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A Weighted Sum Method for Evaluating Environmental Responsibility in the Supply Chain of the Textile and Clothing Industry

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1 Abstract

Evaluating decision-makers' environmental responsibility index is crucial for assessing their performance in incorporating environmental considerations into their decision-making processes. This evaluation encompasses a range of criteria, including reducing carbon emissions, improving energy efficiency, managing waste, and utilizing sustainable materials. By analyzing the impact of decision-makers on the environmental performance of the textile and clothing industry's supply chain, it becomes possible to identify areas that require improvement and devise targeted strategies to promote responsible and sustainable management practices. To address this, the study presents a bi-objective mathematical model that aims to minimize both cost and carbon emissions. The weighted sum approach method is utilized to solve the model and evaluate decision-makers' environmental responsibility index within the direct supply chain. This analysis sheds light on the influence of factors such as cost and carbon emissions on the configuration of the supply chain.

2 Introduction

Significant research has been conducted on production decisions in manufacturing companies, yielding valuable results. However, most of these studies have primarily focused on meeting customer needs while minimizing costs or maximizing revenues, overlooking the environmental and energy impacts of production activities. In a recent report from the Intergovernmental Panel on Climate Change (IPCC) published on March 22, 2023, it is warned that global warming is projected to exceed 1.5°C above pre-industrial levels by the early 2030s. This underscores the urgent need to target sectors with high greenhouse gas (GHG) emissions for substantial reductions. In this context, analyzing the environmental responsibility index of decision-makers in the supply chain and optimizing supply chain configuration becomes crucial. It is imperative to reevaluate production and supply chain management decisions by comprehensively integrating environmental and energy considerations.

Numerous studies have been conducted in the field of sustainability and carbon emissions reduction within the supply chain. Cui et al. ([2]) highlight the importance of sustainable supplier selection for managing sustainable supply chains. They propose a validated model through a case study and provide practical recommendations for selecting sustainable suppliers in diverse supply chain structures. Mezatio et al. ([3]) integrate a carbon taxation approach into the supply chain and propose a single-objective mathematical model that minimizes overall costs while considering planning deadlines and horizons. However, this method lacks a concise assessment of the supply chain's environmental responsibility and becomes less effective with very low carbon taxes. Naghi Beiranvand et al. ([4]) introduce a conceptual model for evaluating the performance of sustainable product and service supply chains (PSSCs) in the oil and gas industry. They conduct an extensive literature review to identify relevant indicators and establish ten criteria for the model, including environmental, customer, financial, IT, social, risk, logistics, operational, organizational, and innovation and growth performance.

In this paper, we propose a multi-objective model that combines the cost minimization objective from Mezatio et al. ([3]) as the first objective, with a second objective of minimizing carbon emissions. This model utilizes the Weighted Sum method to find an optimal balance between the two objectives and enables the assessment of a supply chain's environmental responsibility. It also facilitates the analysis of various supply chain configurations at each decision level.

3 Problem statement and mathematical modelling

The supply chain examined in this article, is based on **Mezatio et al.([3])**. It simultaneously integrates economic, environmental, and energy constraints.

In the depicted supply chain, there are two primary flows in the supply chain model. Firstly, there is an information flow, represented by the numbers 1, 2, and 5 in the figure. They signify the flow of information regarding the production requirements or demands within the supply chain. Secondly, there are material flows represented by numbers 3, 4, 6, and 7 in the figure. These material flows represent the movement of physical goods or materials within the supply chain.

3.1 Mathematical modelling

The mathematical model is designed with two main objectives. The first objective, denoted as f_1 , focuses on minimizing the total costs associated with the supply chain. This objective aims to optimize various cost-related factors such as procurement, production, transportation, and inventory management.

The second objective, denoted as f_2 , aims to minimize the carbon emissions generated throughout the entire supply chain. This objective emphasizes the reduction of greenhouse gas emissions resulting from various activities within the supply chain, such as energy consumption, transportation, and waste management.

The model has eight indices: F (Factories), U (Subcontractors), S (Suppliers), R (Raw materials), P (Products), W (Warehouses), N (Retailers), and V (Transport modes). These indices represent different entities or components within the supply chain. Additionally, the model includes 52 parameters, and 26 decision variables.

The f_1 cost function is defined by :

$$\text{minimize } f_1 = P_c + M_c + H_c + T_c \quad (1)$$

Where, P_c represents the procurement cost, M_c represents the manufacturing cost, H_c represents the holding cost, and T_c represents the transportation cost.

