A Green Supply Chain Design with Product Life Cycle Considerations

Due to rising consciousness in recent decades about environmental protection, many issues related to green supply chain management have been discussed by businesses and governments at all levels. Different from traditional supply chain management, green supply chain management concerns itself with environmental impacts and material utilization issues, which make the selection of the supply chain actors a more complicated decision than usual. However, the procedure of selecting the supply chain actors is strongly guided by the product life cycle.

This article emphasizes the importance of taking into account the product life cycle in a green supply chain design and suggests a way to do so.

Key words: multi-channel retail, e-fulfillment, customer expectation, economic performance, key performance indicators (KPIs)

Introduction

Emergence of green supply chain management could be attributed to the rising public awareness of environmental problems. Consumers say they increasingly prefer to purchase products that are produced with a minimum of pollution and with minimal environmental impact. Therefore, companies that successfully adopt a green policy can generate profits, reduce environmental impact, and provide positive social impact.

In a traditional sense, supply chain management consists of planning, designing, and controlling all activities involved in the transformation of products from the raw material stage to the final product stage to fulfill the demand of the consumer. Thus, as realization set in that traditional supply chain management could not last as a sustainable industrial practice, it gave way to green supply chain management (GSCM). However, conventional and green chains differ in several ways. The most important one is that conventional chains often concentrate on economic objectives, whereas green chains also give significant considerations to ecological causes.

Thus, GSCM consists of two important phenomena: environmentally conscious management and supply chain management (Wang & Gupta, 2012). This study proposes a method that considers these two aspects at the same time while emphasizing the importance of taking into account the product life cycle in supply chain management.

This article is structured as follows: in section 2 we start by discussing the supply chain and supply chain management. In section 3 we introduce the different product types, the product life cycle, and the different supply chain strategies to adopt for each corresponding case. In section 4, we emphasize the importance of initiating the environmental actions from the design stage of the green
supply chain. In section 5 we present the methodology adopted to design a green supply chain while considering the product life cycle stages. Section 6 presents a real-life numerical example. We end the article with a conclusion and some perspectives.

What exactly are supply chain and supply chain management?

Numerous definitions of a supply chain exist in the literature. According to Beamon (1998) a supply chain is “an integrated process wherein a number of various business entities; namely suppliers, manufacturers, distributors, and retailers; work together in an effort to: (1) acquire raw materials, (2) convert these raw materials into specified final products, and (3) deliver these final products to retailers.” This chain is traditionally characterized by the flow of materials and information within and between business entities.

Mentzer et al. (2001) defined the supply chain as a set of organizations linked directly by one or more of the upstream and downstream flows of products, services, finances, and information from a source to a customer.

According to the Council of Supply Chain Management Professionals, supply chain management encompasses the planning and management of all activities involved in sourcing, procurement, conversion, and logistics management. It also includes the crucial components of coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.

This definition leads to several observations. First, supply chain management takes into consideration every aspect that has an impact on cost and plays a role in making the product conform to customer requirements: from supplier and manufacturing facilities through warehouses and distribution centers to retailers and stores. Indeed, in some supply chain analysis, it is necessary to account for the suppliers’ suppliers and the customers’ customers because they have an impact on supply chain performance.

Second, the objective of supply chain management is to be efficient and cost-effective across the entire system; total system wide costs, from transportation and distribution to inventories of raw materials, work in process, and finished goods, are to be minimized. Thus, the emphasis is not simply on minimizing transportation costs or reducing inventories but, rather, on taking a systems approach to supply chain management.

Selecting the green supply chain actors is strongly guided by the product life cycle

However, the process of delivering goods and services better, faster, and cheaper sounds simple but can sometimes be unpredictable and lead to shortages or surpluses. Since the 1990s, the supply chain journey has evolved through a number of distinct phases along with a shift in power from suppliers to customers. Over the course of this evolution, supply chain professionals have expanded their perspective and philosophy from an inventory-centric view in the 1980s to an order-centric view in the 1990s to a product-centric view today.

