A Framework for a Green and Lean Supply Chain: A Construction Project Application

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Abstract

Despite the increased amount of attention to developing lean and green supply chains, there is a lack of comprehensive frameworks and a shortage of information on how to integrate environmental initiatives and lean techniques into supply chain functions. This has mainly occurred as a result of four challenges: conceptual, technical, operational, and measurement. To face these challenges, a practical framework is developed for incorporating leanness and greenness across the supply chain. The green and lean supply chain (GL-SC) framework emphasizes the combined adoption of lean and green techniques to various supply chain elements and functions. Static and dynamic Value Stream Mapping (VSM) is proposed as a platform for the development and verification of the GL-SC. The focus is on maximizing the value throughout the SC through lean and green techniques. The paper concludes by setting the measures and discussing the barriers of adopting the GL-SC. The framework is set for the application in the context of construction projects.

Keywords
Supply Chain Management, Green Supply Chain, Lean Supply Chain, Lean Manufacturing, Lean Construction.

1. Introduction

The new global reality that has emerged from the current economic crisis calls for supply chains to be more lean and cost effective. To survive in today's competitive market, it has become important for both manufacturing and construction companies to improve the quality of their work, increase operation effectiveness, reduce waste and costs, while being environmentally responsible. Lean manufacturing and lean construction are aimed at achieving such objectives. In addition, and due to stricter regulations and increased community, legislatives, and consumer pressures, construction companies as well as manufacturers need to effectively integrate environmental concerns into their regular business including logistics and supply chain operations. The differences between manufacturing and construction determine how lean and green practices should be adopted across the supply chain. The Environmental Protection Agency (EPA) in the United States issued in 2000 a practical guide called ''The Lean and Green Supply Chain''. The purpose of the guidebook is to demonstrate the opportunities for improving both financial and environmental performance and to briefly review specific tools and methods. As defined by Bowersox and Closs (1996), the supply chain refers to all those activities associated with the transformation and flow of goods and services, including money and information flows, from the sources of materials to end users. Supply Chain Management (SCM) includes the management of supply chain operations. Details of SCM can be found in Fredendall *et al.* (1999). Figure 1 depicts the main components in a supply chain.

Lean and green initiatives are emerging technologies in the area of SCM that aim at increasing the effectiveness of the Supply Chain (SC) by reducing numerous types of waste using lean techniques while making the SC less harmful to the environment through the utilization of green technology. Therefore, there exists an overlap between green and lean practices in waste reduction and flow streamlining. As noted by Kleindorfer *et al.* (2005), such practices expand the scope of waste reduction efforts beyond the organization to include inbound and outbound logistics along with reverse logistics.

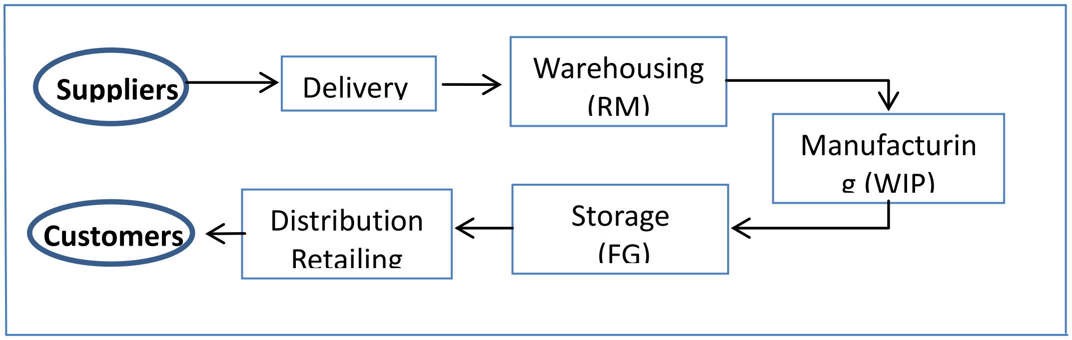


Figure 1: The main components in a supply chain

However, it is not typically clear or universally agreed upon if companies can find cost savings by reducing the environmental impact of their supply chain processes. This is typically due to the indirect savings and the long term nature of green initiatives. As noted by Melnyk *et al.* (2003), firms that have successfully reduced their internal waste through lean production methods also implement practices for better environment management. Firms will need to learn to balance their lean and green supply chain strategies. By re-evaluating the company's supply chain from a lean and green perspective and to better manage the use of materials from source to disposal. Savings can be then identified as a benefit of implementing lean and green policies.

Construction is a project-based industry with unique characteristics that are related to project kind and nature. Quality, time, and cost are the three pillars/criteria of successful construction project. That is in line with the key measures of the supply chain in terms of quality, cost, speed, and flexibility. In the context of a construction project, lean aims at achieving highest level of work quality with shortest lead time and lowest cost possible. To this end, lean construction applies lean principles and lean production techniques to the construction process through the full project life-cycle. The focus is on increasing the effectiveness of the construction industry by reducing the numerous types of waste in the construction projects (in both conversion and workflow). Details of lean construction approach can be found in Koskela (1993), Diekmann *et al.* (2004), and Mann (2005). Examples of lean construction applications can be found in Thomassen *et al.* (2003), Höök and Stehn (2008), and Senaratne and Wijesiri (2008).

