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Integrating Economic and Environmental Factors: A Decision Model Framework for Supply Chain Development

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Abstract
Drawing upon an extensive review of existing literature on supply chain decision models, the proposed framework is divided into five distinct stages. The first stage involves defining the key actors and operations within the supply chain. Next, the model's parameters, variables, and performance metrics are established in order to capture the relevant economic and environmental aspects. The third stage focuses on defining the modeling process itself, ensuring that it captures the complexities of the supply chain system while incorporating the desired sustainability goals. To ensure the reliability and effectiveness of the model, the fourth stage emphasizes the importance of verifying, pre-testing, and validating the proposed framework. Rigorous testing and validation procedures help confirm that the model accurately represents the intricacies of the supply chain and successfully integrates economic and environmental factors. Finally, the fifth stage involves selecting an appropriate solution approach, considering the specific requirements and goals of the supply chain under consideration. By offering valuable insights into the development of accurate decision models and their corresponding solutions, this framework makes a significant contribution to the existing body of knowledge. It equips modelers with the necessary guidance to improve sustainability performance within the supply chain while taking into account the crucial aspects of both economic and environmental considerations.
Keywords: Supply Chain, Economic, Environmental, Decision Model, Framework

Introduction

Supply Chain Management (SCM) has emerged as a highly effective approach to handle cost management, information flow, and product movement spanning from initial vendors to end customers. Over time, researchers have extensively investigated supply chain (SC) models to optimize SC operations through managerial decision-making. Traditionally, these decisions have primarily focused on economic performance metrics, such as cost, profit, customer service levels, and response time (Gunasekaran et al., 2004; Arshinder et al., 2008). Moreover, decision complexity varies depending on the actors involved and the specific SC operations encompassed, such as procurement, production, inventory management, and transportation (Manuj et al., 2011). As a result, previous research on SC models has predominantly concentrated on economic aspects and the intricacies of SC operations.

In recent times, there has been a notable shift in research focus within the realm of supply chain (SC) models towards incorporating environmental considerations, reflecting a growing awareness of the need for sustainability. Numerous researchers have undertaken efforts to redefine the field of SC studies by integrating environmental factors into Supply Chain Management (SCM) practices (Nouira et al., 2014; Brandenburg et al., 2014). This shift is primarily driven by the alarming acceleration of global warming, which poses a significant threat to humanity. The primary culprit behind this threat is the increasing emission of carbon dioxide (CO2), largely attributed to human activities like the combustion of fossil fuels and deforestation (IPCC, 2007; Hua et al., 2011). Furthermore, it is acknowledged that SC operations can be a contributing factor to CO2 emissions, thereby further emphasizing the need to address environmental concerns within the supply chain (Chaabane et al., 2012).

To tackle this challenge, it is imperative to integrate environmental impact reduction into the decision-making processes of each operation within the supply chain (SC). By doing so, when economic considerations are taken into account, these decisions can contribute to the overall sustainability of the SC. Consequently, such decisions have the potential not only to yield cost savings but also to generate a positive environmental impact. While Seuring and Muller (2008) defined a sustainable SC as one that encompasses three objectives (economic, environmental, and social), incorporating the economic and environmental dimensions alone can also enhance the sustainability of the SC (Ahi and Searcy, 2013). Figure 1 provides a comprehensive overview of the sustainable SC, depicting the integration of these objectives.

