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Integrating Lean, Agile, Resilience and Green Paradigms in Supply Chain Management (LARG_SCM)

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1. Introduction

1.1 What is the problem?

Different management paradigms, such as the lean, agile, resilience and green have been adopted for the management of supply chains. The lean supply chain is a paradigm based on cost reduction and flexibility, focused on processes improvements, through the reduction or elimination of the all "wastes", i.e., non-value adding operations (Womack et al., 1991). It embraces all the processes through the product life cycle, starting with the product design to the product selling, from the customer order to the delivery (Anand & Kodali, 2008). The agile supply chain paradigm intends to create the ability to respond rapidly and cost effectively to unpredictable changes in markets and increasing levels of environmental turbulence, both in terms of volume and variety (Agarwal et al., 2007). However, when organizations are subject to eventual disruptions, caused by sudden and unforeseen events (like economic and politic crisis or environmental catastrophes), the lean practices may have contributed to rupture conditions (Azevedo et al., 2008).

In a global economy, with supply chains crossing several countries and continents, from raw material to final product, those events (even if they happen in a remote place) can create large-scale disruptions (Craighead et al., 2007). These disruptions are propagated throughout the supply chain, causing severe negative effects in supply chains leading to unfulfilled orders. So, it seems that what can be good from the competitive point of view, can cause a disaster on crisis situations; it may be worst if the organizations can not be resilient and robust enough to recover the loosed competitiveness. In actual competitive market, it is necessary that supply chains become more resilient to disruption events (Sheffi & Rice, 2005; Tang, 2006).

Other pertinent issue in supply chain management is the environmental sustainability. The green supply chain management is as an important organizational philosophy to achieve corporate profit and market share objectives by reducing environmental risks and impacts while improving ecological efficiency of these organizations and their partners (Rao & Holt, 2005; Zhu et al., 2008). As a synergistic joining of environmental and supply chain management, the competitive and global dimensions of these two topics cannot go unnoticed by organizations.

1.2 What has been done by other researchers?

The literature shows that almost researches have been focused on the study of individual paradigms in supply chain management (Anand & Kodali, 2008; Agarwal et al. 2007; Hong et al. 2009; Glickman & White, 2006); or on the integration of only a couple of paradigms in supply chain management, e.g., lean vs. agile (Naylor et al., 1999), lean vs. green (Kainuma & Tawara, 2006), resilience vs. agile (Christopher & Rutherford, 2004) or resilience vs. green (Rosič et al., 2009). However the simultaneous integration of lean, agile, resilient, and green paradigms in supply chain management may help supply chains to become more efficient, streamlined, and sustainable.

1.3 What have we done?

In this chapter we use the acronym LARG_SCM to refer the integration of lean, agile, resilient, and green paradigms in supply chain management. The leanness in a supply chain maximizes profits through cost reduction, while agility maximizes profit through providing exactly what the customer requires. Resilient supply chains may not be the lowest-cost but they are more capable of coping with the uncertain business environment. Also, environmental policies must be addressed to assure that the system sustainable. The tradeoffs between lean, agile, resilient, and green management paradigms are actual issues and may help supply chains to become more efficient, streamlined, and sustainable.

This chapter intends to explore the integration of these paradigms and present a conceptual model to provide a deep understanding of synergies and divergences between all of them; this idea is expected to contribute for a more sustainable and competitive supply chain. The main objective is to identify the supply chain attributes that should be managed to obtain the necessary organizational agility; to speed-up the bridging between states that require more or less degree of resilience; to preserve the dynamic aspects of the lean paradigm and; to assure its harmonization with the ecologic and environmental aspects that production processes may attend. To this end, a conceptual model with the relationships between lean, agile, resilient and green practices and supply chain performance was developed. A deductive research approach was used to develop a conceptual model from the literature review; the model was developed using a causal diagram to capture the supply chain dynamics (Sterman, 2000). To construct the cause-effect diagram it was supposed that the supply chain attributes values, are consequence of different supply chain practices implementation and they will affect directly the supply chain key performance indicators values.

This chapter is organized as follows. First, a literature review related to lean, agile, resilient and green supply chain management paradigms is presented. Next, the deployment of the different paradigms in supply chain management is explored; being identified the main supply chain attributes and their relationships with supply chain key performance indicators. In the next section is developed a conceptual model exploring the relationship between the different supply chain paradigms practices and the supply chain key performance indicators. Finally, the main conclusions are drawn.

2. Supply chain management paradigms review

2.1 Lean

The Lean management approach, developed by Taiichi Ohno (1998) at Toyota Motor Corporation in Japan, forms the basis for the Toyota Production System (TPS) with two main pillars: 'autonomation' and 'just-in-time' (JIT) production. The focus of the lean approach has essentially been on the waste reduction for increasing actual value-added, to fulfil customers needs and maintaining profits. This new structural approach and the way Toyota used lean production to change the nature of automobile manufacturing, has been better described in the book "The Machine that Changed the World" (Womack, 1991).

The lean supply chain is a strategy based on cost reduction and flexibility, focused on processes improvements, through the reduction or elimination of the all "wastes" (non-value adding operations). It embraces all the processes through the product life cycle, starting with the product design to the product selling, from the customer order to the delivery. Reichhart and Holweg (2007) had extended the concept of lean production to the downstream or distribution level: "we define lean distribution as minimizing waste in the downstream supply chain, while making the right product available to the end customer at the right time and location". To Vonderembse et al. (2006) a lean supply chain is the one that employs continuous improvement efforts that focus on eliminating waste or non-value steps along the chain. The internal manufacturing efficiency and setup time reduction are the enablers of the economic production of small quantities, cost reduction, profitability, and manufacturing flexibility (Vonderembse et al., 2006).

At operational level, the lean paradigm is implemented by using a number of techniques such as Kanban (visual signal to support flow by 'pulling' product through the manufacturing process as required by the customer), 5S (a visual housekeeping technique which devolved control to the shop floor), visual control (method of measuring performance), takt time (i.e. the production rate that equals the rate of sales), Poke yoke (an 'error-proofing' technique), SMED (a changeover reduction technique) (Melton, 2005). The application of these techniques throughout the network has a consequence in decreasing of redundancy in materials, processing and transportation activities, as well as in information and knowledge supply (Adamides et al., 2008).

However, there are some drawbacks of lean paradigm when applied to the supply chain: the short setup times provide internal flexibility, but a lean supply chain may lack external responsiveness to customer demands, which can require flexibility in product design, planning and scheduling, and distribution (Vonderembse et al., 2006). Extending lean beyond the factory and component supply system into distribution operations results in a potential conflict: the need of production smoothing and kanban systems (that cannot cope with high levels of variability) and the need to link the production pull signal to variable demand in the marketplace (Reichhart & Holweg, 2007).

