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Towards supply chain sustainability: economic, environmental and social design and planning

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ABSTRACT

Costumers and governments are pressuring companies to become more sustainable. However, the lack of research on how to incorporate these issues makes this a challenging task. To fill this gap a generic multi-objective mathematical programming model for the design and planning of supply chains, integrating the three dimensions of sustainability is presented. The economic pillar of sustainability is addressed in this work considering the costs of the supply chain. Then ReCiPe, an environmental assessment methodology, indicated in the literature and by the European Commission as the most developed one currently available, is for the first time applied to supply chain design optimization. Finally, a social indicator appropriate to assess strategic decisions is proposed. This social indicator considers the impact of social and political concerns on company's performance. The relevance of this model as a decision support system is highlighted with its application to a real case study of a Portuguese battery producer and distributor. A set of strategies to select the best solution among the obtained optimal ones is presented. Results show that the model allows improvements in all the three dimensions of sustainability and offers important managerial insights.

1. Introduction

The global context of modern economy forces companies to achieve excellence in terms of efficiency in their logistics operations, in particular, when customer satisfaction is directly affected (Stock et al., 2010). Customers are becoming more and more demanding not only in terms of product quality but also on a fast, flexible and consistent delivery service (Christopher, 2012). With customers being the centre of the business, companies want to develop a service level that meets customers' expectations, but at the same time they want it at the lowest possible cost. Additionally, most companies have a large number of customers geographically disperse and deal with a large number of products and transportation modes. With such a complex supply chain, it is important to assure that conscious decisions are made at the design and planning levels.

Adding to the problem, in the last decades the social and political consciousness woke up for the negative environmental and social impacts of industry (Hutchins and Sutherland, 2008). Climate change, resource depletion, and human health problems are leading to a point of no return (Carvalho et al., 2013). Sustainable development, defined in 1987 as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland, 1987), is now more important than ever. Yet, if in the past this concept was more environmentally oriented, in current literature sustainability is considered to be supported by three main pillars: economic, environmental and also social sustainability (Elkington, 2004).

The European Commission has stated its concern and commitment to these matters, declaring that "*Sustainable development remains a fundamental objective of the European Union under the Lisbon Treaty*". A sustainable development strategy was developed as well as a broad range of policies which continue to be updated, as the European Commission clearly states: "*unsustainable trends persist and the EU still needs to intensify its efforts*" (Commission, 2009).

Putting all these aspects into perspective, companies are pressured to look at their entire supply chain in order to become more sustainable while maintaining their competitiveness. Sustainable supply chain management (SSCM) was defined by Seuring and Müller (2008) as *"the management of material, information and*

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capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements". It is the balance between these three pillars that offers a challenge, from the strategic to the operational level. The social pillar in particular has been left unaccounted for and we are still far from achieving the so called sustainable supply chain (Seuring, 2013).

This work aims to address this challenge from the strategic point of view, aiming to give a step forward into answering the following research question:

How can sustainability be integrated into supply chains' design and planning decisions?

A generic multi-objective mathematical programming model for the design and planning of closed loop supply chains that simultaneously considers economic, environmental and social performances is proposed in this work. A social indicator has been created to assess social impact at a strategic level. An environmental assessment methodology, ReCiPe, extensively used in the literature but not on supply chain optimization models, is implemented. The model is applied to a case study developed with the collaboration of a Portuguese lead battery producer and distributor.

The paper is organized as follows. In the next section, the background literature is presented, focusing on closed loop supply chain research, as well as environmental and social impact assessment. In Section 3 the developed model is characterized. In Section 4, the case study is described, being the results presented and discussed in Section 5. Lastly, in Section 6, final conclusions are drawn and future work directions discussed.