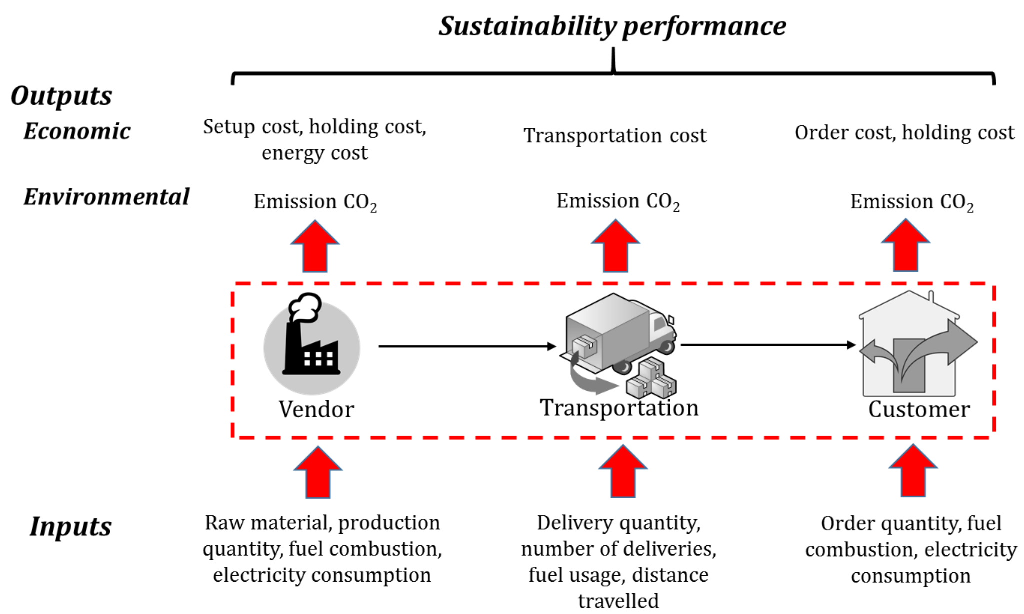

Figure 1: General scheme of sustainable SC.

Figure 1 illustrates the distinct inputs and outputs associated with each operation within the supply chain (SC), involving vendors, transportation, and customers. The economic and environmental outputs play a crucial role in determining the overall sustainability performance. Achieving improved sustainability performance necessitates making accurate decisions that encompass both economic and environmental aspects for all inputs across each stage of SC operations. Undoubtedly, this presents a challenging task, as effective decisions must be made considering both performance indicators and the intricacies of SC operations. The primary objective of this paper is to propose a framework for developing a sustainable SC decision model capable of effectively addressing issues within SC systems that are subject to economic and environmental regulations. The proposed frameworks stem from a comprehensive review of existing literature on SC decision models. When considering the integration of economic and environmental factors into a SC decision model, numerous intriguing questions emerge: How many actors are involved in the SC? Which parameters and variables significantly impact economic and environmental performance? What model types and modeling techniques should be employed to accurately simulate the real SC system? Which validation techniques are suitable for ensuring the model's reliability? Lastly, what solution approach should be adopted to arrive at effective decisions for enhancing model performance? By addressing these theoretical research questions, this paper contributes valuable insights to the existing body of knowledge concerning the development of SC decision models.

Methodological Of Framework For Sustainable Supply Chain Decision Model

The key advantage of this framework lies in its comprehensive guidance for modelers to follow to develop a robust supply chain (SC) model that accurately represents the real system and enables the determination of optimal decisions to enhance sustainability performance. The framework is specifically tailored to consider both economic and environmental factors, ensuring that the model aligns with the sustainability objectives of the SC. Figure 2 provides a visual representation of the step-by-step process involved in developing quantitative SC models while incorporating economic and environmental considerations. The subsequent sub-chapter will delve into the finer details of this proposed framework, offering a more comprehensive discussion.

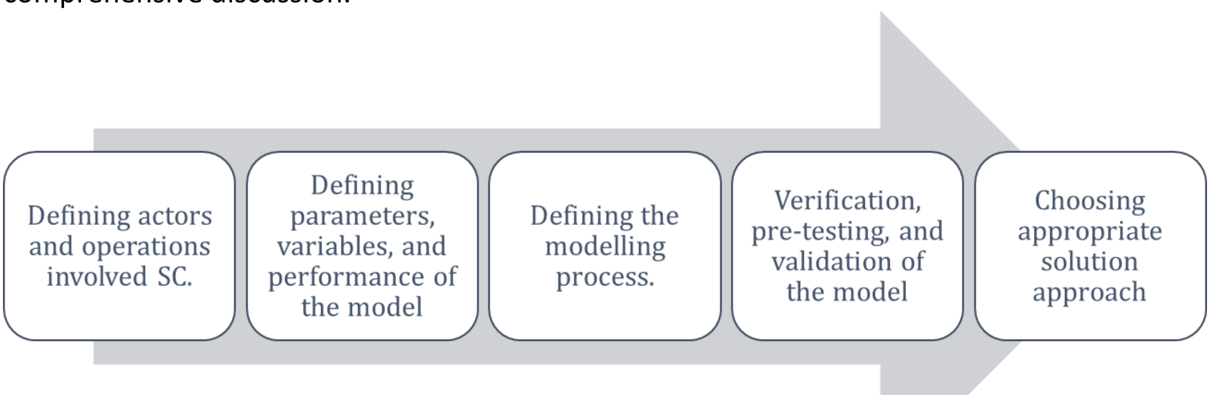

Figure 2: A proposed framework for developing sustainable quantitative decision SC model.