The lean approach has been considered to perform better when there is high volume, low variety and predictable demand with supply certainty, so that functional products can be created. Conversely, in high variety and volatile supply chains, where customer requirements are often unpredictable, a much higher level of agility is required (Cox & Chicksand, 2005; Naylor et al., 1999; Agarwal et al., 2007). To add value to the customer, the lean approach seeks to find ways to manage variability and to create capability by utilising assets more effectively than in traditional systems (Hines et al., 2004). Leanness may be an element of agility in certain circumstances, but it is not a sufficient condition to the organization to meet the precise needs of the customers more rapidly (Agarwal et al., 2007; Christopher & Towill, 2000).

2.2 Agile

The supply chain objective is to delivering the right product, in the right quantity, in the right condition, to the right place, at the right time, for the right cost. Since customer requirements are continuously changing, supply chains must be adaptable to future changes to respond appropriately to market requirements (and changes).

In lean supply chains the focus is on "waste" elimination, but in agile supply chains the focus is on the ability of comprehension and rapid responding to market changes. An important difference is that lean supply is associated with level scheduling, whereas agile supply means reserving capacity to cope with volatile demand (Christopher & Towill, 2000). The agile supply chain intends to have the ability to respond rapidly and cost effectively to unpredictable changes in markets and increasing levels of environmental turbulence, both in terms of volume and variety (Agarwal et al., 2007; Christopher, 2000). Baramichai et al. (2007) used the following definition: "An agile supply chain is an integration of business partners to enable new competencies in order to respond to rapidly changing, continually fragmenting markets. The key enablers of the agile supply chain are the dynamics of structures and relationship configuration, the end-to-end visibility of information, and the event-driven and event-based management".

Naylor et al. (1999) used the decoupling point concept to divide the part of the supply chain that responds directly to the customer (demand is variable and high product variety) from the part of the supply chain that uses forward planning and a strategic stock to buffer against the demand variability (demand is smooth and products are standard). He proposed the designation "leagile" supply chain where the lean principles are followed up to the decoupling point and agile practices are followed after that point.

Agarwal et al. (2007) have shown that supply chain agility depends on the following: customer satisfaction, quality improvement, cost minimization, delivery speed, new product introduction, service level improvement, and lead-time reduction. Literature on supply chain agility describes the agility dependence on some performance variables; however, the influence of interrelationships among the variables on the supply chain agility has been hardly taken into account (Agarwal et al., 2007).

2.3 Resilience

There is evidence that the tendencies of many companies to seek out low-cost solutions, because of pressure on margins, may have led to leaner but more vulnerable supply chains (Azevedo et al., 2008; Peck, 2005). Today's marketplace is characterized by higher levels of turbulence and volatility. As a result, supply chains are vulnerable to disruption and, in consequence, the risk to business continuity has increased (Azevedo et al., 2008). Whereas in the past the principal objective in supply chain design was cost minimization or service optimization, the emphasis today has to be upon resilience (Tang, 2006). Resilient supply chains may not be the lowest-cost but they are more capable of coping with the uncertain business environment.

Resilience refers to the ability of the supply chain to cope with unexpected disturbances. It is concerned with the system ability to return to its original state or to a new one, more desirable, after experiencing a disturbance, and avoiding the occurrence of failure modes. The goal of supply chain resilience analysis and management is to prevent the shifting to undesirable states, i.e., the ones where failure modes could occur. In supply chain systems, the objective is to react efficiently to the negative effects of disturbances (which could be more or less severe). The aim of the resilience strategies has two manifolds (Haimes, 2006): i) to recover the desired values of the states of a system that has been disturbed, within an acceptable time period and at an acceptable cost; and ii) to reduce the effectiveness of the disturbance by changing the level of the effectiveness of a potential threat.

The ability to recover from the disturbance occurrence is related to development of responsiveness capabilities through flexibility and redundancy (Rice & Caniato, 2003). Flexibility is related to the investments in infrastructure and resources before they actually are needed, e.g., multi-skilled workforce, designing production systems that can accommodate multiple products, or adopting sourcing strategies to allow transparent switching of suppliers. Redundancy is concerned to maintaining capacity to respond to disruptions in the supply network, largely through investments in capital and capacity prior to the point of need, e.g., excess of capacity requirements, committing to contracts for material supply (buying capacity whether it is used or not), or maintaining a dedicated transportation fleet. Rice and Cianato (2003) differentiated flexibility from redundancy in the following way: redundancy capacity may or may not be used; it is this additional capacity that would be used to replace the capacity loss caused by a disruption; flexibility, on the other hand, entails restructure previously existing capacity.

Tang (2006) propose the use of robust supply chain strategies to enable a firm to deploy the associated contingency plans efficiently and effectively when facing a disruption, making the supply chain firm become more resilient. This author proposes strategies based on: i) postponement; ii) strategic stock; iii) flexible supply base; iv) make-and-buy trade-off; v) economic supply incentives; vi) flexible transportation; vii) revenue management; viii) dynamic assortment planning; ix) silent product rollover. Christopher and Peck (2004) proposes the following principles to design resilient supply chains: i) selecting supply chain strategies that keep several options open; ii) re-examining the 'efficiency vs. redundancy' trade off; iii) developing collaborative working; iv) developing visibility; v) improving supply chain velocity and acceleration. Iakovou et al. (2007) refer the following resilience interventions: i) flexible sourcing; ii) demand-based management; iii) strategic emergency stock (dual inventory management policy that differentiates regular business uncertainties from the disturbances, using on the one hand safety stocks to absorb normal business fluctuations, and on the other hand, keeping a strategic emergency stock); iv) total supply chain visibility; and v) process and knowledge back-up.

2.4 Green

Environmentally sustainable green supply chain management has emerged as organizational philosophy to achieve corporate profit and market share objectives by reducing environmental risks and impacts while improving ecological efficiency of these organizations and their partners (Zhu et al., 2008; Rao, 2005). Changes in government policies, such as the Waste Electrical and Electronic Equipment directive in European Union (Barroso & Machado, 2005; Gottberg, 2006), had make the industry responsible for post-consumer disposal of products, forcing the implementation of sustainable operations across the supply chain. At the same time, the increased pressure from community and environmentally-conscious consumers forces the manufacturers to effectively integrate environmental concerns into their management practices (Zhu et al., 2008).

It is necessary to integrate the organizational environmental management practices into the entire supply chain to achieve a sustainable supply chain and maintain competitive advantage (Zhu et al., 2008; Linton et al., 2007). The green supply chain management practices should cover all the supply chain activities, from green purchasing to integrate life-cycle management, through to manufacturer, customer, and closing the loop with reverse logistics (Zhu et al., 2008).

