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# Redesign of a sustainable reverse supply chain under uncertainty: A case study

Michael Feitó-Cespón [a], William Sarache [b,*], Frank Piedra-Jimenez [c], Roberto Cespón-Castro [c]

[a] Department of Industrial Engineering, Universidad de Cienfuegos, Carretera a Rodas km 3 1/2, Cuatro Caminos, Cienfuegos, Cuba
[b] Departamento de Ingeniería Inudstrial, Universidad Nacional de Colombia, Campus La Nubia, Cra. 27 No. 64-60, Manizales, Caldas, Colombia
[c] Department of Industrial Engineering, Universidad Central "Marta Abreu" de Las Villas, Campus Central, Carretera a Camajuaní, km $5_{1/2}$, Santa Clara, Villa Clara, Cuba

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ABSTRACT

This paper presents a Stochastic Multi-Objective Mixed Integer Non-Linear Problem (SMOMINLP) to redesign the sustainable supply chain to recycle certain products. The model integrates economic, environmental and social objectives to support strategic decisions such as facility location, material flow design and transport selection. The environmental impact objective is calculated through the Life Cycle Assessment (LCA) methodology using the Eco-indicator 99 method. A multi-criteria programming approach algorithm to manage several objectives linked with stochastic programming to address uncertainty is developed in this investigation. In addition, to assess the solutions obtained and to reduce the uncertainty effect on decision-making, a performance indicator is proposed. Model feasibility has been tested in Cuba. In this case study, the redesign of a supply chain for plastic recycling is examined. The experimental results show supply chain configurations that improve sustainability performance.



## 1. Introduction

Sustainability science addresses problems that cannot be resolved using classical methodological tools (Bettencourt and Kaur, 2011; Hasna, 2010). Certain authors suggest that sustainability mainly depends on three dimensions: economic, environmental and social (Carter and Rogers, 2008; Elkington, 1998; Hassini et al., 2012). In scientific literature, the concept of sustainability has been addressed from several different perspectives that depend on particular contexts (Elkington, 1998; Frederick, 1994; Gray, 2010; Prahalad and Hart, 2004; Visser, 2011). According to Roca and Searcy (2012), this conceptual diversity demonstrates the lack of consensus regarding a universal definition of sustainability. However, to address technological problems, two main perspectives stand out: weak sustainability and strong sustainability (Daly, 1991).

Weak sustainability is a branch of neoclassical environmental economics that is grounded on the assumption that human capital (man-made capital) can substitute for natural capital, and therefore they are interchangeable. For instance, natural resources can be consumed if the quality of human lives is improved. Human capital is defined as "*... a set of complex systems, consisting of evolving biotic and abiotic elements, that interact to determine the capacity of an ecosystem to directly and/or indirectly provide human society with a wide array of functions and services*" (Pelenc and Ballet, 2015). According to the weak sustainability approach, natural resources can be used and replaced without limit as long as human capital evolves (Ekins et al., 2003). Carbon credits trading is a typical example of this perspective (Chaabane et al., 2012).

In contrast, from the perspective of ecological economics, strong sustainability promotes a necessary balance between the socio-economic system and its ecosystem (Naredo, 1994). Ecological economics argues that there is an interdependence and coevolution of human economies and natural ecosystems over time and space (Ahmed et al., 2012). Thus, because certain environmental functions cannot be performed by man-made resources, human and natural capital are complementary but not interchangeable (Baumgärtner and Quaas, 2010; Stern, 1997). From the ecological economic perspective, strong sustainability is a multidisciplinary

* Corresponding author.
*E-mail addresses:* mfeito@ucf.edu.cu (M. Feitó-Cespón), wasarachec@unal.edu.co (W. Sarache), fpiedra@uclv.cu (F. Piedra-Jimenez), rcespon@uclv.edu.cu (R. Cespón-Castro).

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field aimed to understand and manage economic environmental relations (Ahmed et al., 2012).

At the same time, strong sustainability is closely related to the concept of sustainable supply chain management. According to Seuring et al. (2008), sustainable supply chain management can be defined as *"the management of material and information 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, and stakeholder requirements into account"*. This concept is also related to the so called Tripe Bottom Line (TBL) approach which promotes a balance between environmental, social and economic performance (Seuring and Müller, 2008).

To ensure a sustainable supply chain, the network design must consider the impact that strategic decisions (*i.e.* capacity allocation, facility location, etc.) generate on the economic, environmental and social performance. From this perspective, the problem of design (and redesign) of a sustainable supply chain has been identified as a relevant investigation topic.