Indeed, the integration of product lifecycle in the supply chain management can provide fresh perspectives and critical insights that are often missed due to the extreme fragmentation of functions within the enterprise and across supply chains. This is the new frontier for value creation, an untapped area of opportunity to create competitive differentiation and growth for businesses.

Indeed, since the new millennium, researchers have begun to realize that the decision and integration efforts in supply chain management should be driven by the manufactured product, specifically, product characteristics and product life cycle. This problem has two main aspects: the importance of the product life cycle in the supply chain strategy and the decision support models for the supply chain network design. Consequently, we review the relevant literature pertaining to these two themes.

Product types, product life cycle, and supply chain strategies

Product types

Generally, products can be categorized into three types, namely, functional, innovative, and hybrid (Huang et al., 2002). Functional product demands can be forecasted quite accurately and their market share remains fairly constant. They enjoy along life cycle with superficial design modifications leading to different product types.

Innovative products are new products developed by organizations to capture a wider share of the market. They are significantly different from the available product types and are more adapted to the customer requirements (mass customization). They, at times, represent a breakthrough in product design. Innovative products are the result of customer designs, which reflect ever-changing requirements. Hybrid products can consist of either (1) different combinations of functional components or (2) a mix of functional and innovative components.

Product life cycle

The product life cycle represents the unit sales for some product, extending from the time it is first placed on the market until it is
removed (Buzzell, 1966). The evolution of product attributes and market characteristics through time acts so that the product life cycle can be used prescriptively in the selection of marketing and planning. Schematically, the product life cycle may be approximated by a bell-shaped curve (figure 1) that is divided into several stages (Scheuing, 1969).

The product life cycle can be classified into four discrete stages: introduction, growth, maturity, and decline.

When the product is introduced, sales will be low until customers become aware of the product and its benefits. The distribution is selective and scattered as the firm commences implementation of the distribution plan. During the introductory stage the firm is likely to incur additional costs associated with the initial distribution of the product. These higher costs coupled with a low sales volume usually make the introduction stage a period of negative profits.

With time, sales volume grows as more customers become aware of the product and additional market segments are targeted. An improvement of the product quality may be considered. The distribution becomes more intensive and trade discounts are minimal if wholesalers show a strong interest in the product. The growth stage is a period of rapid revenue growth.

The maturity stage is the most profitable. Into this stage, sales volume continues to increase, but at a slower pace. New distribution channels are selected in order to avoid losing shelf space. The primary goal during the maturity stage is to maintain market share and extend the product life cycle.

After a period of maturity, eventually sales begin to decline as the market becomes saturated, the product become technologically obsolete, or customer tastes change. In this decline stage, distribution becomes more selective and channels that are no longer profitable are phased out.

Table 1 summarizes the different business characteristics over the product life cycle. From this table we can clearly note that the key business opportunities, as well as the key business risks, are very different from one stage to another. So, timely and sufficient attention should be given to such changes; otherwise, this could affect the efficiency of the whole supply chain.

Supply chain strategies

Typically, supply chains can be defined by three categories: lean supply chain, agile supply chain, and hybrid supply chain. A lean supply chain employs continuous improvement to focus on the elimination of waste or non-value-added steps in the supply chain. It is supported by the reduction of setup times to enable the economic production of small quantities, thereby achieving cost reduction, flexibility, and internal responsiveness.

An agile supply chain basically focuses on responding to unpredictable market changes and capitalizing on them. It tries to achieve a speedier delivery and lead time flexibility. It deploys new technologies and methods, uses information systems and technologies and data interchange facilities, puts more emphasis on organization issues and people (knowledge and empowered employees), integrates the whole businesses process, enhances innovations all over the company, and forms virtual companies and production based on customer-designed orders.

