quality throughout the processes.	Increasing green issues to sustain their processes. Designing and developing

		processes considering their environmental impact.
Key metrics	Lead time; costs; quality.	Scrap or non-product output, materials use, hazardous materials use, energy use, water use, air emissions, hazardous waste and water pollution.
Performance analysis	Helps to improve performance in many industries. Problem-solving through frequent feedback.	Reporting performance along environmental information.

Through the deployment of both paradigms, the supply chain can be considered as a hybrid system (Duarte and Cruz-Machado, 2011). The authors Carvalho *et al.* (2011) provide examples of synergies among lean and green: i) high levels of capacity utilization (lean fix higher utilization rate of the supply chain resources and green prescribe the efficiency of resources consumption contributing to the reduction of the excess capacity along the supply chain), ii) minimization of inventory levels (lean ask for inventory reduction and green ask for the reduction of redundant and necessary materials). Their research concludes that both paradigms contribute to the increase of information frequency and integration level, for the decrease in the production and transportation lead time, and of the capacity surplus and inventory level (Carvalho *et al.*, 2011). Therefore, companies can manage the supply chain applying the synergies between both paradigms supply chain (Mollenkopt et *al.*, 2012). The integrated lean and green approach is implemented in all industry sectors.

3. Industry 4.0 paradigm

The Industry 4.0 is the paradigm of the fourth industrial revolution. It represents the future, the high technology industry, revolutionizing how to make things and deliver services. It decentralized the production through technological advances transforming the conventional industrial process logic. The industrial processes improvements arose from new ideas, algorithms, and technologies. Information and communication technologies (ICT), such as internet of things and internet of services (e.g. big data, cloud computing, and artificial intelligent technology) are enabling factors (Wang *et al.*, 2016). According to GTAI (2014), the merging of the virtual and the physical worlds through cyber-physical systems (CPS) and the resulting fusion of technical processes and business processes are leading the way to the Industry 4.0 paradigm. To implement Industry 4.0, three features should be considered (Kagermann *et al.*, 2013; Stock and Seliger, 2016; Wang *et al.*, 2016):

- Horizontal integration across the entire value networks: cooperation with entities and competition between entities. Throughout the horizontal integration, information, material and cash flows can easily run among entities creating a new value network. This interrelationship between entities can form an efficient ecosystem.
- Vertical integration and networked manufacturing system: integration of the various information and physical systems at the different hierarchical levels, inside a factory to create flexible and reconfigurable manufacturing system (e.g. production management, manufacturing and execution, and corporate planning).
- End-to-end digital integration of engineering across the entire value chain or product life cycle: digital integration of engineering across the entire value chain to support product customization. (e.g. from the raw material acquisition to manufacturing product, and product in use and the end of life). The end-to-end solution is the result of the horizontal and vertical integration.

Through these features, an implementation of an environment more efficient, flexible and sustainable is expected. The idea is to individualize the customer requirements, as a customized product through a mass customization. It is expected the improvement on productivity and higher levels of quality with a manufactured profitably result (Davis, 2015). Also, it implies an extensive integration between customers and between suppliers (Shrouf *et al.*, 2014).

The internet of things and services provides transparency almost in real time, allowing for optimization across

all company functions and between companies (Shrouf *et al.*, 2014; Wang *et al.*, 2016). Knowing the production status in real time, reduce waste, save energy and improve efficiency (Shrouf *et al.*, 2014). Different aspects of processes are dynamically reconfigured as the quality, time, price, risk, robustness, and ecological/green aspects (Kagermann *et al.*, 2013; Wang *et al.*, 2016). It is understandable that Industry 4.0 influences the production environment with radical changes enabling real time planning of production plans and self-optimization (Sanders *et al.*, 2016). Processes are optimized at different levels, in real time and on a case-by-case basis (Shrouf *et al.*, 2014). The entire factory environment becomes smart (Sanders *et al.*, 2016).

Indeed, the smart factory uses an entirely new approach to production (Kagermann *et al.*, 2013). Shrouf *et al.* (2014) considers the following characteristics of a smart factory: i) mass customization, ii) flexibility, iii) visibility and optimized decision-making; iv) new planning methods for factories, v) new services creation, vi) value creation from big data collected, vii) remote monitoring, viii) automation and change role of man, ix) proactive maintenance, x) connected supply chain, and xi) energy management. Thus, smart factories have several interrelated concepts, namely smart machine, smart devices, smart manufacturing, smart engineering, smart logistics, smart task, smart supplier, smart data and smart grid (Shrouf *et al.*, 2014; Stock and Seliger, 2016; Sanders *et al.,* 2016). Table 2 provides the definition of these diferent concepts.