According to Bowen et al. (2001) green supply practices include: i) greening the supply process - representing adaptations to supplier management activities, including collaboration with suppliers to eliminate packaging and implementing recycling initiatives; ii) product-based green supply - managing the by-products of supplied inputs such as packing; iii) advanced green supply - proactive approaches such as the use of environmental criteria in risk-sharing, evaluation of buyer performance and joint clean technology programs with suppliers.
The greening of supply chain is also influenced by the following production processes characteristics (Sarkis, 2003): i) process' capability to use certain materials; ii) possibility to integrate reusable or remanufactured components into the system (which would require disassembly capacities); and iii) design for waste minimization (energy, water, raw materials, and non-product output).
Eco-design is defined as the development of products more durable and energy efficient, avoiding the use of toxic materials and easily disassembled for recycling (Gottberg et al., 2006). It provides opportunities to minimize waste and improve the resource consumption efficiency through modifications in product size, serviceable life, recyclability and utilization characteristics.However, the eco-design strategy presents some potential disadvantages including: high level of obsolete products in fashion driven markets, increased complexity and increased risk of failure, among others (Gottberg et al., 2006).
The reverse logistics focuses primarily on the return of recyclable or reusable products and materials into the forward supply chain (Sarkis, 2003). To reintroduced recycled materials, components and products into the downstream production and distribution systems, it is necessary to integrate reverse material and information flows in the supply chain. Due to the reverse material flow, traditional production planning and inventory management methods have limited applicability in remanufacturing systems (Srivastava, 2007). Therefore, it is necessary to consider the existence of the returned items that are not yet remanufactured, remanufactured items and manufactured items.
Distribution and transportation operations networks are also important operational characteristics that will affect the green supply chain (Sarkis, 2003). With the rapid increase of long-distance trade, supply chains are increasingly covering larger distances, consuming significantly more fossil-fuel energy for transportation and emitting much more carbon dioxide than a few decades ago (Venkat & Wakeland, 2006) . Lean supply chains typically have lower emissions due to reduced inventory being held internally at each company, but the frequent replenishment generally tends to increase emissions. As distances increase, it is quite possible for lean and green to be in conflict, which may require additional modifications to the supply chain (perhaps moving it away from the ideal lean configuration) if emissions are to be minimized (Venkat & Wakeland, 2006). Therefore, lean may be green in some cases, but not in others.
According to Srivastava (2007) green supply chain management can reduce the ecological impact of industrial activity without sacrificing quality, cost, reliability, performance or energy utilization efficiency; meeting environmental regulations to not only minimizing ecological damage, but also leading to overall economic profit.

2.5 Paradigms characterization

Although some authors (Vonderembse et al., 2006; Naylor et al., 1999; Christopher & Towill, 2000; Agarwal et al., 2006) provide an overview and comparison between lean and agile supply paradigms they don't consider the resilient and green paradigms. To fulfil this situation, the characterization of resilient and green supply chains was added to the framework proposed by Vonderembse et al. (2006). Table 1 presents the characterization of lean, agile, resilient and green supply chains in what is concerned to purpose, manufacturing focus, alliance type, organizational structure, supplier involvement, inventory strategy, lead time, and product design.

From Table 1, it is possible to identify differences between lean, agile, resilient and green paradigms; for example, lean, agile and green practices promote inventory minimization, but resilience demands the existence of strategic inventory buffers. Although, there are some "overlapping" characteristics that suggest that these paradigms should be developed simultaneously for supply chain performance improvement. According to Naylor et al. (1999) leanness and agility should not be considered in isolation; instead they should be integrated. The lean paradigm deployment in supply chain management produce significant improvements in resource productivity, reducing the amount of energy, water, raw materials, and non-product output associated with production processes; minimizing the ecological impact of industrial activity (Larson & Greenwood, 2004). According to Christopher and Peck (2004) resilience implies flexibility and agility; therefore, for the development of a resilient supply chain, it is necessary to develop agility attributes.

	Lean	**Agile**	**Resilient**	**Green**
Purpose	Focus on cost reduction and flexibility, for already available products, through continuous elimination of waste or non-value added activities across the chain[(a)]	Understands customer requirements by interfacing with customers and market and being adaptable to future changes[(a)]	Ability to return to its original state or to a new one, more desirable, after experiencing a disturbance, avoiding the occurrence of failures modes	Focus on sustainable development and on reduction of ecological impact of industrial activity
Manufacturing focus	Maintain high average utilization rate [(a)]. It uses just in time practices, "pulling" the goods through the system based on demand[(b)]	Has the ability to respond quickly to varying customer needs (mass customization), it deploys excess buffer capacity to respond to market requirements[(a)]	The emphasis is on flexibility (minimal batch sizes and capacity redundancies) improving supply chain responsiveness. The schedule planning is based on shared information[(d)]	Focus on efficiency and waste reduction for environmental benefit and developing of re-manufacturing capabilities to integrate reusable/remanufactured components [(i)]
Alliances (with suppliers	May participate in traditional alliances such as	Exploits a dynamic type of alliance known	Supply chain partners join an alliance network	Inter-organizational collaboration involving

and customers)	partnerships and joint ventures at the operating level [(a)]. The demand information is spread along the supply chain[(b)]	as a "virtual organization" for product design [(a)]. It promotes the market place visibility	to develop security practices, share knowledge[(e)] and increasing demand visibility[(d)]	transferring or/and disseminating green knowledge to partners[(l)] and customer cooperation[(f)]
Organizational structure	Uses a static organizational structure with few levels in the hierarchy[(a)]	Create virtual organizations with partners that vary with different product offerings that change frequently[(a)]	Create a supply chain risk management culture[(d)]	Create an internal environmental management system and develop environmental criteria for risk-sharing[(h)]
Approach to choosing suppliers	Supplier attributes involve low cost and high quality[(a)]	Supplier attributes involve speed, flexibility, and quality[(a)]	Flexible sourcing [(c; e)]	Green purchasing [(f; h)]
Inventory strategy	Generates high turns and minimizes inventory throughout the chain[(a)]	Make in response to customer demand[(a)]	Strategic emergency stock in potential critical points[(c; d; e)]	Introduce reusable/ remanufactured parts in material inventory[(j)]. Reduce replenishment frequencies to decrease carbon dioxide emissions[(k)]. Reduce redundant materials[(m)]
Lead time focus	Shorten lead-time as long as it does not increase cost[(a)]	Invest aggressively in ways to reduce lead times[(a)]	Reduce lead-time[(c; d)] and use flexible transportation systems [(c; e)]	Reduce transportation lead time as long it does not increase carbon dioxide emissions[(k)]
Product design strategy	Maximize performance and minimize cost [(a)]	Design products to meet individual customer needs[(a)]	Postponement[(c)]	Eco-design and life cycle for evaluating ecological risks and impact[(f; g)]
Legend: (a) Vonderembse et al. (2006); (b) Melton (2005); (c) Tang (2006); (d) Christopher & Peck (2004); (e) Iakovou et al. (2007); (f) Zhu et al. (2008); (g) Gottberg et al. (2006); (h) Bowen et al. (2001); (i) Sarkis (2003); (j) Srivastava (2007; (k) Venkat & Wakeland (2006); (l) Cheng et al. (2008); (m) Darnall et al. (2008)				

Table 1. Lean, agile, resilient and green characterization.

