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Sustainability optimization for global supply chain decision-making

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Abstract

Modern enterprises of all sizes operate in global manufacturing networks and complex global supply chains. Because sustainability is now a major concern, global manufacturing enterprises must optimize their global supply chain over multiple objectives including sustainability. It is important for such enterprises to analyze their global supply chain across all the three pillars of sustainability (society, economy and environment) when making a distribution network decision. A cradle-to-gate approach is taken, which means this decision can depend on the manufacturing site, all its suppliers, raw material source and transportation right until the customer gate. In this article, a multi-objective optimization model is presented that provides a rigorous method to optimize over all the three pillars of sustainability using a cradle-to-gate approach.

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Keywords: Sustainability; Green supply chain; Multi-objective optimization; Decision making

1. Introduction

Nowadays, besides huge multinational companies, small and medium-sized enterprises (SME) also operate in globally distributed supply chain networks [9]. Individual steps of the manufacturing process are performed on globally distributed sites. Furthermore, by focusing on core competencies, the proportion of purchased parts has significantly increased [18]. The industrial sector, particularly, has several impacts on the environment due its large supply chain and auxiliary processes like transportation and packaging [21]. The design of global supply chain networks is of increasing importance for the competitiveness of companies in the global market but also a growing challenge for the management. Currently, teams of experts advise on strategic decisions and mostly intuitively make quasi-rational decisions that, by far, do not include all the correlations of the global manufacturing network and its environment [17]. Such decisions can be supported by approaches in the field of operations research that map cause-effect relationships in the supply chain through optimization after applying stringent rules. By applying supply chain network optimization problems, exclusive consideration of costs based on attractive factor advantages is unsuitable for sustainable supply chain planning. Rather, multiple objectives have to be integrated into the evaluation [9, 11]. Following this, sustainability is increasingly becoming an important objective for decision-making in global enterprises. Sustainability evaluation is sub-divided into three broad categories, namely environmental, social and economic sustainability - often referred to as the 'triple bottom line'. Environmental sustainability deals with the direct impact on the environment whereas economic sustainability refers to the involved costs and financial stability. Social sustainability, the least studied component of the three pillars of sustainability, deals with health, safety and livable conditions for people, communities, consumers and other stakeholders without compromising their rights or freedom. In order to fully understand and evaluate the sustainability of a production network or a global supply chain, a combined study of all these three branches of sustainability is required. It is not only significant to evaluate the sustainability of a supply chain, but also to optimize it over the three branches of sustainability and aid in supply chain decision-making.

2. State-of-the-art

The evaluation and optimization of sustainable

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manufacturing is becoming increasingly important. Several models have been developed over the recent years in order to estimate and understand the environmental impact of manufacturing processes, enterprises and their supply chains. Some of the approaches focus on the machinery and process level, others on process chains and factory level. A few approaches, such as [3,10], focus on global supply chains.

The planning of global supply chain networks is increasingly discussed taking into account environmental and social aspects. Reinhart [15] presents an approach for the holistic optimization of energy and resource consumption within supply chains. The approach focuses on the optimization of energy and resource efficiency at the three levels machinery, factory and supply chain. Energy and resource consumption are in the center of interest, based on the transport volume between the different factories.

Reich-Weiser et al. [14] developed a tool for supply chain optimization considering environmental sustainability based on energy payback time. Sarkis [16] developed decision-making frameworks for green supply chains which primarily pertained to environmental sustainability.

Metrics for social sustainability were developed by Hutchins and Sutherland [5] and a methodology for evaluating social sustainability in supply chains was proposed. A 31-subcategories system for social sustainability was published by the UNEP [12] which categorized each of the subcategories under stakeholders like community, worker, supplier and consumer. Standards like the ISO 26000 and the UN Global Compact have encouraged and enabled global enterprises to evaluate their Corporate Social Responsibility.

Few attempts have been made recently at evaluating the complete sustainability of a system including economic, environmental and social aspects. Erol et al [4] developed a fuzzy multi-criteria framework for sustainability evaluation, but an optimization technique cannot be coupled to this model to aid decision-making. Zhou et al [22] assessed the sustainability performance of continuous processes using a Goal Programming optimization model, but their study was limited to a single-stage manufacturing system.

The approaches of Chaabane [2], Naini [13], and Sundarakani [19] allow an assessment of supply chains in terms of their economic and environmental sustainability. Similar approaches described by Tseng [20] Abdalla [1] Jamshidi [7] and Zhou et al. [22] involve optimization models in which economic and environmental objectives were considered.

In summary, none of the presented approaches aid in decision making over the indicators of social, environmental and economic sustainability in combination with a modular optimization model to optimize the structure of a global supply chain. Therefore, the objective of the presented article is to formulate all the indicators to evaluate sustainability in global supply chains, derive a complete multi-objective optimization model for global supply chains and to find the optimal supply chain structure using the cradle-to-gate approach.

3. Measures for sustainability in global supply chains

The sustainability measures for optimization are developed separately for environmental sustainability in section 3.1 and social sustainability in section 3.2. Previous work on economic sustainability are discussed in section 3.3.

3.1. Environmental sustainability

Every component of the global supply chain has an impact on the environment. Since a cradle-to-gate approach is employed, the impacts from extraction of raw material right up to transportation of the final product to the customer gate is considered. The sub-measures are developed separately for the different components of the supply chain, namely, suppliers, sites, technologies and transport.

The sub-measures developed for the evaluation of environmental sustainability are summarized in Table 1 for a technology element as an example. The indicators in Table 1 are formulated for a typical machining process. The sub-measures for a single manufacturing process, referred to as a 'Technology Element' in the model, are developed based on an input-output diagram as shown in Figure 1. Similarly, Figures 2, 3 and 4 show the input-output diagrams for Supplier, Site and Transport elements respectively.

The indicators of all the environmental sustainability sub-measures are of different units, but due to the widespread use of Life-Cycle Analysis (LCA) techniques and inventory databases, each of these indicators can be converted into a common unit using an LCA software. For example, the total GWP (Global Warming Potential) of the entire supply chain can be evaluated from the environmental sustainability sub-measures and indicators by using a relevant LCA database.
The broad sub-measures for any technology element are identified as Energy, Consumables, Maintenance, Wastes and By-Products. Consumables for a technology element include water, coolant, oils, tooling, gauging and packaging material.

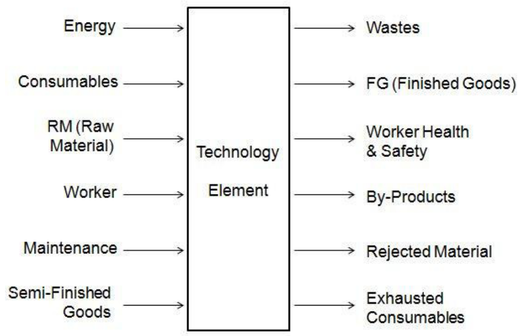

Fig. 1. Input-Output Diagram of a Technology Element.