Table 2. Concepts of Industry 4.0
[Source: Duarte and Cruz-Machado, 2017B]

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

4. Conceptualization

Through a modern information and communication technologies is possible a better understanding of the customer needs and the quick sharing of the demand data throughout complex value chain (GTAI, 2014). Industry 4.0 involves an exchange of materials, information and energy both within a company (e.g. logistics, production, and marketing), and between several different companies (Kagermann *et al.*, 2014). It idealizes the network concept where machines and products interact with each other without people. In this kind of networks, supply chains have dynamic structures which change in real time (Ivanov *et al.*, 2016). The internet of services will improve supply chain efficiency by providing information more detailed and in real time, mitigating the bullwhip effect, delivering customized product and improving product traceability (Roblek *et al.*, 2016). Indeed, industry 4.0 allows a different way to understand the customer needs, share the information faster throughout all the entities of the supply chains. This will allow producing faster (with less waste) and reducing the inventories drastically between supply chain entities. This is in line with lean and green supply chain integrated approach. Lean and green supply chain required the reduction of all kind of waste (being lean or green). The minimization of the inventories all over supply chain is also a lean and green supply chain characteristic (Carvalho *et al.*, 2011).

Lean and green supply chains demand high levels of information sharing (Mollenkopt *et al.*, 2010). In Industry 4.0 the smart data is highly driven by the different entities of the value creation networks (Stock and Seliger, 2016). According to Brettel *et al.* (2014) to satisfy the customer requirement, high levels of information sharing and synchronization between companies is needed.

The close cooperation with suppliers, which is a lean and green characteristic, is also critical for the Industry 4.0. Through better communication mechanisms as hardware and software, a high compatibility is develped. Standardized interfaces and synchronization of data allow a close connection between suppliers and manufacturer (Sanders *et al.*, 2016). Smart supplier will help to increase flexibility based production needs (Shrouf *et al.*, 2014) which can reduce natural resources (e.g. raw materials). With this kind of relationship it is possible confirm a minimization of errors and a better control on waste. This is in line with the lean and green supply chain characterization.

The product design sets the conditions for the process and product development (Johansson and Winroth, 2009). The lean and green concept ask for reduction of waste through all over the supply chain activities, considering the material selection, manufacturing and logistics processes. This is also considered in Industry 4.0 by the smart engineering which includes product design and development and all related processes (e.g. production planning and control logistics) (Shrouf et al., 2014).

In manufacturing process, lean and green ask for a better usage of natural resources, including energy and raw materials (EPA, 2007). This is in line with Industry 4.0 which considers this issue as a topic of matter. As example, knowing the production in real time it is possible control better the use of resources (e.g. incomplete material utilisation).

To understand the customer value and satisfy the customer needs is a concern of lean and green supply chain (Johansson and Winroth, 2009). Industry 4.0 is going to improve this issue through a more flexibility processes and allowing the customer define their product (Roblek *et al.*, 2016; GTAI, 2014). Through the high technology the close relationship with customer will be even stricter.

These examples highlight that lean and green supply chain paradigms can evolve to Industry 4.0. Also, the lean and green paradigms give insides how Industry 4.0 should act. In literature, there are studies developing supply chains frameworks; in a lean perspective, Anand and Kodali (2008) design a lean supply chain framework. It is considered the application of information technology to link the different stages of the supply chain. Also, with supply chain elements allow the correct flow of materials through the various stages of the supply chain and the lean elements to eliminate waste across the supply chain. A green perspective is found in the Olugu *et al.* (2011) for the material flow; these authors mentioned the reverse logistics for making the supply chain become a closed loop taking in the consideration, after customer use, the reuse, recycling and manufacturing of materials into new materials. Integrating the two paradigms, Kainuma and Tawara (2006) presented for material flow, a supply chain in

two stages: the first stage as the typical supply chain and the second stage the reuse and recycling throughout the life cycle of products. This is in line with Vais *et al.* (2006) who refer that 3R – reuse, recycle and reduce - is one of the foundation for lean and green concept.

In addition, all of these are considered in Industry 4.0 concept. According to Stock and Seliger (2016), "the approach for the sustainable design of products focuses on the realization of closed-loop life cycles for products by enabling the reuse and remanufacturing of the specific product or by applying cradle-to-cradle principles." Therefore, in industry 4.0, supply chain must introduce these issues. In addition, Shrouf *et al.* (2014) propose an architecture for the internet of things-based smart factory. Considering the evidences on literature review, a conceptualization of the supply chain with lean and green characteristics in the Industry 4.0 is proposed (Figure 2).