3. Deployment of LARG_SCM

3.1 Supply chain management practices and attributes

According to Morash (2001) supply chain management paradigms or strategies should be supported on suitable supply chain management practices. Li et al. (2005) defined supply chain management practices as the set of activities undertaken by an organization to promote effective management of its supply chain. Some authors also deploy supply chain management practices in a set of sub-practices, or activities or even in tools. From table 1 is possible to infer the following practices for each one of the paradigms:

- Lean practices: inventory minimization, higher resources utilization rate, information spreading trought the network, just-in-time practices, and shorter lead times;
- Agile practices: inventory in response to demand, excess buffer capacity, quick response to consumer needs, total market place visibility, dynamic alliances, supplier speed, flexibility and quality, and shorter lead times;
- Resilient practices: strategic inventory, capacity buffers, demand visibility, small batches sizes, responsiveness, risk sharing, and flexible transportation;
- Green practices: reduction of redundant and unnecessary materials, reduction of replenishment frequency, integration of the reverse material and information flow in the supply chain, environmental risk sharing, waste minimization, reduction of transportation lead time, efficiency of resource consumption;

Supply chain management practices are enablers to achieve supply chain capabilities or core competences. Morash et al. (1996) defined supply chain capabilities or distinctive competencies as those attributes, abilities, organizational processes, knowledge, and skills that allow a firm to achieve superior performance and sustained competitive advantage over competitors. Therefore the supply chain practices, through the constitution of capabilities, have a direct effect on supply chain performance. In this chapter the word "supply chain attribute" is used to describe a distinctive characteristics or capabilities associated to the management of supply chains. These characteristics are related to the supply chain features that can be managed through the implementation of supply chain management practices. The attributes values may have a nominal properties (e.g. a product is reusable or not), ordinary properties (e.g. the integration level between two supply chain entities is higher or lower than the average) or cardinal properties (i.e. the attribute can be compute, like the production lead time).

In this chapter the following supply chain attributes were considered: "capacity surplus", "replenishment frequency", "information frequency", "integration level", "inventory level", "production lead time", and "transportation lead time". The attributes value can be altered by the deployment of the different supply chain paradigms. Supply chain attributes are key aspects of the supply chain strategies and determine the entire supply chain behaviour, so the supply chain attributes will enable the measuring of supply chain performance.

3.2 Supply chain performance

To develop an efficient and effective supply chain, it is necessary to assess its performance. Performance measures should provide the organization an overview of how they and their supply chain are sustainable and competitive (Gunasekaran, 2001). Several authors discuss which performance indicators are the key metrics for lean and agile supply chains (Nailor et al., 1999; Argwal et al., 2006; Christopher & Towill, 2000; Mason-Jones at al., 2000). Kainuma & Tawara (2006) refer that "there are a lot of metrics for evaluating the performance of supply chains. However, they may be aggregated as lead time, customer service, cost, and quality".

Christopher & Towill, (2000) discuss the differences in market focus between the lean and agile paradigms using market winners (essential requisites for winning) and market qualifiers (essential requisites to sustain competitiveness). These authors consider that when cost is a market winner and quality, lead time and service level are market qualifiers, the lean paradigm is more powerful to sustain supply chain performance. When service level (availability in the right place at the right time) is a prime requirement for winning and cost, quality and lead time are market qualifiers, agility is a critical dimension. In the resilient paradigm, the focus is on recovery the desired values of the states of a system (characterized by a service level and a certain quality) within an acceptable time period and cost. Hence, for resilient supply chains, the cost and time are critical performance indicators. The green paradigm is concerned with the minimization of the negative environmental impacts in the supply chain; however this minimization cannot be done to the detriment of supply chain performance in quality, cost, service level and time.
In this perspective, it is possible to state that the critical dimensions for each paradigm are: cost for lean; service level for agile; time and cost for resilient. Therefore in this chapter, "cost", "service level" and "lead time" were selected as key performance indicators to evaluate the effect of each paradigm in the supply chain performance. Quality was not considered in this analysis since is a prerequisite for lean, agile, resilient and green paradigms to sustain the supply chain performance.
To evaluate the effect of the paradigms deployment in supply chain management, it necessary to establish the relationship between the supply chain attributes (derived from the paradigms deployment) with the selected key performance indicators. Figure 1 contains a diagram with the relationships between supply chain performance indicators and attributes.

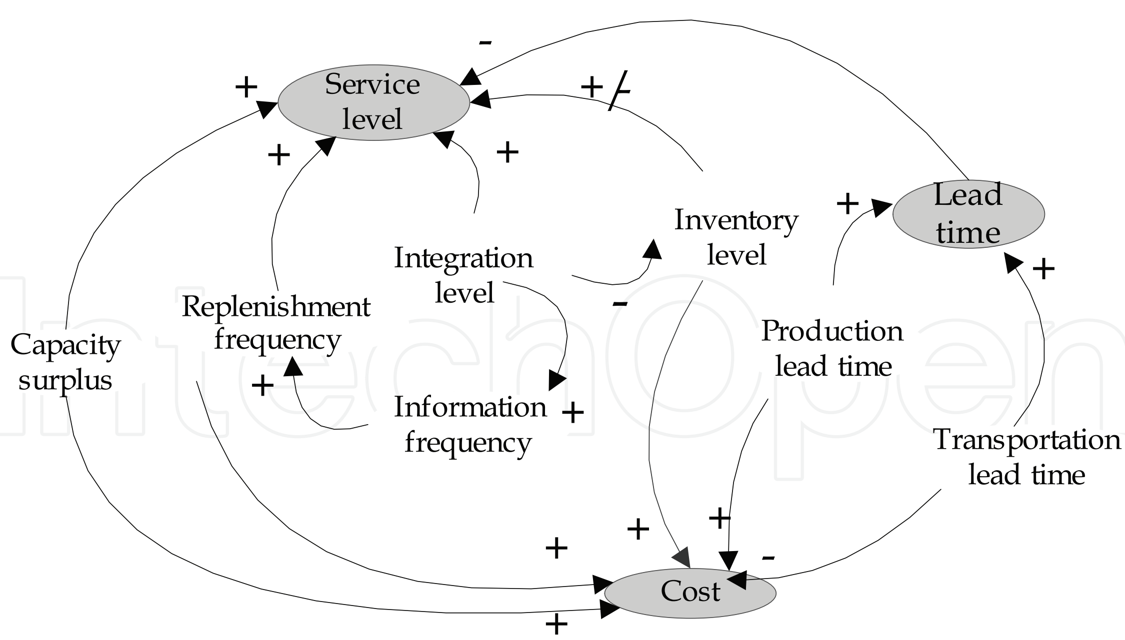

Fig. 1. Performance indicator and supply chain attributes relationships.