Similarly green practices were adopted by many construction companies across the world to comply with local and international regulations and to capitalize on their effort to reduce the CO_2 footprints of their logistics and construction operations. This includes a focus on their products through green buildings and sustainable development as well as on the supply chain, the construction process, and the overall project delivery system. However, there is a little research available on the green practices in construction projects. Most research is focused on the design of green buildings (energy efficiency, water conservation, cooling/heating, etc.). Examples and details of green construction can be found in Bradbury (2010) and Kestle *at al.* (2011).

This paper reviews the literature and presents the basic concepts and practices of lean and green supply chain and aggregates them into a unified framework. The traditional framework of the supply chain is extended to include the reverse logistics and the essential lean and green practices. The framework represents a roadmap towards a Green and Lean Supply Chain (GL-SC). The GL-SC framework includes operations for recycling, remanufacturing, and reuse in addition to inventory reduction and effective material handling. The waste and disposed materials are reduced in lean and then recycled in green. Similarly, harmful byproducts are eliminated in lean to make the supply chain green. The paper presents the measures and challenges of a GL-SC. The framework is then adapted to potential implementation in construction projects.

1.1 Lean Supply Chain

The lean concept is based around reducing waste, controlling resources, streamlining flow, and running a demand-based production. The concept was introduced by Toyota in the 1950s and was labeled lean manufacturing in the 1990 (Womack *et al*., 1990). Since then, lean thinking has developed into a management philosophy that focuses on reducing waste and increases the effectiveness of the organization. Womack and Jones (2003) describe waste (*muda* in Japanese) as any activity which uses resources, but creates no value. This includes over production, excess processing, inventory, rework, motion, transport and material handling, defects, failures, setup and underutilizing skills and resources.

Lean principles are fundamentally driven by customer value, which makes them appropriate in the context of SCM. This involves understanding customer value, value stream analysis, reducing non-value adding activities. To achieve these principles, a variety of lean tools have been developed and widely applied. Commonly used lean tools include value stream analysis, layout redesign, Kanbans, total productive maintenance (TPM), quality-at-the-source, single minute exchange of die (SMED), visual aids, 5S, work standards and Kaizen. Details of these tools can be found in George (2003), Womack and Jones (2003), and Dennis (2002).

The lean supply chain is a multi-dimensional approach that is focused on cost reduction by eliminating non-value-added activities through the adoption of lean tools. To this end, lean principles and techniques are applied to the supply chain elements and functions (purchases, shipping, order management, warehousing, manufacturing, transportation, distribution) to transform it into a value chain (a VSM for the supply chain). The focus is on increasing the effectiveness of the construction industry by reducing the numerous types of waste in the construction projects (in both conversion and workflow). As a result, a lean SC will reflect the key principles associated with lean thinking including the capability of delivering products quickly to the end customer, with minimal waste, maximum flexibility, minimal inventory, and highest quality.

As noted by Scherrer-Rathje *et al.* (2009), lean tools should not be only adopted within the organization but also along the company's supply chain network. Many other researchers presented applications of lean principles to supply chains. For example, Zarei *et al.* (2011) developed an integrated approach that links Lean Attributes (LAs) and Lean Enablers (LEs) to increase the leanness of a food supply chain. They used Quality Function Deployment (QFD) to identify viable LEs to be practically implemented in order to increase the leanness of a food supply chain. Further details of lean supply chains can be found in Christopher and Towill (2000) and Mclvor (2001).

1.2 Green Supply Chain

The trend towards developing a green supply chain is now gaining popularity amongst most companies. The literature on green SC has stretched to cover green purchasing, the green flow of material from supplier to manufacturer to customer, and the feedback of reverse logistics. Srivastava (2007) defines green SCM as ‘‘integrating environmental thinking into SCM, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life’’. He also highlighted the importance of closing the loop with reverse logistics.

The main objective of green SCM is to extend the traditional SC to deal with the effects of products and processes. Extended supply chain models often include recycling and remanufacturing operations along with measures to reduce emissions and conserve energy. As an outcome, green SCM can reduce waste, minimize pollution, save energy, conserve natural resources, and reduce carbon emissions. Eltayeb and Zailani (2009) reviewed more than twenty literatures on green supply chain initiatives and concluded that the green supply chain can be generally classified into three major elements, namely; design for environment, green purchasing, and reverse logistics. Details on adding the “Green” component to the supply chain management can be found in Azevedo *et al*. (2011) and Beamon (1999).

Several researchers discussed the concept and the practical aspects of green SCM. For example, Walker *et al*. (2008) studied the drivers of environmentally friendly practices in the supply chains of public and private sector organizations, and the barriers these organizations face in implementing green SCM practices. Azevedo *et al.* (2011) investigated the relationships between green practices of SCM and supply chain performance. Through an empirical study, they identifies the most important green practices considered by managers, as well as the performance measures that are most appropriate and most widely used as means to evaluate the influence of green practices on supply chain performance. The developed model provided evidence as to which green practices have positive effects on quality, customer satisfaction and efficiency. It also identified the practices which have negative effects on supply chain performance.

