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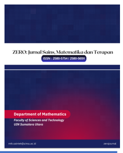

A Multi-Objective Optimization Model For Sustainable Supply Chain Network

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ABSTRACT

Sustainable supply chains provide a strategic approach to tackling global challenges associated with operational efficiency and the three dimensions of sustainability: economic, environmental, and social. This research develops a multi-objective optimization model that integrates all three elements into the supply chain network. This model encompasses objectives like profit maximization, carbon emission reduction, waste minimization, enhancement of worker welfare, and resource optimization. This model's constraints embody actual restrictions, encompassing production and distribution capacity, demand, emissions, and social welfare. This case study of Mega Motor Company demonstrates the practical use of the methodology. This model is assessed using synthetic data through the Mixed-Integer Linear Programming (MILP) approach to determine its efficacy in meeting sustainability objectives. The evaluation results indicate that this model can deliver balanced solutions to enhance long-term efficiency and sustainability. This model functions as a strategic decision-making instrument for firms aiming to thoroughly establish a sustainable supply chain system.

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1. INTRODUCTION

The supply chain is a system of activities, organizations, resources, information, and technology that are interconnected to facilitate the production and distribution of goods or services [1]. The concept of a sustainable supply chain represents a strategic strategy that integrates economic efficiency, environmental stewardship, and social considerations. The three elements serve as the fundamental pillars of sustainability that must be integrated in a balanced manner within operational processes [2].

Attaining this equilibrium is inherently challenging due to the existence of opposing objectives. For instance, the reduction of operational expenses frequently contradicts initiatives aimed at decreasing emissions or enhancing worker welfare [3]. These trade-offs affect decision-making in practical supply chain scenarios. Prior research has emphasized this concern: Ehtesham Rasi and Sohanian (2020) observed that corporations frequently prioritize financial returns at the expense of environmental and social performance, whereas Jayarathna et al. (2021) highlighted the intricacy of concurrently optimizing profit, emissions, and social effect within actual operational limitations. This highlights the necessity for a mathematical methodology adept in addressing multidimensional objectives.

Despite the increasing interest in sustainable supply chain modeling, numerous existing studies reveal significant deficiencies. This encompasses the inadequate representation of social variables, such as employee welfare, and the dependence on heuristic/metaheuristic approaches, which despite their computing efficiency do not provide global optimality. Moreover, few models explicitly integrate operational restrictions that represent actual supply chain capacities and limitations.

This research introduces a multi-objective optimization model employing Mixed-Integer Linear Programming (MILP) that simultaneously optimizes economic (profit), environmental (emissions and waste), and social (worker welfare) objectives. The model incorporates a constraint framework based on real operational data, hence improving its capacity to produce practical and optimal solutions for promoting sustainable supply chain transformation.

2. RESEARCH METHOD

2.1 Supply Chain and Its Network

The supply chain is a cohesive system comprising suppliers, manufacturers, distributors, retailers, and end consumers, designed to effectively handle the flow of commodities, information, and funds [4]. The primary aim is to enhance customer value and secure a competitive edge by effectively managing costs, time, and product quality [5]. Supply chain networks enhance this notion by highlighting the arrangement of locations and the interconnections among components inside the system. The efficacy and reactivity of the network are significantly affected by the choice of facility locations, distribution routes, and logistics strategies [6].

In that context, making optimal judgments becomes intricate as it necessitates the simultaneous consideration of multiple aspects, including production capacity, market demand, logistics expenses, and environmental consequences. This complexity necessitates the application of optimization strategies to ensure that each decision within the network, from supplier selection to distribution allocation, yields overall efficient and sustainable performance.

2.2 Sustainable Supply Chain Network

Sustainable supply chain networks encompass three characteristics of sustainability: economic, environmental, and social. In this context, concerns include not only cost efficiency but also carbon emission reduction, waste management, and the enhancement of labor welfare [7] [8]. This concept is gaining prominence as societal demands for accountable and transparent company practices escalate. Social sustainability underscores the significance of human rights, education, and justice [9]. Economic sustainability emphasizes efficiency and optimal resource utilization. Simultaneously, environmental sustainability seeks to mitigate pollution and conserve natural resources [10]. These three facets mutually reinforce one another to address present requirements without compromising the demands of future generations.