Along with the lean and agile supply chain, the existence of an intermediate chain known as the hybrid supply chain was proposed by Huang et al. (2002). It generally involves “assemble to order” products whose demand can be quite accurately forecasted. The chain helps to achieve mass customization by postponing
product differentiation until final assembly. Both lean and agile techniques may be used for component production. The company-market interface has to be agile to understand and satisfy customer requirements by being responsive, adaptable, and innovative.

The discussions in marketing and logistic literature universally conclude that product life cycle stages have a great impact on appropriate supply chain design. Consequently, depending on the product life cycle stage, a firm should select its effective supply chain partners and dynamically match the supply chain strategies so as to satisfy the product requirements across multiple criteria and to maximize competitiveness over time. Indeed, the competitive criteria generally differ depending on the product type and the product life cycle phase. Derived from Wang et al. (2004), table 2 summarizes the supply chain classification based on product type and product life cycle.

**The green supply chain**

The ever-growing volume of activity generated by passenger and freight transportation not only benefits the growth and sustainability of international economy and globalization but also has its own consequences, particularly those pertaining to the environment. Transportation activities are significant sources of air pollution and greenhouse gas emissions, with the former being known to have harmful effects on human health and the latter being responsible for global warming. These issues have raised concerns on reducing the amount of emissions worldwide. In this respect, many countries, including developed and developing countries, have set strict targets on reducing their carbon emissions in the near future. For example, China, in its eleventh five-year developing plan, sets a clear objective to reduce the carbon emission by 10% (Leggett, 2011). The central government is studying and ready to publish regulatory policies for protecting the environment, which is expected to play positive effects on resolving current environment problems.

Billions of dollars are spent each year by government and private enterprises on environmental pollution control. Some leading companies are now proactively implementing “green” initiatives. For example, the largest furniture manufacturer, IKEA, built a train transportation network with an emphasis on the “greenness” of train operations. HP, IBM, and GE are all talking “green” as an important merit in their enterprise’s value system in order to maintain good public images. They are designing greener products by adopting new energy-saving technology. In addition to product design, they are also thinking of enhancing their supply chain management capability to...
assuage environmental concerns. For example, the global procurement center of IBM, located in Shenzhen, China, has added “CO2 emission, solid waste produced” and other environment-related indicators in the logistics management performance measures.

Similarly, the challenge to some European governments, such as Germany, was to shape environmental policy so that it is possible to combine economic growth with decreasing the environmental burden, because these are also expressed in the objective formulated in Lisbon for economic development in Europe (“Clean, clever competitive”). The European Union has also implemented several measures to make transport greener and more sustainable. To intensify its efforts, the European Commission presented two different initiatives. The first focuses on making the polluter pay through internalizing the external costs of transport. This means that individual modes of transport must pay for “hidden” costs generated by their contribution to air pollution, noise, climate change, congestion, and accidents in road transport. The second initiative includes a package of regulatory instruments combined with infrastructure and technological measures.

However, to face these challenges, companies have to make more effort to implement green logistics at an early stage. Indeed, many companies are starting to view GSCM as a strategic analysis tool. They realized that, to maximize their effectiveness for the global company, greening the supply chain initiatives should begin from the supply chain design. This means that greening initiatives should be considered from the beginning when selecting actors and designing the supply chain network.

This study proposes a model that enables selecting supply chain actors that are environmentally friendly in their sourcing, production, delivery, usage, and disposal in order to design a green supply chain while minimizing the supply chain total cost and complying with the different stages of the product life cycle.

**Methodology**

The proposed method consists of two phases. Phase I evaluates potential suppliers, manufacturers, and distributors by determining their efficiencies with respect to the product life cycle stages. For performance evaluation, aggregation models are used. At the end of this phase, we obtain efficiency scores for each of the potential actors and at each stage independently. In order to minimize the supply chain design total cost as well as the environmental impact, phase II involves the application of a linear integer programming model, which optimally selects candidates for the supply chain network design and identifies the optimal routing decisions for all entities in the network by integrating the efficiencies identified in phase I, demand, capacity requirements, the environmental constraints, location, and flow conservation constraints.