Cruz (2008) developed a dynamic framework for the modeling and analysis of supply chain networks with corporate social responsibility through integrated environmental decision-making. Zhu *et al.* (2008) empirically investigated the construct of and the scale for evaluating green SCM practices implementation among manufacturers. Sundarakani *et al.* (2010) examined the carbon footprint across supply chains and thus contributes to the knowledge and practice of green supply chain management. The results show that carbon emissions across stages in a supply chain can constitute a significant threat that warrants careful attention in the design phase of supply chains.

According to Beamen (1999), manufacturing companies may achieve green supply chain by following the basic principles in ISO 14000. Azevedo *et al.* (2011) recommended the following Green practices: Environmental collaboration with suppliers, environmentally friendly purchasing practices, working with designers and suppliers to reduce and eliminate product environmental impact, minimizing waste, decrease the consumption of hazardous and toxic materials, ISO 14001 certification, reverse logistics, environmental collaboration with customers, environmentally friendly packaging, and working with customers to change product specifications.

2. Lean-Green Supply Chain (LG-SC)

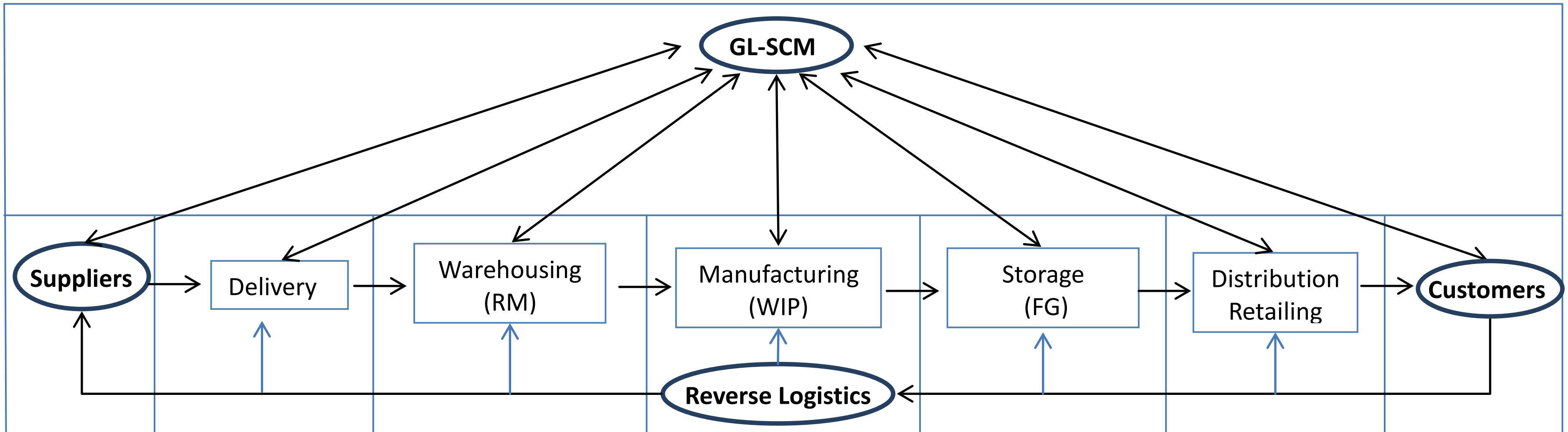
Firms need to re-evaluate the cost effectiveness of green and lean initiatives from a combined perspective. While lean and green are often seen as compatible initiatives due to their joint focus on waste reduction, lean strategies that require just-in-time delivery of small lot sizes require increased transportation, packaging, and handling that may contradict a green approach. As discussed earlier, green initiatives may be costly and difficult to justify based on their indirect and long-term savings. This is particularly important under the pressure of slow economy and financial crisis. Unless enforced through regulatory actions, companies will be reluctant to adopt such initiatives. However, and when combined with lean initiatives, the business case of a green-lean supply chain will look much better. Lean initiatives justify and compensate for the cost of green initiatives by eliminating non-value-adding costs within the supply chain. As the benefits of green initiatives start to materialize in terms of savings from using less energy, recycling, and recovering materials, improved company image, and increased business with green-focused clients and the government, the firm will realize a dual gain from an effective and a green supply chain where lean and green strategies work synergistically throughout the supply chain. This triggers the simultaneous pursuit of lean and green supply chain initiatives.

Yang *et al.* (2011) explored the relationships between lean manufacturing practices, environmental management, and business performance outcomes. The findings suggest that environmental management practices alone are negatively related to market and financial performance. Kainuma and Tawara (2006), therefore, developed a ‘‘the lean and green supply chain’’ method using a multiple attribute theory approach. The metrics used are supply chain Return on Asset (ROA), customer satisfaction, and Life Cycle Assessment (LCA).