Numerous studies have formulated several methodologies for developing sustainable supply chain network models. Ehtesham Rasi and Sohanian (2020) proposed a multi-objective optimization model utilizing Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) to concurrently optimize costs, delivery time, and carbon emissions. A study conducted by Jayarathna et al. (2021) examines diverse optimization techniques employed to tackle sustainability challenges in logistics and supply chains. Awadallah et al. (2024) investigated the efficacy of the Multi-Objective Ant Colony Optimization (MOACO) method in addressing intricate optimization challenges across multiple domains, including supply chain management.

An increasing number of companies are producing sustainability reports to showcase their dedication to environmental and social concerns. This promotes increased focus on supply chain sustainability. The Sustainable Supply Chain Network incorporates environmental and social considerations at each phase of the supply chain to improve overall efficiency and performance [11]. Consequently, the formulation of a sustainable supply chain is an essential strategic choice for attaining enduring sustainability.

The objectives of the supply chain network encompass attaining competitive advantage, enhancing efficiency [12], fulfilling client requirements, maximizing revenues, and mitigating risks. These objectives can be attained by a cohesive, cooperative, and strategic methodology in supply chain management.

2.3 Multi-Objective Optimization

Multi-objective optimization is a mathematical methodology for addressing problems characterized by many, frequently conflicting objectives. This technique identifies Pareto optimal solutions that reconcile diverse objectives, including cost efficiency and reduced environmental impact, within sustainable supply chains [13].

Diverse techniques have been established to address multi-objective optimization challenges, including Mixed-Integer Linear Programming (MILP), genetic algorithms (GA), and Particle Swarm Optimization (PSO). MILP is a precise technique extensively employed in network modeling because of its capacity to manage both discrete and continuous variables concurrently [14].

MILP was selected for its capacity to deliver mathematically optimal answers, which corresponds with the aim of this research to generate dependable and accurate decisions. Despite the computational restrictions of MILP, the scope of this study is sufficiently reasonable to facilitate its practical application without imposing an undue computational cost.

Nonetheless, a trade-off exists between employing MILP and utilizing heuristic/metaheuristic approaches. MILP ensures mathematically optimal answers; yet, it necessitates substantial computing time and exhibits diminished efficiency when addressing large and intricate issues. Conversely, heuristic and metaheuristic approaches, such Genetic Algorithms, Particle Swarm Optimization, and Ant Colony Optimization, can address extensive issues with greater speed and adaptability, however they do not consistently ensure optimal solutions [15]. Moreover, heuristic approaches necessitate accurate parameter calibration to guarantee that the outcomes approximate optimality. The selection of approach is contingent upon the problem's complexity, the necessity for solution precision, and the accessibility of computer resources [16].

2.4 Research Methodology

This study employs a quantitative methodology by formulating a mathematical model utilizing Mixed-Integer Linear Programming (MILP) to enhance a sustainable supply chain network. This strategy aims to concurrently achieve three primary objectives: profit maximization, carbon emission reduction, and enhancement of social sustainability. The model is formulated as a dual objective function with linear constraints, representing actual conditions in the supply chain system, including production capacity, emission limitations, and customer demand.

The procedures implemented in this study encompass:

1. Examining obstacles in sustainable supply chain networks, encompassing cost efficiency, environmental effect, and social welfare.
2. A literature study analyzing theories pertinent to supply chain optimization, the Multi-Objective Optimization approach, and the Mixed-Integer Linear Programming (MILP) method employed in the model.
3. Formulating a multi-objective optimization mathematical model that incorporates economic, environmental, and social considerations.
4. Establishing the objective function:
   In MILP for sustainable supply chains, many objective functions are typically optimized concurrently, including:
   a. Total Profit Maximization
   b. Carbon Emission Minimization
   c. Social Sustainability Maximization
   d. Production Waste Minimization
   e. Resource Utilization Maximization
5. Identifying the restrictions employed in the model, specifically:
   Model constraints are established to guarantee that the derived solutions are operationally valid. Examples of significant constraints:
   a. Demand Limitations
   b. Production Limitations
   c. Production Capacity Limitations
   d. Distribution Capacity Limitations
   e. Carbon Emission Limitations
   f. Production Waste Limitations
   g. Resource Utilization Limitations
   h. Worker Welfare Limitations
   i. Raw Material Availability Limitations
   j. Transportation Limitations
   k. Storage Limitations at the Distribution Center
   l. Decision Variable Limitations
6. Formulation of the MILP Model
   Upon the mathematical formulation of the goal function and restrictions, a comprehensive MILP model is established, incorporating both continuous and integer variables that represent strategic and operational decisions.
7. Assessing the influence of the model on cost efficiency, environmental sustainability, and comprehensive supply chain performance.
8. Formulating conclusions derived from the research findings concerning the efficacy of the established multi-objective optimization model