Defining actors and operations involved in SC

The initial step is crucial for identifying the specific actors and operations within the supply chain (SC) that necessitate improvements in terms of both economic and environmental performance. This step offers a comprehensive understanding of how modelers can make informed decisions regarding product movement and inventory management at each actor and operation throughout the SC. Furthermore, the complexity of the decision models correlates with the number of actors and operations involved in the SC. Table 1 provides an overview of SC structures based on existing literature, offering insights into the variations in the number of actors and operations observed in different SC cases under study.

Table 1
Actors and operations involved in supply chain

Author (Year)	Number of actors					Operations			
	A	B	C	D	E	W	X	Y	Z
Hua et al., (2011)				1	1	√		√	
Chaabane et al., (2012)	2	2	2	2	4	√	√	√	√
Jaber et al., (2013)	1			1	2	√	√	√	
Tseng and Hung, (2014)	3	3	2		3	√	√		√
Mohajer and Fallah., (2015)		3	2	3	3		√		√
Nouira et al., (2016)	4			2	2	√	√		√

Note: A: Supplier, B: Manufacturer, C: Distributor, D: Customer/Retailer, E: Number of echelon, W: Procurement/Purchasing, X: Production, Y: Storage, Z: Transportation.

Defining parameters, variables, and performance of the model
In the process of model development, a crucial step is to establish clear definitions for the model's parameters, variables, and performance metrics. Considering the objective of this paper, which is to enhance economic and environmental performance through managerial decision-making, it becomes imperative to identify suitable metrics that can be easily quantified. Previous studies by Chaabane et al (2012); Ahi and Searcy (2013) have provided valuable insights into the quantifiable aspects of economic and environmental performance, as depicted in Table 2.

Table 2
Economic and environmental performance in supply chain

Performance	Measurable performance
Economic	Costs, profit, inventory level, customer service level, quality, responsiveness, risk, product characteristic, return investment, and market share.
Environmental	CO_2 emission, energy use/consumption, solid wastes, water wastes/consumptions, and recycling rate.

Furthermore, it is important to acknowledge that each operation within the supply chain will have its own unique set of parameters and variables. When developing a model, it is crucial that these parameters and variables exhibit a causal relationship with performance outcomes (Seuring, 2013). In this context, variables are typically associated with the decisions made based on the model's parameters, which can directly impact performance. Moreover, the decision-making process should be hierarchical, encompassing various facets of supply chain planning, including strategic, operational, and tactical decisions. By referring to the economic and environmental performance indicators for each supply chain operation, as presented in Table 3, we can effectively define the parameters and variables within the model that correspond to each operation.

Table 3
Example of parameters and variables used in the decision model

SC operations	Parameters		Decision variables
	Economic	Environmental	
Procurement/ Purchasing	-Ordering cost -Demand -Raw material cost	-Emission tax -Emission limit -Emission penalty	-Order size -Demand -Transfer quantity of emission
Production	-Production cost -Setup cost -Production capacity -Recovery cost	-Electricity usage - tCO_2 per executing the product -fuel/gas consumption	-Production quantity -Producing time
Storage	-Holding cost -Warehouse capacity	-Electricity usage - tCO_2 per holding the product	-Inventory level of the product
Transportation	-Transportation cost -Transportation mode -Transport capacity -Distance -Weight of product	-Transportation emission/shipment - tCO_2/weight/distance -fuel consumption	-Number of deliveries -Number of vehicle -Delivery quantity

Defining the Modelling Process
A model is an abstract representation of reality. As a result, it is critical to classify modelling processes according to their purpose, type, and technique, as illustrated in Table 4. In this case, the modeller should determine the model's purpose, type, and technique for development based on the case study selected.