2.1 A proposed GL-SC framework

The proposed framework for a Green and Lean Supply Chain (GL-SC) is based on a simultaneous implementation of lean and green practices across the supply chain. The framework emphasizes the need for a closed loop strategy in the SC through reverse logistics. It involves methods to recover the product from customer or scrap and to re-use it or re-use part of it through recycling, repair, remanufacturing, or refurbishment. Recovered items can be sent to customer or to another customer (second grade) or even returned to supplier. To emphasize the simultaneous application of the green and lean initiatives, the framework covers all SC components and operations, specifies their environmental impacts, and assigns lean and green practices at each SC component or business function. Static and/or dynamic Value Stream Mapping (VSM) is proposed as a platform for developing and verification of the GL-SC. As shown in Figure 2, the proposed GL-SC consists of six swim lanes/levels:

- The GL-SCM level: This level controls all components of the SC from suppliers to customers through management coordination, business decisions, and operational actions. It deals with customers' orders and translates them into shipments distributed to customers. This also includes adopting ISO 14000, implementing ERP and ABC, design for the environment, and leading other lean and green initiatives and actions.



Sourcing SRM	Transportation	Inventory/ Material Handling	Processing/ Material Handling	Inventory/ Material Handling	Transportation	Consumption CRM
Extraction Wastes	Emission Greenhouse	Unwrapping	Conversion Wastes	Packaging	Emission Greenhouse	Wastes Disposals Landfills
Green Suppliers/ Purchasing	Hybrid/ Clean Transport	Recycling/ Reuse	Re-manufacturing Clean Technology & Energy	Biodegradable/ Recyclable Packaging	Hybrid/ Clean Transport	Recycling Take-back Recovery
JIT and re-engineered Supplies	Fast Delivery/ Improved Fuel Mileage	Enhanced EOQ model and MRP system	Kanban, Flow Analysis Line balancing Quality-at-source TPM, SMED	Pull Strategy/ Reduced Stock	Fast Delivery/ Improved Fuel Mileage	Forecasting Orders

Figure 2: A GL-SC Framework

- The SC level: This level includes SC components from suppliers to customers. At the suppliers end, it includes inbound delivery of supplies, within the company, it includes Raw Materials (RM) warehousing, Work-In-Process (WIP) processing, and Finished Goods (FG) storage, and at the customer end, it includes shipping and distribution of products or outbound to retailers or end users. Reverse logistics is included as a major green SC component.
- The SC operations level: This level includes the key operation at each SC component starting from suppliers sourcing and Supplier Relationship Management (SRM) and ending with consumption and Customer Relationship Management (CRM). The other two main functions include transportation and inventory management of RM, WIP, and FG.
- The SC environmental impacts level: This level shows the activities of the SC that have negative impacts on the environment starting from the wastes of material extraction at the supplier end and ending with the wastes and disposals after consumption. The level also highlights the negative impacts of emissions from transportation and material handling as well as the wastes of unwrapping, conversion, and packaging.
- The green SC level: This level shows the green actions and practices that reduce/eliminate the negative environmental impacts of SC operations from green sourcing and purchasing to recycling, reuse, and material recovery.
- The lean SC level: This level shows the lean practices that reduce/eliminate the wastes of SC operations from Just-In-Time (JIT) shipping at the suppliers end to demand forecasting at the customers end.

2.2 Green SC practices

A green focus in the supply chain context requires working with upstream suppliers and downstream customers, analysis of internal operations and processes, environmental considerations in the product development process, and extended stewardship across the multiple life-cycles of products. All steps and elements of the supply chain must be analyzed for its environmental impact. Table 1 summarizes the key green SC practices at each SC element. Other green SC practices include, but not limited to:

- Green purchasing from suppliers: Adopt green purchasing practices to buy products and services from suppliers who adopt green technology, observe environmental regulations, and ISO 14000.
- Use/hire environment friendly transportation and freight systems for both inbound and outbound delivery/shipping. This includes hybrid vehicles and clean transports.
- Recycle or reuse wrapping materials and use biodegradable or recyclable packaging materials for inbound and outbound materials and products.
- Reduce/eliminate the wastes of processing/conversion and energy consumption and remanufacture/refurbish/repair used and nonconforming products.
- Recycle products after consumption, recover material, and adopt a product take-back policy.

Table 1: Green supply chain practices

SC Element	Key Impact	Green Objective(s)	Green Practice(s)
Supply	- Extraction waste - Hazards	- Reduced wastes - Reduced hazards	- Green suppliers - Safe supplies
Transportation	- CO_2 emission - Greenhouse Gases	- Less emission - Less gases	- Clean Transportation - Hybrid systems
Warehousing	- Unwrapping wastes - Spills and Hazards	- Less material and recycling - Safety	- Biodegradables - Safe storage
Processing/ Conversion/ Manufacturing/ Construction	- CO_2 emissions - Energy Consumption - Pollution - Conversion wastes - Packaging wastes	- Reduced wastes - Reduced hazards - Less pollution - Less energy - Less packaging	- Clean production - Reduced Energy - Green technology - Green energy - Recycling
Distribution/ Retailing	- CO_2 emissions - Hazards	- Less emission - Less gases	- Clean Transportation - Hybrid systems
Consumption	- Consumption wastes - Disposal	- Less wastes - Recycling	- Recycling - Take-back