**Phase I: Multi-criteria decision-making problem**

Decision makers initiate phase I with the identification of the required objectives, criteria, and sub-criteria. The criteria encompass the most important resources used by the business process, and the sub-criteria should include a range of performance and activity measures. Because the importance of these components change according to the product life cycle stage, this multi-criteria decision-making phase will be repeated for each stage, for the three supply chain processes separately, namely, for suppliers, producers, and distributors.

At the end of this phase, each potential actor will have an efficiency score related to each product life cycle stage. At this level, the decision maker intervenes once again to set a threshold of efficiency. Any potential actor having a score below this threshold automatically will be eliminated through the efficiency constraint set in the mathematical model during phase II.

To evaluate the potential actors, we suggest using an analytic hierarchy process (AHP) as an aggregation method. This method, first introduced by Saaty (1980), is a
Step 1: Problem structuring
As in the AHP procedure, we begin by structuring the problem. This step consists of the creation of the decision hierarchy by structuring the decision problem into a hierarchy of decision elements, generally going from the most general objectives to the most specific ones. The last level of the hierarchy contains the alternatives, the possible choices. In the context of this article, a typical five-level hierarchy of goal, objectives, criteria, sub-criteria, and alternatives has been considered. The hierarchical structure of the decision problem is shown in figure 2. For more simplicity in the model, we will take into account only emissions as a criterion related to the environmental objective.

Step 2: Collection of preference information
As we have already mentioned, the performance criteria, as well as their importance during the different product life cycle stages, are adopted as subjective criteria for evaluating the company’s performance. In this step, we obtain from the decision maker the input data that reflect the importance of the different objective criteria and sub-criteria through pair-wise comparisons, made on a semantic scale, of the elements emanating from a node of the hierarchy with regard to the parent node. All these pair-wise comparisons are stored in matrices. Ratio scales are shown in table 3.

Step 3: Determination of component weights
The eigenvector associated with each pair-wise comparison matrix represents then the relative weight of the decision elements.

Step 4: Calculation of alternative scores
In this step, we take into account the relative weights to get the overall efficiency scores of each alternative.

Phase II: The green supply chain design
Taking into account the efficiency scores at each product life cycle stage, the capacity of the potential actors, their locations, the total customer demands, and the CO2 emission constraints, the supply chain network design framework needs to identify the optimal supply chain actors as well as the deployment plans. The proposed model enables identifying the optimal routing of material from selected suppliers to manufacturers to warehouses by minimizing the supply chain total cost. The verbal formulation of the supply chain network design problem can be set as follows:

Objective functions
1. Minimize the sum over the product life cycle stages of the supply chain total cost
2. Minimize the sum over the product life cycle stages of the CO2 emissions across the whole chain

where

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Ratio scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity of importance</td>
<td>Verbal judgment of performance</td>
</tr>
<tr>
<td>1</td>
<td>Equal importance</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Intermediate values between adjacent scale values</td>
</tr>
</tbody>
</table>

The total CO2 emissions = Sum of (CO2 emissions at each facility, which depend on the quantity produced and the energy required) + Sum of (CO2 emissions during the transport and the distribution of the product, which depend on the quantity transported and on the distances between the facilities)

Subject to
1. Efficiency constraints (related to the efficiency scores obtained in phase I for each potential actor at each product life cycle stage and to the threshold efficiency set by the decision maker)
2. Supplier capacity limits
3. Production capacity limits of the plants
4. Distributor capacity limits
5. Market total demand satisfaction
6. Flow conservation constraints
7. Bounds on decisions variables

This problem has been translated into a linear bi-objective mathematical program and solved using the weighted goal programming method. The objective weights were provided in phase I using the AHP method.