3. RESULT AND ANALYSIS

A case study was conducted on Mega Motor Company to evaluate the efficacy of the created multi-objective optimization methodology. This study examines four primary components of the supply chain network: suppliers, production and warehouse facilities, distribution centers, and retailers. Each component is crucial for ensuring the seamless movement of commodities, information, and funds from upstream to downstream throughout the supply chain system.

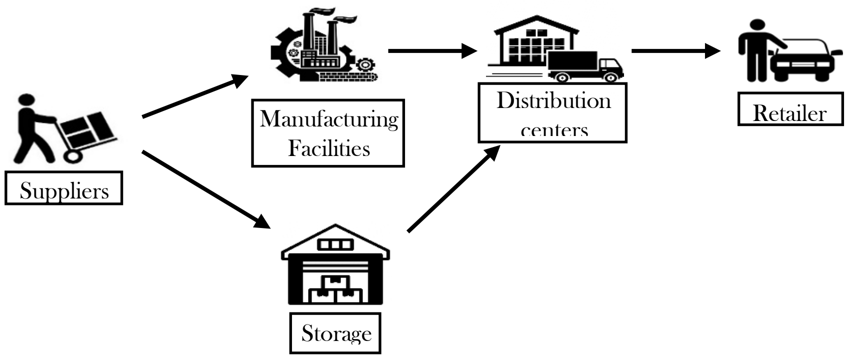

Figure 1. Design of Sustainable Supply Chain Networks

The graphic above illustrates the progression of a sustainable supply chain network originating with raw material suppliers and subsequently directed to industrial facilities or warehouses. Upon completion of processing into completed items, the goods are stored and subsequently delivered via distribution centers to merchants, serving as the final juncture before reaching customers. All elements inside this network are interlinked and function systematically to maintain operational efficiency, minimize environmental impact, and improve social dimensions. The incorporation of this flow is essential for facilitating strategic decision-making in capacity planning, distribution route selection, and sustainable supply chain management.

This study develops a multi-objective optimization model utilizing the Mixed-Integer Linear Programming (MILP) method, aimed at improving the efficiency of sustainable supply chains. This approach incorporates the three principal components of sustainability economic, environmental, and social through five objective functions: maximizing profit, limiting carbon emissions, minimizing production waste, maximizing social welfare, and optimizing resource utilization.

3.1 Problem Statement

Sustainable supply chain networks encounter difficulties in reconciling economic, environmental, and social dimensions within manufacturing and distribution processes. The primary concern in this approach is optimizing the supply chain by addressing cost efficiency, minimizing environmental impact, and improving social welfare.

This model encompasses strategic decisions such as the selection of raw material suppliers, administration of production facilities, distribution of products to distribution centers, and delivery to retailers to meet client demand. This approach concurrently optimizes multiple objective functions, including maximizing overall profit, minimizing carbon emissions, minimizing manufacturing waste, optimizing social sustainability, and maximizing resource use. This model incorporates several constraints to attain its objectives, including production capacity, distribution limitations, carbon emission thresholds, and worker welfare criteria. This model use the Mixed-Integer Linear Programming (MILP) method to generate optimal decisions that improve operational efficiency and ensure the long-term sustainability of the supply chain.