2.3 Lean SC practices

Similarly, a lean focus in the supply chain context requires working with upstream suppliers and downstream customers, and analysis of internal operations and processes, including the product development process, to reduce all types of waste, increase effectiveness, and streamline the flow. All steps and elements of the supply chain must be analyzed from a waste reduction perspective. Table 2 summarizes the key lean SC practices at each SC element. Other lean SC practices include, but not limited to:

- Adopt JIT shipping from suppliers to reduce delays and stock levels of inbound materials.
- For shipping, use/hire fast and cost effective transportation systems to reduce delays and lead time.
- For inventory control, enhance the Economic Order Quantity (EOQ) model and the Material Requirement Planning (MRP) system to increase the holding cost of hazardous materials and to include the cost of recycling/disposal in the per unit cost.
- For processing/manufacturing, implement lean techniques that reduce lot size and delays, balance operations, streamline flow, reduce stoppages and changeovers, and reduce defects and nonconformities.
- At the customer end, improve demand forecast and adopt a demand-based pull strategy of FG from storage.

Table 2: Lean supply chain practices

SC Element	Key Waste(s)	Lean Objective(s)	Lean Technique(s)
Supply	- Defects - Errors	- Quality - Delivery Reliability	- Quality-at-the-source - JIT shipping
Transportation	- Delays - Excessive cost	- Speed - Efficiency	- Transportation networks - Scheduling
Warehousing	- High inventory - Material handling	- Reduced inventory level and cost - Effective material handling	- EOQ model - Facility layout
Processing/ Conversion/ Manufacturing/ Construction	- Excessive motions - Over-processing - Over-production - High WIP level - Material handling - Scrap and defects - Defects and rework	- Reduced cycle time - Reduced batch size - Streamlined flow - Less WIP - Less interruptions and stops - Clean production - Quality production	- Work standards - Kanban system - Flow analysis - Line balancing - TPM and SMED - 5S and visual aids - Quality control
Distribution/ Retailing	- Errors - Delays - Costs	- Delivery reliability - Distribution centers - Effective distribution	- Distribution networks - Facility location - JIT shipping
Consumption	- Rejects - Returns	- Scrap/rework reduction - Customer satisfaction	- Quality Assurance - Customer relations

3. GL-SC Metrics and Challenges

Performance measurement is crucial to better SCM in general (Wong, 2009). Consequently, 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. Askariazad and Wanous (2009) rank SC performance measures according to their importance in the evaluation of value-added activities (supply, manufacturing, logistics, marketing and sales, and support activities) throughout the SC, considering qualitative, quantitative, financial, non-financial, input and output criteria. Bhagwat and Sharma (2007) developed a balanced scorecard for performance measurement of the supply chain. The model measures and evaluates day-to-day business operations through four perspectives: finance, customer, internal business process, and learning and growth. Similarly, for GL-SC performance metrics can facilitate understanding and integration of green and lean practices among SC components while revealing the effects of these strategies and their potential opportunities. However, there is a lack of metrics for a combined GL-SC. Azevedo *et al.* (2011) provided a summary of measures and metrics that can be used to evaluate the influence of green practices on supply chain performance. They used the following: quality, customer satisfaction, cost, efficiency, environmental, and business wastage. The proposed framework includes qualitative and quantitative performance measurements of the GL-SC. Those are measured at each component of the supply chain to assess the leanness and the greenness of the SC. The proposed GL-SC measures at each SC element are summarized in Table 3. Other overall measure may include the total cost including disposal and recycling, total orders lead time, and the overall customer satisfaction.

Table 3: Green-Lean supply chain measures

SC Element	Lean Measures	Green Measures
Supply	% Delivered on time lead time	Supplier green certification
Transportation	Transportation cost, speed	Mileage efficiency, emissions
Warehousing	Inventory cost, amount of waste	Hazard level, % biodegradables
Processing/ Conversion/ Manufacturing/ Construction	WIP level, defect rate, cycle time, productivity, efficiency, waste	% of re-manufacturing, emissions, Energy consumption, solid wastes
Distribution/ Retailing	Distribution cost, % on-time delivery	Mileage efficiency, emission
Consumption	Order-fulfillment, % Satisfaction	Disposal cost, % recycled/recovered

As green and lean initiatives are evaluated for adoption, conflict amongst the multiple objectives and Key Performance Measures (KPIs) is often expected to surface. The assessment of such initiatives/alternatives translates into a multi-objective optimization problem that could be modeled and potentially solved using mathematical methods (e.g., using Linear Programming), heuristics and simulation models, and randomized search engines (e.g., Genetic Algorithms, Tabu Search, Simulated Annealing). Practically, it is difficult and in some cases impossible to include all aspects of SC lean and green practices in the solution achieved with such methods. The proposed framework recommends managerial decision support tools, namely Analytical Hierarchy Process (AHP), for selecting an applicable strategy for attaining a green and lean supply chain. To this end, AHP is utilized to determine an overall score of combined green and lean proposals based on the ratings and relative importance of the selected green and lean KPIs. This is essential in order to arrive at realistic and comprehensive assessment of the proposed strategies. The AHP approach can be also used to assess and select among suppliers based on a combination of lean and green criteria. Due to the size of the problem, the proposed framework recommends using computerized AHP systems such as ExpertChoice™.