A causal diagram was selected to capture the supply chain dynamics. With this diagram, it is possible to visualize how the supply chain attributes affect the performance indicators. A positive link means that the two nodes move in the same direction, i.e., if the node in which the link start decreases, the other node also decreases (if all else remains equal). In the negative link, the nodes changes in opposite directions, i.e., an increase will cause a decrease in another node (if all else remains equal) (Sterman, 2000).

To construct the cause-effect diagram it was supposed that the supply chain attributes, which are the consequence of the policies implementation, are directly responsible for the supply chain performance measures value. For example, the “replenishment frequency” (a supply chain attribute) will establish the value of the performance measures “service level” and “cost”, since more frequent deliveries imply a higher distribution cost, leading to higher supply chain costs

The key performance indicator “service level” is affected positively by the “replenishment frequency” (it increases the capacity to fulfil rapidly the material needs in supply chain) (Holweg, 2005), “capacity surplus” (a slack in resources will increases the capacity for extra orders production) (Holweg, 2005) and “integration level” (the ability to co-ordinate operations and workflow at different tiers of the supply chain allow to respond to changes in customers requirements) (Gunasekaran, 2008). An increasing of “integration level” will lead to a high frequency of information sharing between supply chain entities; it will make possible a high “replenishment frequency”. The lead-time reduction improves the “service level” (Agarwal et al., 2007).

The “inventory level” has two opposite effects in the “service level” (the mark +/- is used to represent this causal relation in Figure 1). Since it increases materials availability, reducing the stock-out ratio, a higher “service level” is expected (Jeffery et al., 2008). However, high inventory levels also generate uncertainties (Van der Vorst & Beulens, 2002) leaving the supply chain more vulnerable to sudden changes (Marley, 2006) and therefore reducing the service level in volatile conditions. This apparent contradict behavior is also present when an increasing in the “integration level” occurs, which may lead to an improvement in the “service level”. However, the “inventory level” is affected negatively by the “integration level” (since it increases the supply chain visibility, minimizing the need of material buffers), improving the “service level”.

The key performance indicator “cost” is affected positively by the “capacity surplus” and “inventory level”, since they involve the maintenance of resources that have not being used. An increase in the “replenishment frequency” also increases the “cost”, due to the frequent transport of small quantities. To reduce “transportation time” premium services may be used; usually these services are more expensive. The “production lead time” affects “positively” the cost (Towill, 1996).

Finally, the key performance indicator “lead time” is positively affected by the “production lead time” and “transportation time”.

4. LARG_SCM practices and supply chain attributes inter-relationship Conceptual model

The tradeoffs between lean, agile, resilient, and green supply chain management paradigms (LARG_SCM) must be understood to help companies and supply chains to become more efficient, streamlined, and sustainable. To this end, it is necessary to develop a deep understanding of the relationships (conflicts and commitments) between the lean, agile, resilient and green paradigms, exploring and researching they contribute for the sustainable competitiveness of the overall production systems in the supply chain. Causal diagrams may be used to represent the relationships between each paradigm practices and supply chain attributes.

4.1 Lean practices vs. supply chain attributes

Lean practices are characterized by (see Table 1): inventory minimization, higher resources utilization rate, information spreading throught the network, just-in-time practices, traditional alliances and shorter lead times. Figure 2 was drawn to infer the lean practices impact in the supply chain performance - the diagram shows the relationships between the lean practices and the supply chain chain performance.

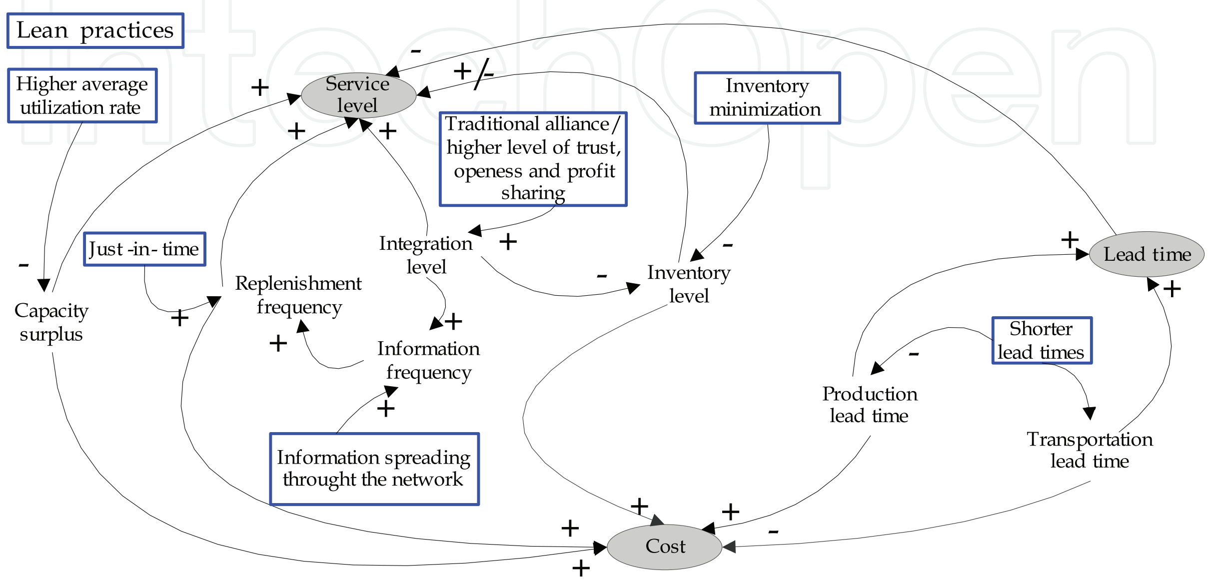

Fig. 2. Lean practices and supply chain performance relationships.

This figure may be better understood having in mind the following interpretation:

- The "inventory level" is affected negatively by the inventory minimization (a higher level of inventory minimization provokes a lower level of inventory).
- The "integration level" is positively related to the level of trust, openness and profit sharing of the traditional alliances in lean supply chains.
- The "information frequency" is improved by information spreading throught the network.
- The implementation of just in time practices increases the "replenishment frequency".
- The lean paradigm is characterized by a higher utilization rate of the supply chain resources causing a decrease in the supply chain "capacity surplus".
- The reduction of lead time affects negatively the "production and transportation lead times" (an increment level of lead time reduction provokes a reduction production and transportation lead times).

4.2 Agile practices vs. supply chain attributes

It is possible to conclude that the main agile supply chain practices are (see Table 1): inventory in response to demand, excess buffer capacity, quick response to consumer needs, total market place visibility, dynamic alliances, supplier speed, flexibility and quality, and shorter lead times. Figure 3 shows the relationships between the supply chain agile attributes and the supply chain performance:

- The "inventory level" is affected negatively by the inventory in response to customer demand (if the inventory is designed to respond to costumer needs, then lower levels of inventory in supply chain are expected) and by the supplier flexibility, speed and quality (if the supplier have higher levels of flexibility, speed and quality the need of inventory buffers is low, which may lead to lower inventory levels).