The variables and parameters employed in the multi-objective optimization model for sustainable supply chain networks are as follows:

3.2 Notation used in the multi-objective optimization model for sustainable supply chain networks

t : Time period, where t = 1, 2, ...T
j : Product, where j = 1, 2, ..,J
i : Raw materials, where i = 1, 2, ...I
s : Supplier, where s = 1, 2, ...S
f : Production facilities, where f = 1, 2, ...F
d : Distribution center, where d = 1, 2, ...D
r : Retailer, r = 1, 2, ..., R

3.3 Parameters

Economy

C_{tisf} : The expense of acquiring raw material *i* from supplier *s* for facility *f* during the time period *t*.
C_{tjfd} : The expense associated with product *j* and its distribution from facility *f* to distribution center *d* during time period *t*.
C_{tjdr} : The distribution expense of product *j* from distribution center *d* to retailer *r* within time period *t*.
P_{tjr} : The retail price of product *j* at retailer *r* during the time frame *t*.
S_{tjr} : The quantity of product *j* sold at retailer *r* during the time interval *t*.

D_{tjr} : Demand for product *j* by retailer *r* during time period *t*.
D_{tjfd} : Demand for product *j* manufactured at facility *f* and transported to distribution center *d* during time period *t*.
Environment
E_{tisf} : Carbon emissions produced from the acquisition of raw material *i* from supplier *s* to facility *f* during time period *t*.
E_{tjfd} : Carbon emissions produced from the manufacturing and distribution of product *j* from facility *f* to distribution center *d* during time period *t*.
E_{tjdr} : Carbon emissions produced during the transport of product *j* from distribution center *d* to retailer *r* over the time interval *t*.
The subsequent parameters are utilized in the Social Sustainability model:
L_{tisf} : Waste generated from raw material *i* obtained from supplier *s* to facility *f* during time period *t*.
L_{tjfd} : Waste produced during the manufacturing and distribution of product *j* from facility *f* to distribution center *d* over the time frame *t*.

The subsequent parameters are employed in the Resource Utilization model:
S_{tisf} : The use of resources from raw material *i* obtained from supplier *s* to facility *f* during time period *t*.
S_{tjfd} : The utilization of resources for the manufacturing and transport of product *j* from facility *f* to distribution center *d* during time period *t*.
S_{tjdr} : The allocation of resources in the distribution of product *j* from distribution center *d* to retailer *r* during time period *t*.
Social
W_{tisf} : Social welfare index for raw material *i* acquired from supplier *s* to facility *f* during time period *t*.
W_{tjfd} : Social welfare index for the manufacturing and distribution of product *j* from facility *f* to distribution center *d* during time period *t*.
W_{tjdr} : Social welfare index for the allocation of product *j* from distribution center *d* to retailer *r* during time period *t*.
Additional sustainability
E_{max} : Maximum carbon emissions threshold
EC_{max} : Upper limit on carbon emission costs
L_{max} : Upper threshold for manufacturing waste.
R_{min} : Minimum resource capability.
W_{min} : Restrictions on worker welfare
K_{max} : The maximum capacity of raw material *i* available from supplier *s* during time period *t*.
T_{tdj} : Maximum transportation cost capacity from distribution center *d* for product *j* in time period *t*.
S_{tdj} : The upper limit of storage capacity at distribution center *d* for product *j* in time period *t*.

3.4 Decision Variable

X_{tisf} : The amount of raw material *i* sent from supplier *s* to production facility *f* during time period *t*.
X_{tjfd} : The number of product *j* sent from facility *f* to distribution center *d* during time period *t*.
X_{tjdr} : The quantity of product *j* dispatched from distribution center *d* to retailer *r* within time period *t*.

3.5 Objective Function

The multi-objective optimization model for a sustainable supply chain network is established through five objective functions, which encompass: Total Profit Maximization, Carbon Emission Minimization, Social Sustainability Maximization, Production Waste Minimization, and Resource Utilization Maximization.