AHP, as a decision support tool, uses a multilevel hierarchical structure of objectives, criteria, sub criteria and alternatives. It works as a multi-attribute decision making methodology which was first developed and applied by Saaty in 1977. Since its introduction, many different problems have been successfully approached with AHP include Supply Chain optimization (e.g., Kuei *et al.*, 2011 Kumar and Bisson, 2008, and Lu, *et al.*, 2007) . According to Saaty (2000), AHP methodology is based on the principles of decomposition, comparative judgments and synthesis of priorities. Decomposition structures the problem according to its main components: focus, set of criteria for evaluation, and the decision alternatives. Comparative judgments are required for pairwise comparison of criteria and investment alternatives so as to derive the criteria weights and relative priorities of investment alternatives. Finally the priorities of alternatives and the criteria for weights are synthesized into an overall rating based on which the best alternative is decided. Another advantage of AHP that is essential for the functionality of the multi discipline teams working on green and lean strategies is its emphasis on team decision-making. The involvement of different parties with in-depth knowledge on technical, strategic and economic issues related to green and lean strategies makes sure that all the important criteria are included in the rating of different alternatives. Other advantages of AHP include its ease, numeric translation of judgment, built-in consistency tests, and the use of appropriate measurement scales.

3.1 Implementation aspects of GL-SC

The next step is to implement the proposed framework to a case study. The researchers are considering the construction industry as an application case. The implementation is still in progress and no results are available yet. However, several difficulties are expected to face the adoption of a GL-SC framework. The majority of these difficulties are related to green initiatives due to the cost element (Rao and Holt, 2005). As noted by Walker *et al.* (2008), obstacles of implementing green supply chain were classified in literature into internal or external. Internal barriers are cost, and lack of legitimacy, whereas external barriers include regulation, poor supplier commitment, and industry specific barriers. Based on interviews methodology, they found that organizations are more influenced by external factors. Simpson *et al.* (2004) found that most of Small and Medium Enterprises (SMEs) think that adopting good environmental practice unable to gain competitive advantage and improvements in their business. Zailani (2010) investigated on the barriers in the context of SMEs in Malaysia. He highlighted four barriers including resistance to change, lack of awareness and information, technical barrier, and resource barrier.

A key factor to consider for a smooth transition to a green SC is to align green SC goals with business goals. For example, by offering refurbished items to customers, businesses can increase purchasing options to their customers and widen their customer base. Companies should also use green practices to improve the effectiveness of supply chain processes (companies should review each process along the supply chain to identify if a more environmentally sound approach will help cure the inefficiencies that occur). Many companies that have been through this exercise have identified processes where raw materials were wasted; resources underutilized and unnecessary energy used due to inefficient equipment. The company should also focus on minimizing their environmental impact without reducing the quality of products or significantly raising costs. Finally, management support and leadership is essential for a successful transition to a green SC.

A key factor to consider when implementing lean principles in the supply chain is to better understand the supply of materials and the consumption of products (in what quantities and at what rates). This helps reducing the waste of excessive inventory and overproduction. A second factor is to reduce lead-time and increase speed throughout the supply chain by focusing on continuous flow of materials and products (smaller and more frequent lot sizes). This reduces delays and pipe line inventory but may increase transportation cost. However, it also results in leveling the flow of information and materials through the supply chain including production (line balancing) which compensate for the savings obtained from large orders and the economy of scale (an enhanced EOQ model is needed). Companies can accomplish this step by implementing pull systems that allow customer consumption to trigger the pace for the rest of the supply chain. A real collaboration with both suppliers and customers is essential to achieve such objective. Finally, the company needs to adopt a focus on the total cost of order fulfillment rather than on some parts/functions of the supply chain. This is crucial to the correct assessment of unit cost of a product. Activity Based Costing (ABC) will play a major role in that direction.

4. Construction Project Considerations

The GL-SC framework is not exclusively for those companies who manufacture products. The researchers plan to implement the framework to the supply chain of the construction industry in Abu Dhabi area in the UAE. In the context of construction industry, the GL-SC framework should be enhanced to meet the specifics of the construction projects. Construction companies have a number of areas in their supply chain where waste can be identified as time, costs, or inventory. To create a leaner supply chain for the construction project, construction companies must examine each area of the supply chain. The same thing applies to implementing green practices across the supply chain to reduce emissions, pollutants, and wastes. The green construction initiative is focused on reducing the environmental impacts of the construction project including the wastes and pollution caused by the construction process and the environmental effects of the project supply chain. Therefore, and due to the distinctions of the construction project compared to production, the GL-SC framework recommends that lean and green practices can be applied to the project delivery system.