- The "information frequency" is improved by eventual increasing in the supply chain visibility.
- The "integration level" is positively related to the existence of dynamic alliances in the agile supply chains.
- The quick response to customer needs increases the "replenishment frequency".
- The agile paradigm prescribes the existence of a capacity excess in the supply chain resources provoking an increasing in "capacity surplus".
- The reduction of lead time affects negatively the "production and transportation lead times" (an increment level of lead time reduction provokes a reduction in production and transportation lead times).

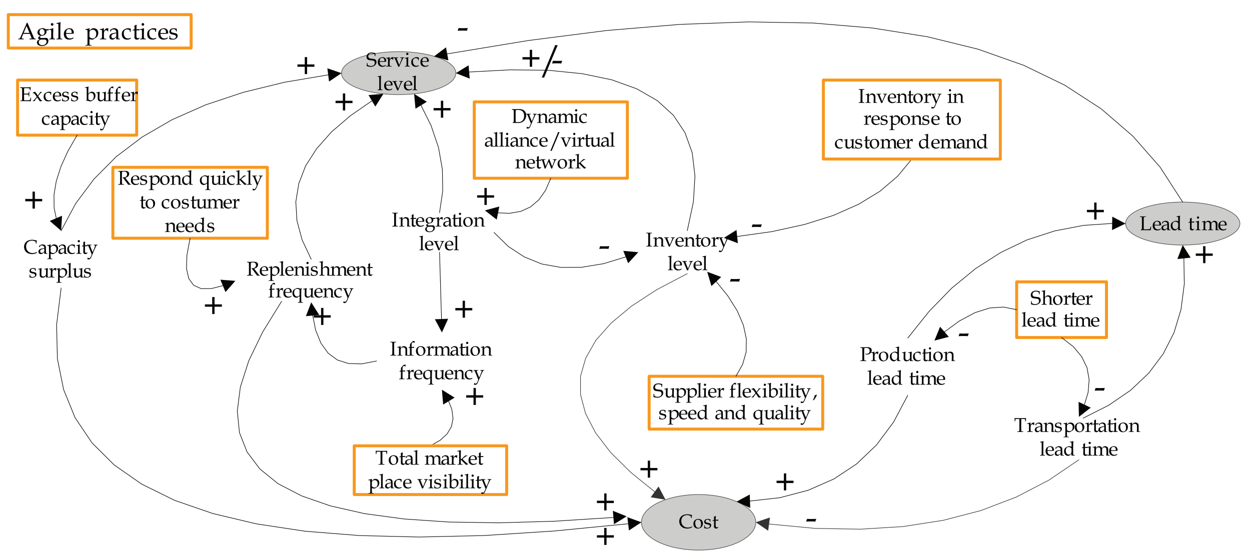

Fig. 3. Agile attributes and supply chain performance relationships.

4.3 Resilient practices vs. supply chain attributes

From Table 1, it is possible to verify that the main resilient supply chain practices are: strategic inventory, capacity buffers, demand visibility, small batches sizes, responsiveness, risk sharing, and flexible transportation. Figure 4 contains a diagram with the relationships between the supply chain resilient attributes and the supply chain performance:

- The "inventory level" is affected positively by the strategic stock policies (the constitution of strategic inventory buffers in supply chain increases the inventory levels).
- The "information frequency" is improved by the increasing in the demand visibility.
- The "integration level" is positively related to the risk sharing strategies in the resilient supply chains. A higher level of responsiveness increases the "replenishment frequency".

- The resilience practices prescribe the existence of supply chain capacity buffers provoking an increasing in "capacity surplus".
- The utilization of small batch sizes allows the reduction of the "production lead time". The flexible transport strategy contributes to a reduction in the "transportation lead time".

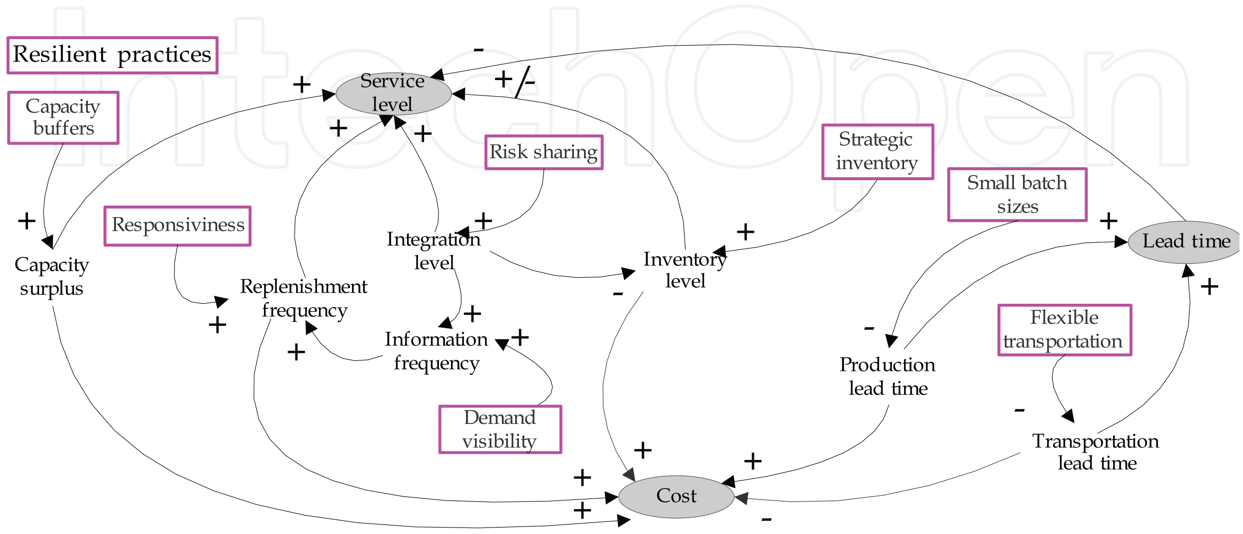

Fig. 4. Resilient practices and supply chain performance relationships.

4.4 Green practices vs. supply chain attributes

From Table 1, the main green supply chain practices were identified as: reduction of redundant and unnecessary materials, reduction of replenishment frequency, integration of the reverse material and information flow in the supply chain, environmental risk sharing, waste minimization, reduction of transportation lead time, efficiency of resource consumption. Figure 5 contains a diagram with the relationships between the supply chain green attributes and the supply chain performance:

- The "inventory level" is affected negatively by the reduction of redundant and unnecessary materials in the supply chain.
- The "integration level" is positively related to the development of environmental risk sharing strategies and to the level of reverse material and information flow integration in the supply chain.
- It was not found evidences in literature that supports the influence of green supply chain practices on "information frequency".
- The higher level of replenishment frequencies reduction decreases the "replenishment frequency".
- The green practices prescribe the efficiency of resources consumption contributing to supply chain "capacity surplus" reduction.
- The waste minimizations contribute negatively the "production lead time" (an increment in waste minimizations provokes a reduction in the production lead times). The reduction of transport lead time, without an increment in dioxide carbon emissions, contributes to a reduction in the "transportation time".