Although there are numerous contributions addressing the problem of Sustainable Supply Chain Network Design (SSCND) several knowledge gaps were identified in our literature review. These can be summarized as follows:

- Most contributions are focused on the design of new supply chains and a lack of models addressing redesign has been identified.
- From the mathematical perspective, opportunities exist to improve the SSCND related to environmental functions.
- Few models addressing the redesign of reverse supply chains consider the simultaneous analysis of economic, environmental and social goals.
- Uncertainty in waste sourcing and demand for recycled products as well as handling multiple materials are topics that require further investigation.
- The effect of the number and location of facilities on the environment is not considered.

Based on the above, this article proposes a multi-objective mathematical model to redesign a reverse supply chain network. The model allows the recycling of multiple products using the strong sustainability approach. Despite the similarities identified in the contributions of our literature review, the proposed model includes the following characteristics:

- The usage of the strong sustainability approach to redesign a recycling supply chain network, considering several material flows and uncertainty in both waste generation (raw materials) and final demand (recycled products).
- The construction of a mathematical function to assess the environmental performance per the LCA using the Eco-indicator 99 method. This function supports the trade-off analysis between strategic and tactical network design decisions such as facility location, capacity allocation and transportation mode selection.
- The construction of an expected performance indicator to evaluate the new supply chain configurations, considering environmental and economic objectives for different scenarios.

The model was applied to redesign a plastic recycling supply chain in Cuba. In this country, reverse logistic operations are managed by state-owned Enterprises for Raw Material Recovery (ERMR). Over the last few years, an increase in waste generation has been observed and, therefore, the current design of the recycling supply chain must be revised. In particular, plastic recycling presents a great business opportunity not only because of the economic benefits of this material but also for its environmental and social impact (Feitó Cespón et al., 2015).

Based on a proper balance between the three goals of the strong sustainability approach, the model's results provide useful information to support strategic decisions regarding the supply chain structure. In this case study, the model suggested the creation of two new recycling plants to improve the sustainable performance of the existing supply chain.

The paper is structured as follows: in Section 2, a literature review on SSCND is presented. Section 3 presents a brief description of the proposed SSCND and its assumptions. Subsequently, the mathematical formulation and a detailed description of its components are provided in Section 4. In Section 5 the proposed solution approach is explained. To apply the model, a case study is developed in Section 6. Finally, in Section 7, the main conclusions of the investigation are outlined.

## 2. Literature review

A supply chain is a network of organizations involved through forward and reverse material flow, funds, services and information from the original producer to the final consumer (Ahi and Searcy, 2013; Stock and Boyer, 2009). Adding economic value for customers and other stakeholders is the primary objective of a typical supply chain (Walters and Lancaster, 2000).

In turn, the Supply Chain Network Design (SCND) addresses the physical configuration and infrastructure of the organizations involved in the supply chain. Relevant strategic decisions related to capacity allocation, facility location and transport selection, among others, must be considered in the SCND problem (Chandra and Grabis, 2007). According to Autry et al. (2013), from the perspective of operations research, SCND is a discipline to establishes the optimal location and size of facilities and the flow through them. In contrast to the SCND, the supply chain redesign problem begins with an existing supply chain and the objective is to obtain a new network configuration by changing the aforementioned strategic decisions. According to Razmi et al. (2013) supply chain network redesign is a more complex problem since changes must be made in a planned manner by maintaining operations.

Although SCND is a topic supported by extensive literature, solutions focused on improving economic performance are the most common; therefore, a lack of contributions addressing the environmental and social issues has been reported (Boukherroub et al., 2015; Eskandarpour et al., 2015; Seay and Badurdeen, 2014). Consequently, from the strong sustainability and TBL perspective, integrating the three sustainability dimensions into SCND, emerges as a relevant research topic (Eskandarpour et al., 2015; Farahani et al., 2014). This approach is known as Sustainable Supply Chain Network Design (SSCND).

Particularly, one of the business processes associated with a sustainable supply chain is reverse logistics (RL). According to the Council of Supply Chain Management Professionals (CSCMP, 2010), RL can be defined as a *"... specialized segment of logistics focusing on the movement and management of products and resources after the sale and after delivery to the customer, including product returns for repair and/or credit"*. Instead of handling return products as waste, RL adds value through the development of a new supply chain or by improving pre-existing ones.

Intended to reduce the consumption of virgin materials, RL involves several activities such as reuse, repair, restoration, disassembly for remanufacturing, cannibalization and recycling (Hanafi et al., 2008). Regarding recycling operations, several particularities