Numerical example
This section presents a small-scale supply chain design problem adapted from a real-life situation. The purpose is neither to show any advantage of the modeling process by comparing with other MIP models nor to exhibit the efficiency of problem solving by benchmarking the computation time to other algorithms. Indeed, we aim to illustrate the effectiveness and convenience of the product life cycle consideration in the green supply chain design by introducing a multi-criteria decision making and a multi-objective model to select the effective supply chain actors in the different product life cycle stages. We consider the case of a focal company that is in the
launching process of a new product on the market, namely, environmental coal derived from olive pomace. The company has to design a product-driven green supply chain, with minimal cost and minimal CO2 emissions.

The model demonstrates that the proposed approach cannot only adopt the supply chain strategy according to the degree of concern at different phases but also consider the trade-off effect to avoid selecting inefficient actors in the correspondent product life cycle stage.

We examined the sensitivity of the supply chain performance due to variations in the objective weight values. Figure 3 shows the goal satisfaction levels. From the results shown by this figure, we realize that the two objectives are almost fully achieved. In all cases, almost the same supply chain actors are selected, but flows circulating between these actors are different. Therefore, it can be concluded that fluctuations in the choice of the objective weights doesn’t affect significantly the green supply chain structure.

**Conclusion and perspective**

In this article, an explanation of the importance of considering the product life cycle in the green supply chain design is provided. A detailed green supply chain network design, at the different product life cycle stages, is optimized by simultaneously taking into account economic and environmental aspects. This enables the effective selection of different entities, namely, suppliers, production facilities, and distribution centers, as well as the deployment plans that identify the optimal routing of material among the selected actors. This problem is modeled as a bi-objective optimization problem in which total supply chain cost and environmental impact minimization are considered. The case of production and delivery of multiple products that are in different product life cycle stages is another interesting issue that needs to be considered.

**References**


About the authors

**Khaoula Besbes** is a joint PhD student at the University of Artois in France and at the University of Sfax in Tunisia. She is a member of the research laboratory LGIZA (Laboratory of Computer Engineering and Automatic of Artois) at the Faculty of Applied Sciences in Béthune in France and a member of the research unit LOGIQ (Logistics, Industrial Management and Quality) in the Higher Institute of Industrial Management in Sfax in Tunisia. Her research interest is in product-driven supply chain design.

**Hamid Allaoui** is currently a full professor (Professeur des Universités) at the University of Artois in France. After graduating with an engineering degree in electro-mechanical engineering (option industrial maintenance) in 2000 he joined ST-MicroElectronics Company as a manufacturing engineer. He received a PhD in computer science and management science in 2004. His current research covers design, management, and optimization of supply chains especially scheduling and planning of operations. He is involved in several research projects as well as projects with industrial companies dealing with creating a green supply chain. He has published in several international journals such as the: *International Journal of Production Research, Journal of Computers and Industrial Engineering,* and *Operations Research*.

**Gilles Goncalves** has been a full professor at the University of Artois in France since 1994. He studied computer science at the University of Lille1 and obtained his PhD in 1985. For fourteen years, he was a lecturer and his works concerned parallel and distributed computing. His current research interests include information systems, security management, simulation modeling, discrete optimization, and meta-heuristics. He manages a research laboratory called LGIZA whose main topics are organization and management of logistic processes.

**Taicir Loukil** is the head of the research unit Logistique, Gestion Industrielle et de la Qualité. She worked as a chief of the department development and studied at the Office des Ports Aériens de Tunisie prior to joining the University of Sfax. She received her doctorate from the Faculty of Economics and Management of Sfax, Tunisia. Her research activities include combinatorial optimization, multi-criteria optimization, and applications in scheduling problems. She acted as a guest editor of a special issue called “Developments in Multiple Objective Programming and Goal Programming” at International Transactions in Operations Research (ITOR). Taicir Loukil has authored or coauthored more than twenty scientific papers published in specialized reviews. She has supervised twenty PhD theses and more than thirty master theses. In 2003 she received the best paper award for the conference of the Administrative Sciences Association of Canada.