Lean construction, as defined by the nonprofit Lean Construction Institute (LCI), is a production management-based project delivery system emphasizing the reliable and speedy delivery of value. According to Koskela (1993), all activities in a construction project can be divided into conversions and flows. Conversion activities produce tangible outputs whilst flow activities connect such conversion activities. Traditional thinking of construction focuses on conversion activities and ignores flow and value considerations. In particular, waste is generally associated with waste of materials in the construction site. Activities such as rework, inspection, delays, transportation, and material handling are not typically recognized as waste. Lean construction argues that only conversion activities add value and these should be made more efficient. Other activities should be eliminated or reduced to the bare minimum. The project supply chain involves many of the non-value-adding flow activities across the project delivery process.

According to LCI, the main modules of project delivery system include, but not limited to, lean design, lean supply, lean assembly, lean production, and lean delivery system. Green aspects can be also included in these modules as discussed earlier. The Lean Design phase develops the conceptual design from Project Definition into Product and Process Design, consistent with the design criteria produced in Project Definition. The Lean Supply phase, which is a focus here, consists of detailed engineering of the product design produced in Lean Design, then fabrication or purchasing of components and materials, and the logistics management of deliveries and inventories. The objective of lean supply is to minimize inventories, right sizing them to the flow variability that cannot be eliminated. Where time is of the essence, capacity buffers will be substituted for inventory buffers. Similarly, green supply elements can be integrated into this module. Lean Assembly begins with the first delivery of tools, labor, materials or components to the site and ends when the keys are turned over to the client. Lean Production consists of applying work flow control and production unit control. Finally, lean project delivery is focused on implementing the guidelines of Lean Project Delivery System (LPDS) ™ developed by the LCI (Ballard, 2008).

Key enhancements of the GL-SC framework when applied to construction projects include, but limited to:

- The construction site replaces the manufacturing system
- The project delivery system replaces shipping and distribution
- The inventory systems (EOQ and MRP) are replaced by scheduled deliveries of project supplies and contractors work
- The reverse logistics concept still applies without the need to transport parts.
- We can still recycle/reuse some project wastes and nonconforming items.
- Transportation is almost limited to inbound materials
- Relevant lean techniques are applied but in different manners
- Relevant green techniques are applied in almost a similar manner

5. Conclusion

This paper presented a literature review on the green and lean aspects of supply chains. The paper has also outlined the challenges of adopting green and lean practices in the context of the supply chain. A generic framework is proposed to facilitate the combined application of both green and lean practices. The researchers are considering the construction industry as an application case. The implementation is still in progress and no results are obtained yet.

References

1. Askariazad, M. and Wanous, M. (2009). A proposed value model for prioritising supply chain performance measures. *International Journal of Business Performance and Supply Chain Modelling*, 1(2/3), pp. 115–128.
2. Azevedo, S.G., Carvalho, H., and Machado, V.C. (2011). The influence of green practices on supply chain performance: A case study approach. *Transportation Research Part E: Logistics and Transportation Review*, Volume 47, Issue 6, pp. 850-871.
3. Bhagwat, R. and Sharma, M.K. (2007). Performance measurement of supply chain management: A balanced scorecard approach. *Computers & Industrial Engineering*, Volume 53, Issue 1, pp. 43-62.
4. Ballard, G. (2008). The Lean Project Delivery System: An Update. *Lean Construction Journal*, pp. 1-19.
5. Ballard, G., and Howell, G. (2003). Lean Project Management. *Building Research and Information*, 31(2), pp. 119-133.
6. Beamen, B.M. (1999). Designing the green supply chain. *Logistics Information Management*, 12(4), 332-342.
7. Bowersox, D.J., Closs, D.J. (1996). *Logistical Management*: The Integrated Supply Chain Process. McGraw-Hill, New York.
8. Bradbury, A. (2010). Green Construction. *Harvard International Review*, Vol. 32 Issue 2, pp. 28-31.
9. Christopher, M., Towill, D. (2000). Supply chain migration from lean and functional to agile and customized. *Supply Chain Management*, 5(4), pp. 206–213.
10. Cruz, J.M. (2008). Dynamics of supply chain networks with corporate social responsibility through integrated environmental decision-making. *European Journal of Operational Research*, 184(3), pp.1005-1031.
11. Dennis, P. (2002). *Lean production simplified*: a plain-language guide to the world's most powerful production system. Productivity Press, NY.
12. Diekmann, J.E., Krewedl, M., Balonick, J., Stewart, T., and Wonis, S. (2004). Application of Lean Manufacturing Principles to Construction. CII report #191.
13. Eltayeb, T.K. and Zailani, S. (2009). Going Green Through Green Supply Chain Initiatives Towards Environmental Sustainability. *Operations and Supply Chian Managmenet*, 2(2), pp. 93-110.
14. Environmental Protection Agency (EPA) (2000). A practical guide to Lean and Green Supply Chain. (www.epa.gov/.../pubs/archive/acct-archive/pubs/lean.pdf).
15. Expert Choice Decision Analysis Software (www.expertchoice.com).
16. George, M.D. (2003) *Lean Six Sigma for Service*, McGraw-Hill, New York, NY.
17. Fredendall, *L.D.*, Ed Hill, *E., and* Hill, *J.E.* (1999). *Basics of Supply Chain Management*. CRC Press.
18. Höök, M. and L. Stehn (2008). Lean principles in industrialized housing production: the need for a cultural change. *Lean construction Journal*, pp. 20-33.
19. Kainuma, Y. and Tawara, N. (2006). A multiple attribute utility theory approach to lean and green supply chain management. *International Journal of Production Economics*, Volume 101, Issue 1, pp. 99-108.