2. Background

2.1. Closed-loop supply chains

As defined by Fleischmann et al. (1997), reverse logistics concerns "the logistics activities all the way from used products no longer required by the user to products again usable in a market". Environmental legislation that obliges firms to assume responsibility for the entire life cycle of the product is now common to several countries. However, factors other than legislation compliance instil companies to pursue this option. One of them is the "green" image perceived by the costumers who now more than ever ponder such issues in their purchasing decisions (Fleischmann et al., 1997). Moreover, it has been proven that effective management of reverse logistics operations can in fact increase profitability (Ilgin and Gupta, 2010). Fleischmann et al. (1997) further state that even though adding complexity to the problem, both forward and reverse flows must be considered simultaneously to provide adequate planning. Indeed closed-loop supply chain (CLSC) research has evolved significantly and many papers have been published as stated in several reviews. Fleischmann et al. (2001) first introduce the impact of product recovery on facility location decisions. Guide and Van Wassenhove (2002) claim that the supply chain should be seen as a closed loop system where reverse logistics activities should be included, such as the collection, transportation and reprocessing of collected products. Salema et al. (2010) further include the tactical planning of the CLSC operation in a generic modelling framework, from where our contribution is derived. Guide and Van Wassenhove (2009) review the area over the last 15 years, focusing on profitable value recovery. Ilgin and Gupta (2010) offer a description of the main type of modelling techniques and topics addressed in CLSC research. Stindt and Sahamie (2014) analyse CLSC research in different sectors of the process industry. Dekker et al. (2012) state that most papers focused on CLSC do not explicitly deal with the supply chain environmental impacts, and draw attention to the need for new models to support environment related decision making. Tang and Zhou (2012) claim that models to assess the people/society impact of supply chains are lacking and identify this issue as a future challenging research stream. More recently, Cardoso et al. (2013) presented a model for the design and planning of closed-loop supply chains where activities such as supply, production, assembling or disassembling are detailed while considering the supply chain dynamics. Our contribution arises from these identified research gaps, by providing a model that integrates environmental impact assessment and societal impact in CLSC design and planning.

2.2. Environmental impact

Literature on green supply chains is diverse. Several methods and frameworks have been proposed to assess environmental impact. However, Life-Cycle Assessment (LCA) has been described as the most scientifically reliable method currently available for studying and evaluating the environmental impacts of a certain product or process, allowing both retrospective and prospective assessment (Ness et al., 2007). This is reinforced when the European Commission states that LCA currently provides the best framework for assessing the potential environmental impacts of products and has included in its Sustainable Development Strategy the goal of developing and standardizing LCA methodologies (Commission, 2003).

LCA is an environmental impact assessment method that quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with any goods or services. It takes into account the entire life cycle of the good or service, from the extraction of resources, through production, use, recycling and disposal (Commission, 2010). A typical LCA method follows the generic structure presented in Fig. 1. It begins with the collection of the life-cycle inventory of a given good or service (step 1), followed by the characterization step where the environmental impact of each emitted substance or resource consumed is determined and categorized in either a midpoint and/or endpoint environmental impact category (step 2). Midpoint categories correspond to the environmental mechanism itself while endpoint categories correspond to the subsequent damage. Then follows a normalization step (step 3) and weighting step (step 4) to then arrive at a single score (step 5).

Several different LCA methods are available and continue being developed. These may use different models in the characterization step, different normalization assumptions and/or different weighting factors (Carvalho et al., 2014). Several authors compare different LCA methodologies. Renou et al. (2008) addressed the influence of impact assessment methods in wastewater treatment LCA. Pizzol et al. compared eight different methodologies in the eco-toxicological impact of metals on the aquatic and terrestrial ecosystem (Pizzol et al., 2011a), and compared nine methodologies on the impact of metals on human health (Pizzol et al., 2011b). The European Commission also released a method recommendation report for Life Cycle Impact Assessment in the European context (Commission, 2011).

Some literature exists where authors apply LCA methodologies to supply chain design (Seuring, 2013). Frota Neto et al. (2008) developed a framework for the design and evaluation of sustainable logistic networks, using the European pulp and paper industry as example. The environment index is used to assess ecological impact. Guillén-Gosálbez and Grossmann (2009) addressed the design of sustainable chemical supply chains in the presence of