Incorporation of life cycle analysis indicators in the design of a dynamic supply chain network

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Abstract: The supply chain (SC), composed of entities such as suppliers, plants, distribution centers and customers, carries out the manufacturing and sales processes of a product in its entirety. Its management encompasses a detailed link-by-link relationship management that seeks to determine the best configuration of all its elements with the objective of minimizing total costs while meeting service levels. Therefore, SC network design is an area of decision making that considers parameters such as planning, costs, demand, and supply. A well-structured SC is an important strategic competency that enables companies to be competitive in today's marketplace. Increasing globalization and decreasing profit margins have generated a recent research trend to consider non-cost metrics in network design. Many researchers now focus on designing SCs that can operate effectively in the presence of external and/or internal disruptions. On the other hand, today, environmental protection is increasingly critical, due to factors such as the growing scarcity of natural resources, consumer demands, increased awareness of environmental issues, global laws and agreements that force companies to reconsider and often restructure their SC operations with a focus on sustainability. Considering sustainable development factors in the design of the SC network increases its complexity, however, it is a necessary challenge as it is a business opportunity rather than a constraint.

To achieve a sustainable SC network, methods and tools are needed to measure the environmental impact of a product, one of them is the Life Cycle Analysis (LCA), which is an environmental management tool whose purpose is to analyze in an objective, methodical, systematic, and scientific way, the environmental impact (EI) originated by a process/product during its complete life cycle. To deal with all these variables and challenges, mathematical programming models are a powerful tool for designing sustainable SC networks in which a balance between several conflicting objectives is sought.

The research question answered by this study is about the feasibility of introducing environmental impact indicators, obtained from an LCA, in the design of a dynamic SC network, the main objective being to develop a sustainable SC model that will serve as a decision support for companies. The methodology is based on a 3-stage framework, consisting of Input Data, LCA, and Mathematical Model. The input data refers to information and characteristics of the raw material, energy and waste flows present in the production process, SC characteristic data, logistics, production, and demand. The LCA is developed on the antibacterial gel product and follows the methodology of the ISO 14044 Standard, which consists of 4 steps: definition of the objective and scope, life cycle inventory analysis, life cycle impact assessment and interpretation. Subsequently, Gabi software is used to model the SC and the Recipe 2016 method is used to quantify the characterization factors at midpoint and endpoint level, which reflect the damage in three areas of protection: human health, ecosystem quality and resource scarcity. The last stage, the mathematical model is designed for a four-layer multilevel network and is based on multi-objective mixed integer linear programming where the first objective function refers to utility

maximization. While the second objective function minimizes the environmental impact generated in the whole network. The model constraints are based on capacities and material flow balance throughout the SC. To verify the validity of the model, Gams software is used and a case study of a Mexican company dedicated to the production and distribution of antibacterial gel is executed.

As part of the results, it is shown that the largest EI categories are climate change, fossil depletion and terrestrial ecotoxicity, and it is proven that the raw material extraction stage represents on average 99% of the total impact generated in the SC of the antibacterial gel product. Comparisons are made between the classical models that consider only costs versus the developed model that considers EI indicators of an LCA, showing that the average percentage of profit reduction is between 11% and 15%, how much of this percentage is willing to sacrifice is a particular decision of each company. Finally, it is shown that the model developed is a quantitative tool for decision making, since it allows simulating different scenarios and analyzing their costs and environmental impact. Companies interested in sustainable SC should focus their efforts on seeking environmentally friendly raw materials, researching the application of new technology and new production methods.

Keywords: Supply Chain, Sustainable Supply Chain, Quantitative Models Supply Chain, Multi-objective mathematical models, Life Cycle Analysis, Environmental Impact, Sustainable Development.

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