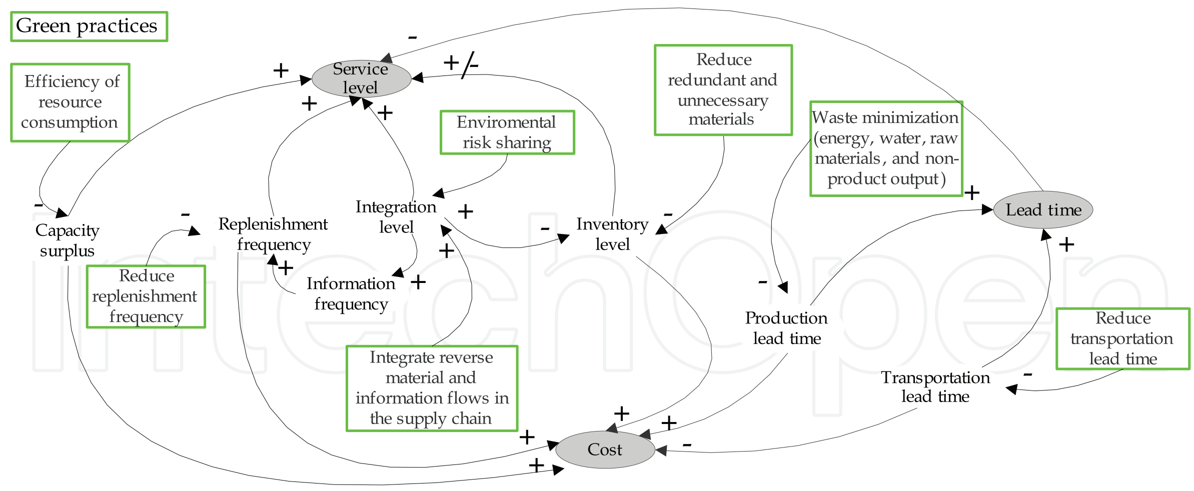

Fig. 5. Green practices and supply chain performance relationships.

4.5 LARG_SCM practices vs. supply chain attributes

To provide the necessary understanding of lean, agile, resilient and green paradigms divergences and commitments an overlap of the diagrams with the relationships between the different supply chain practices and the supply chain paradigms was developed. Figure 6 integrates the paradigms practices and supply chain performance relationships. From the causal diagram, it is possible to verify that some supply chain attributes are positively affected by all paradigms. All paradigms practices contribute to:

- "Information frequency" increasing.
- "Integration level" increasing.
- "Production lead time" reduction.
- "Transportation lead time" reduction.

For the others supply chain attributes, the paradigms implementation result in different directions. The divergences related to the "capacity surplus" are the following:

- The lean and green paradigms prescribe a reduction in the supply chain capacity buffers, in order to reduce the unnecessary wastes and promoting the efficiency of resource consumption.
- The agile and resilient paradigms prescribe an increase in the capacity surplus to increase the supply chain ability to respond to changes in customer's needs and to possible disturbances.

Another divergence is related to the "replenishment frequency":

- The lean, agile and resilient paradigms prescribe an increase in the replenishment frequency in order to respond quickly to costumer's needs and increase the supply chain responsiveness.
- The green paradigm prescribes a reduction in replenishment frequency to reduce transportation emissions, promoting the transport consolidation.

The third divergence between paradigms is related to the "inventory level":

- The lean, agile and green strategies prescribe a reduction in the inventory level.
- The resilient strategy promotes the constitution of strategic inventory buffers.

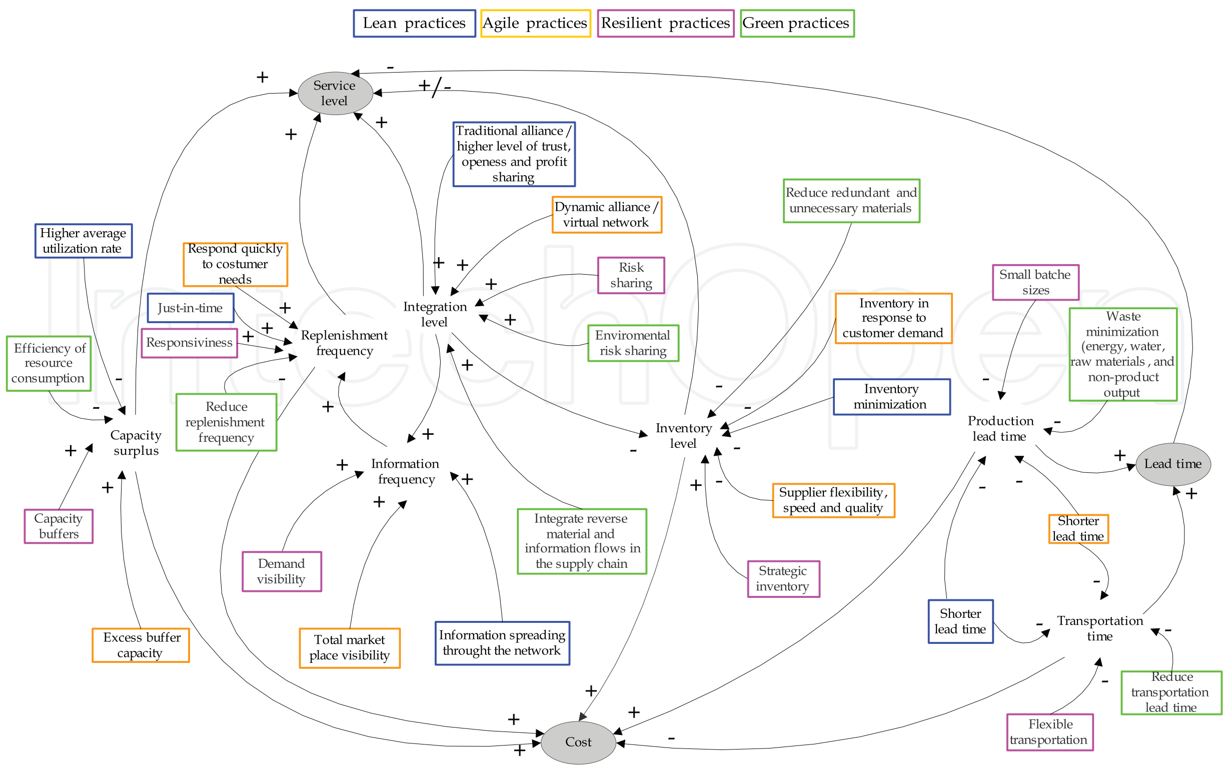

Fig. 6. Conceptual model with lean, agile, resilient and green practices and supply chain performance.