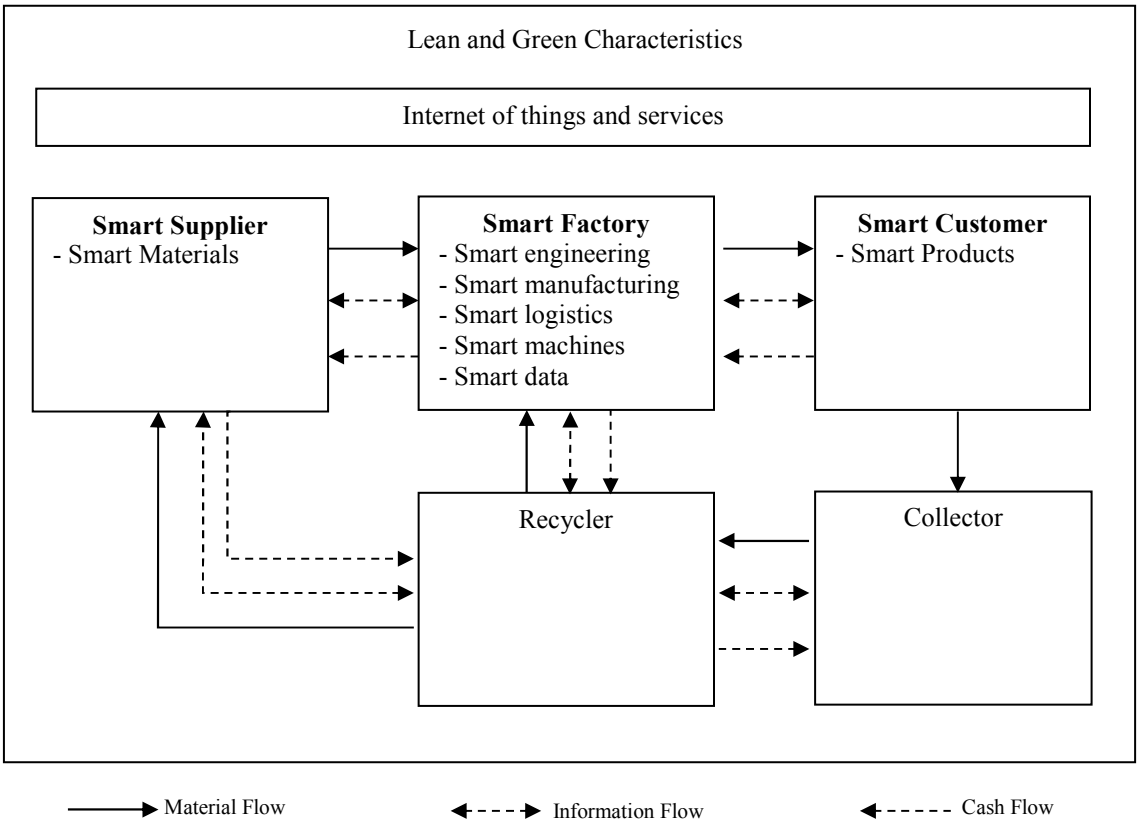

Figure 2. Lean and green supply chain in the Industry 4.0

5. Conclusions

From this study, it is possible to understand that lean and green supply chain will go to evolve and adapt to future requirements of Industry 4.0. Industry 4.0 is based on characteristics that lean and green are already focused. In a general view, the lean and green approach will improve on the Industry 4.0. Several characteristics will adapt: product and process design, manufacturing planning and control, logistics and the cooperation with suppliers, information sharing, and energy and customer value. Among the essential innovations, is the flexibility development supporting the readjusting of processes to the unique customer needs. Another change is related to the information

and materials flow speed. How the communication between entities of the supply chain is made, is crucial for the supply chain competitiveness. All these innovations are possible due the structure of the high-technology application. One of the conclusions of this study is in line with GTAI (2014) "in Industry 4.0 supply chains will evolve into highly adaptive network". Supply chains will be more flexible and with more visibility.

With the application of the requirements of the Industry 4.0 in the different industry sectors, future research is required. For example, understand which lean and green supply chain characteristics are more important on the Industry 4.0 concepts implementation (in different sectors of industry); or the priorities of lean and green characteristics implementation in the Industry 4.0. In this new era of industrialization, it is expected that lean and green supply chain management will have better opportunities to be performed.

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Biography

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