The f_2 carbon emission function is defined by :

$$\text{minimize } f_2 = P_{em} + M_{em} + T_{em} \quad (2)$$

Where P_{em} represent the procurement emission of the raw materials, M_{em} represent the manufacturing emission, and T_{em} represent the transportation emission.

3.2 Resolution and Experimentation

Resolution Method

The model presented is solved using the Weighted Sum method. The advantage of this method is that it allows us to better assess the degree of importance given to each of the objective. The aim of this method is to minimize the function:

$$\text{minimize } f = \alpha \cdot f_1 + (1 - \alpha) \cdot f_2 \quad (3)$$

In the experiment conducted, the parameter α is utilized to determine the relative importance assigned to each objective function during the evaluation process. Ten different values of α were considered, ranging from 0 to 1 with a step size of 0.1. Each value of α represents a different weighting scheme that emphasizes either the cost objective (f_1) or the environmental objective (f_2) to a varying degree.

Experimentation

In the study, test proposed by Mezatio et al.([3]) was used. The instance is defined as follows: 8 suppliers (S=8), 3 factories (F=3), 4 warehouses (W=4), 8 customers (N=8), 9 raw materials (R=9), 8 different products (P=8), 9 subcontractors (U=9), and 3 transport modes (V=3). The customer demands for each product range between 100 and 500 units. The mathematical models were solved using the Cplex 20.1.0 solver on a Core i5 PC with a frequency of 2.3 GHz.

Figure 1 presents the Pareto front, illustrating the trade-off between cost and overall emissions by varying the weight parameter α . The figure provides valuable insights into the relationship between cost and emissions, showcasing the impact of different weightings assigned to these two objectives. It visually represents the different trade-off possibilities between cost and emissions, allowing decision-makers to understand the implications of prioritizing one objective over the other.

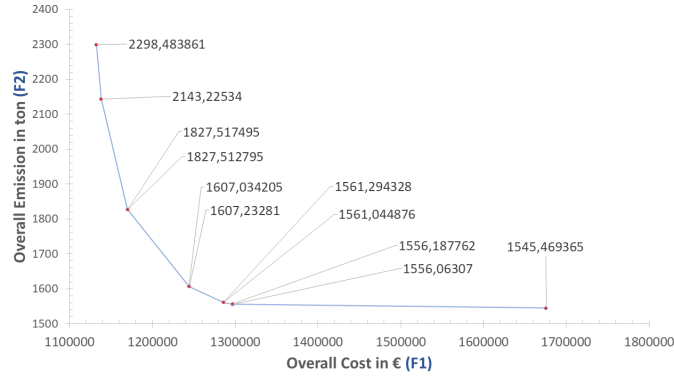


Fig. 1 – The Optimal Pareto Front for cost(F1) and emission(F2) function

Table 1 showcases the different supply chain configurations obtained for each α value. In these configurations, the values of 1 represent the selected actors (such as suppliers, factories, subcontractors, and warehouses), while 0 indicates that the respective actor is not selected or not present in the configuration.

Table 1 – Supply chain configurations

α	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
Suppliers	[1 1 1 1 1 1 1 0]	[1 1 1 0 1 1 1 0]	[1 1 1 0 1 1 1 0]	[1 1 1 1 0 1 1 0]	[1 1 1 1 0 1 1 0]	[1 1 1 1 0 0 1 0]	[1 1 1 1 0 0 1 0]	[1 1 1 1 0 1 1 0]	[1 1 1 1 0 1 1 0]	[1 1 1 1 0 1 1 0]
subcontractor	[0 0 0 1 0 0 0 0]								[0 0 0 0 0 0 1 0 0]	
Factories	[1 0 1]						[1 1 1]			
Warehouse	[1 1 1 1]									

4 Conclusion

The paper proposes an approach to evaluate the responsibility index of a supply chain, considering both cost and carbon emissions. The trade-off between cost and emissions is demonstrated in figure 1 by varying the weight parameter α . The optimal Pareto front obtained in figure 1 shows that the values of functions F1 and F2 are unchanged when $\alpha \in \{0.1,0.2\}$, $\{0.3,0.4\}$, $\{0.5,0.6\}$, $\{0.7,0.8\}$. Table 1 presents the different configurations obtained for supplier, factory, subcontractor, and warehouse choices across various values of α . The number of configurations varies at each decision level, with four configurations for supplier choice, two configurations for factory choice, two configurations for subcontractor choice, and a single configuration for warehouse choice across different α values. Future studies will focus on assessing the costs associated with different supply chain configurations and exploring variations in the supply chain structure. This will provide insights into the financial implications of different configuration choices and enable further analysis of the supply chain’s adaptability and performance under different scenarios.

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