Table 2 shows an overview of main synergies and divergences between the paradigms under study. There are evidences that the lean, agile, resilient and green paradigms are complemented by each others. The implementation of these paradigms in the supply chain creates synergies in the way that some supply chain attributes should be managed, namely, "information frequency", "integration level", "production lead time" and "transportation lead time". However, the impact of each paradigm implementation in the characteristics

Paradigms / Supply chain attributes	Lean	Agile	Resilient	Green	
Information frequency	↑	↑	↑	–	*Synergies*
Integration level	↑	↑	↑	↑	
Production lead time	↓	↓	↓	↓	
Transportation lead time	↓	↓	↓	↓	
Capacity surplus	↓	↑	↑	↓	*Divergences*
Inventory level	↓	↓	↑	↓	
Replenishment frequency	↑	↑	↑	↓	

Legend: ↑ increase; ↓ decrease; – without consequence;

Table 2. LARG_SCM synergies and divergences overview.

magnitude may be different. For example, the lean paradigm seeks compulsively the reduction of production and transportation lead times to promote the total lead time reduction and minimizing the total waste. However, the resilient paradigm, although it prescribes this reduction in lead times, it is not so compulsive, since the objective is to increase the supply chain visibility and capability to respond to unexpected events.
There are some apparent divergences in the application of the paradigms; namely, in what is concerned to the "capacity surplus", "replenishment frequency" and "inventory level". The capacity surplus is an attribute of agile and resilient supply chains, since this buffer in capacity allow to respond to changes in customers needs or to unexpected events. This does not mean that supply chain should have an enormous capacity surplus; that would be unacceptable in terms of cost and efficiency. However, existence of redundancies in critical processes should be considered in conjugation with lean and green paradigm implementation. The same question arises with the inventory level (which is another type of redundancy). The presence of high inventory levels may hide the causes of a poor supply chain performance and generate materials obsolescence; for that reason, the lean, agile and green paradigms prescribe the minimization of inventory levels. Even so, if the inventory of critical materials is maintained in low levels, the supply chain will be more vulnerable to unexpected events that affect these materials supply. Other conflict is related to the replenishment frequency, which should be improved to minimize wastes and increase supply chain responsiveness and adaptation. However, an increase in the replenishment frequency may be obtained trough the numerous deliveries of small quantities to supply chain entities, increasing the number of expeditions and consequently increasing the dioxide carbon emissions due to transportation. The green supply chain prescribes a reduction in the delivery frequency in order to reduce dioxide carbon emissions. However, this could be achieved, through not only the delivery frequency, but using other strategies as the selection of transport modes with low dioxide carbon emission, reducing geographic distances between entities, and transport consolidation, among others.

5. Conclusion

This paper investigated the possibility to merge lean, agile, resilient and green paradigms in the supply chain management (LARG_SCM). These four paradigms have the same global purpose: to satisfy the customer needs, at the lowest possible cost to all members in the supply chain. The principal difference between paradigms is the purpose: the lean supply chain seeks waste minimization; the agile supply chain is focused on rapid responding to market changes; the resilient supply chain as the ability to respond efficiently to disturbances; and the green supply chain pretends to minimize environmental impacts.
A state-of-the-art literature review was performed to: i) characterize and identifing the main supply chain practices of each paradigm; ii) to support the development of a conceptual model focused on the integration of lean, agile, resilient and green practices and supply chain attributes. The main objective was to identify supply chain attributes that should be managed to obtain: the necessary organizational agility; to speed-up the bridging between states that require more or less degree of resilience; to preserve the dynamic aspects of the lean paradigm and; to assure its harmonization with the ecologic and environmental aspects that production processes may attend.

5.1 Our results

The conceptual model development and analysis showed that some supply chain attributes are positively related to all paradigms creating synergies among them. All paradigms practices were found to contribute to: "information frequency" increasing, "integration level" increasing, "production lead time" reduction, and "transportation lead time" reduction. However, there are some apparent divergences in the application of the paradigms; namely, in what is concerned to the "capacity surplus", "inventory level" and "replenishment frequency". However, "capacity surplus" and "inventory level" increases may provide the supply chain with added agility and resilience characteristics, needed to respond to changes in costumer needs and unexpected events. The reduction of the "replenishment frequency" appears to be related to the concerns of reduction dioxide carbon emissions in the supply chain.

5.2 What is new and future research?

The identification of the conceptual relations among LARG_SCM paradigms is a contribution that we hope to become a step forward in the development of a new theoretical approaches and empirical research in supply chain management field. The conceptual model presented in this chapter provides a holistic perspective towards the investigation of the integration of lean, agile, resilience and green paradigms in supply chain management. It represent the first effort to "drill down" the key attributes related to lean, agile, resilience and green paradigms deployment in a supply chain context, providing links between supply chain attributes, paradigms and supply chain performance.

Therefore this chapter scientific contribution is twofold: first, it contributes for research on supply chain management by providing links between the deployment of LARG_SCM paradigms and supply chain performance; and second, it identifies synergies and divergences between the paradigms. From the managerial point of view, since it provides the links between supply chain paradigms with supply chain performance, it gives to supply chain manager's insights on how the adoption of paradigms will affect their network, and how it can increase the supply chain performance.

Despite the important contribution of this chapter, limitations of the study should be noted. The conceptual model was developed using anecdotal and empirical evidences present in the literature and no validation where performed. It is necessary to conduct further empirical research concerning to the deployment of lean, agile, resilience and green paradigms in supply chain management, both in terms of testing the model herein proposed and to the greater understanding of this discipline.

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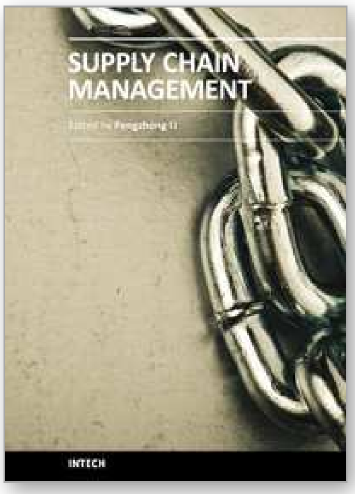

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The purpose of supply chain management is to make production system manage production process, improve customer satisfaction and reduce total work cost. With indubitable significance, supply chain management attracts extensive attention from businesses and academic scholars. Many important research findings and results had been achieved. Research work of supply chain management involves all activities and processes including planning, coordination, operation, control and optimization of the whole supply chain system. This book presents a collection of recent contributions of new methods and innovative ideas from the worldwide researchers. It is aimed at providing a helpful reference of new ideas, original results and practical experiences regarding this highly up-to-date field for researchers, scientists, engineers and students interested in supply chain management.