Table 4
The process of model development

Modelling process steps	Model categorical
Purpose	Descriptive-deterministic, descriptive-stochastic, normative-deterministic, normative -stochastic.
Type	Analytical, heuristics, hybrid, mathematical programming, simulation.
Technique	Artificial intelligence, business game, discrete-event simulation (DES), game theory, meta-heuristics, multi-criteria decision making, multi objective, simple heuristics, single objective, spreadsheet calculation, system dynamics, systemic models

Verification, Pre-testing and Validation of the Model
This step necessitates the inclusion of a numerical example along with a detailed description of the model's verification process. Verification involves the systematic identification, quantification, and rectification of coding or programming errors. The ultimate objective is to obtain a highly accurate numerical solution, ensuring that the model aligns with the modeller's conceptual framework and can be implemented correctly.

In addition, the pre-testing phase involves validating the model using its own parameters. This typically entails conducting a sensitivity analysis on the input parameter to assess the model's performance and solution behavior. Consequently, insights regarding the model's sensitivity to changes in the input parameter are derived from varying the input parameter.
Finally, the model's validation against real-world data is imperative to determine its fidelity in accurately representing the actual system. By comparing the model output with experimental data, the model's acceptability can be established, with an error margin of less than 10% or through statistical validation. The validation process often employs statistical techniques such as cross-validation, chi-square, Mann-Whitney, and t-test to ensure the model's reliability and validity.

Choosing Appropriate Solution Approach
After successfully validating the model, the subsequent step involves optimizing its performance by determining the optimal solution. It is important to differentiate between the model itself and the solution approach. While the model serves as a representation of a real-world problem, the solution approach refers to the specific methods or algorithms employed to solve the problem at hand. In this context, the modeler must carefully choose the most suitable solution approach based on the model techniques outlined in Table 5.

Table 5
Type of solution approach based on modelling technique

Modelling technique	Solution approach
Single/Multi objective	Linear programming, goal programming, dynamic programming, queuing models, non-linear programming, mixed integer linear programming.
Artificial intelligence	Petri net, case based reasoning, Bayesian networks, fuzzy logic, neural networks, rough set.
Meta-heuristic	Genetic algorithm, particle swarm optimization, differential evolution, ant colony optimization, simulated annealing
Systemic models	Life cycle analysis, input/output analysis, metrics.

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Conclusion
In this article, we put forth a framework aimed at developing a decision model for the supply chain (SC) that considers both economic and environmental factors. The framework proposed here is built upon an extensive review of the existing literature on SC decision models. The primary objective of this framework is to create a model that effectively captures the essence of the real SC system and enables the resolution of sustainability challenges. In essence, the decision-making process within this framework strives to achieve a harmonious integration of economic and environmental objectives. By providing valuable guidance to modelers, this framework contributes significantly to the development of accurate models and their solutions, thereby enhancing sustainability performance within the constraints imposed by economic and environmental considerations.

The proposed framework for developing a decision model in the supply chain, considering economic and environmental factors, carries significant theoretical and managerial implications. Theoretical implications stem from the framework's contribution to the existing knowledge base on supply chain decision models. By emphasizing the integration of economic and environmental considerations, the framework enriches theoretical understanding by providing a systematic approach for developing accurate models that represent real systems. The comprehensive perspective offered by the framework enhances understanding of the relationships between actors, parameters, variables, and performance metrics in supply chain decision-making.

From a managerial standpoint, the implications are equally profound. The framework provides practical guidance to supply chain managers, empowering them to make informed decisions that balance economic and environmental objectives. By following the structured approach outlined in the framework, managers can incorporate sustainability considerations into their decision-making processes, leading to improved sustainability performance. The identification of parameters, variables, and performance metrics specific to each supply chain operation helps managers gain insights into areas requiring improvement, enabling resource allocation and strategic decision-making that align with sustainability goals.

Moreover, the emphasis on model verification and validation against real-world data ensures the accuracy and reliability of the decision model. This instills confidence in managers, allowing them to rely on the model's guidance for decision-making processes. By leveraging the framework, managers can make evidence-based decisions that take into account both economic and environmental factors, thereby enhancing the overall sustainability of their supply chain operations.

In summary, the proposed framework carries theoretical implications by contributing to the knowledge base on supply chain decision models, while also providing practical managerial implications by guiding managers in incorporating economic and environmental considerations into their decision-making processes. The framework's systematic approach and emphasis on accuracy and reliability empower managers to improve sustainability performance and make informed decisions for their supply chains.

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