20. Kestle, L., Potangaroa, R., Storey, B. (2011). Integration of Lean Design and Design Management and its Influence on the Development of a Multidisciplinary Design Management Model for Remote Site Projects. *Architectural Engineering & Design Management*, Vol. 7 Issue 2, p139-153.
21. Kleindorfer, P.R., Singhal, K., Van Wassenhove, L.N., (2005). Sustainable operations management. *Production and Operations Management*, 14 (4), 482–492.
22. Koskela, L. (1993). "Lean production in construction". *In: L.F. Alarcon, ed. Lean Construction*. Rotterdam: A.A. Balkema, 1-9.
23. Kuei, C.H, Christian, N., and Lin, C. (2011). Developing global supply chain quality management systems. *International Journal of Production Research*, Vol. 49 Issue 15, pp. 4457-4481.
24. Kumar, S. and Bisson, J. (2008). Utilizing analytic hierarchy process for improved decision making within supply chains. *Human Systems Management*, Vol. 27 Issue 1, pp. 49-62.
25. Lean Construction Institute (http://www.leanconstruction.org).
26. Lu, L.Y., Wu, C.H., and Kuo, T.C. (2007). Environmental principles applicable to green supplier evaluation by using multi-objective decision analysis. *International Journal of Production Research*, Vol. 45 Issue 18/19, pp. 4317-4331.
27. Mann, D. (2005). Creating a lean culture: tools to sustain lean conversions, Productivity Press, NY.
28. McIvor, R. (2001). Lean supply. *European Journal of Purchasing & Supply Management*, 7(4), pp. 227-242,
29. Melnyk, S.A., Sroufe, R.P., Calantone, R.J. (2003). Assessing the impact of environmental management systems on corporate and environmental performance. *Journal of OM*, 21(3), pp. 329–351.
30. Rao, P., Holt, D., (2005). Do green supply chains lead to competitiveness and economic performance? *International Journal of Operations and Production Management* 25 (9), pp. 898-916.
31. Saaty, T. (2000). *Fundamentals of Decision Making with the Analytic Hierarchy Process*. RWS Publications.
32. Scherrer-Rathje, M., Boyle, T.A., Deflorin, P. (2009). Lean, take two: Reflections from the second attempt at lean implementation. *Business Horizons* 52, pp. 79–88.
33. Senaratne, S. and D. Wijesiri (2008). Lean Construction as a Strategic Option: Testing its Suitability and Acceptability in Sri Lanka. Lean construction Journal: pp. 34-48.
34. Simpson, M., Taylor, N., and Barker, K. (2004). Environmental responsibility in SMEs: does it deliver competitive advantage? *Business Strategy and the Environment*, 13(3), pp. 156-171.
35. Srivastava, S.K. (2007). Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Reviews*, 9(1), pp. 53-80.
36. Sundarakani, B., De Souza, R., Goh, M., and Wagner, S.M. (2010). Modeling carbon footprints across the supply chain. *International Journal of Production Economics*, Volume 128, Issue 1, pp. 43-50.
37. Thomassen, M. A., Sander D., Barnes K. A., Nielsen A. (2003). Experience and results from implementing Lean construction in a large Danish contracting firm. *Proceedings of 11th Annual Conference on Lean Construction*, pp. 644-655, Blacksburg, VA.
38. Walker, H., Di Sisto, L., and McBain, D. (2008). Drivers and barriers to environmental supply chain management practices: Lessons from the public and private sectors. *Journal of Purchasing and Supply Management*, 14(1), pp. 69-85.
39. Womack, J.P. and Jones, D.T. (2003). *Lean Thinking*. New York: Simon and Schuster.
40. Womack, J.P., Jones, D.T. and Roos, D. (1990). *The Machine that Changed the World*, Rawson Associates, New York, NY.
41. Wong, W.P. (2009). Performance evaluation of supply chain in stochastic environment: using a simulation based DEA framework. *Int'l Journal of Business Performance and Supply Chain Modelling* 1, pp. 203–228.
42. Yang, M.G., Hong, P., and Modi, S.B. (2011). Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms. *International Journal of Production Economics*, Volume 129, Issue 2, pp. 251-261.
43. Zailani, S. (2010). *Green Supply Chain Initiatives: Investigation on the Barriers in the Context of SMEs in Malaysia*. International Business Management, 4(1): pp. 20-27.
44. Zarei, M., Fakhrzad, M.B., Jamali Paghaleh, M. (2011). Food supply chain leanness using a developed QFD model. *Journal of Food Engineering, Volume 102, Issue 1*, pp. *25-33*.
45. Zhu, Q., Sarkis, J., and Lai, K.H (2008). Confirmation of a measurement model for green supply chain management practices implementation. *International Journal of Production Economics*, 11(2), pp. 261-273.