$$\max Z_1 = \sum_t \sum_j \sum_r P_{tjr} S_{tjr} - \left(\sum_t \sum_i \sum_s \sum_f C_{tisf} X_{tisf} + \sum_t \sum_j \sum_f \sum_d C_{tjfd} X_{tjfd} + \sum_t \sum_j \sum_d \sum_r C_{tjdr} X_{tjdr} \right) \quad (1)$$

$$\min Z_2 = \sum_t \sum_i \sum_s \sum_f E_{tisf} X_{tisf} + \sum_t \sum_j \sum_f \sum_d E_{tjfd} X_{tjfd} + \sum_t \sum_j \sum_d \sum_r E_{tjdr} X_{tjdr} \quad (2)$$

$$\max Z_3 = \sum_t \sum_i \sum_s \sum_f W_{tisf} X_{tisf} + \sum_t \sum_j \sum_f \sum_d W_{tjfd} X_{tjfd} + \sum_t \sum_j \sum_d \sum_r W_{tjdr} X_{tjdr} \quad (3)$$

$$\min Z_4 = \sum_t \sum_i \sum_s \sum_f L_{tisf} X_{tisf} + \sum_t \sum_j \sum_f \sum_d L_{tjfd} X_{tjfd} \quad (4)$$

$$\max Z_5 = \sum_t \sum_i \sum_s \sum_f S_{tisf} X_{tisf} + \sum_t \sum_j \sum_f \sum_d S_{tjfd} X_{tjfd} + \sum_t \sum_j \sum_d \sum_r S_{tjdr} X_{tjdr} \quad (5)$$

This model's objective functions aim to encapsulate sustainability in supply chain networks by equilibrating three primary dimensions: economic, environmental, and social. The five established objective functions represent the strategic aims of the optimized system. The primary function aims to optimize total profit by considering revenue from product sales while minimizing procurement, production, and distribution expenses. The second purpose seeks to reduce carbon emissions as an expression of environmental accountability in supply chain operations. The third function seeks to optimize social welfare, reflecting an emphasis on employee conditions and corporate social respon sibility. The fourth function aims to minimize industrial waste, hence enhancing process efficiency and mitigating adverse environmental effects. The fifth function emphasizes the optimization of renewable resources to promote the use of more sustainable raw materials. The five functions, which both complement and occasionally clash with one another, are concurrently optimized to yield balanced, realistic solutions that promote the long-term sustainability of the entire supply chain system. The five functions, which both complement and occasionally clash with one another, are concurrently optimized to yield balanced, realistic solutions that promote the long-term sustainability of the entire supply chain system.

3.6 Model Constraints

The constraints in the multi-objective optimization model for a sustainable supply chain network are as follows: Demand Limitations, Production Limitations, Production Capacity Limitations, Distribution Capacity Limitations, Carbon Emission Limitations, Production Waste Limitations, Resource Utilization

Limitations, Worker Welfare Limitations, Raw Material Availability Limitations, Transportation Limitations, Storage Limitations at the Distribution Center, and Decision Variable Limitations.

$$S_{tjr} \geq D_{tjr}, \quad \forall t, j, r \quad (6)$$

$$\sum_f X_{tjfd} \geq D_{tjfd}, \quad \forall t, j, d \quad (7)$$

$$\sum_f X_{tjfd} \leq C_{tjfd}, \quad \forall t, j, d \quad (8)$$

$$\sum_d X_{tjfd} C_{tjfd} \leq C_{tjfd}, \quad \forall f, t, j \quad (9)$$

$$\sum_d X_{tjfd} W_{tjfd} \leq W_{tjfd}, \quad \forall f, t, j \quad (10)$$

$$\sum_r X_{tjdr} C_{tjdr} \leq C_{tjdr}, \quad \forall t, d, j \quad (11)$$

$$\sum_t \sum_i \sum_s \sum_f E_{tisf} X_{tisf} + \sum_t \sum_j \sum_f \sum_d E_{tjfd} X_{tjfd} + \sum_t \sum_j \sum_d \sum_r E_{tjdr} X_{tjdr} \leq E_{max} \quad (12)$$

$$\sum_t \sum_i \sum_s \sum_f E_{tisf} X_{tisf} C_{tisf} + \sum_t \sum_j \sum_f \sum_d E_{tjfd} X_{tjfd} C_{tjfd} + \sum_t \sum_j \sum_d \sum_r E_{tjdr} X_{tjdr} C_{tjdr} \leq EC_{max} \quad (13)$$

$$\sum_t \sum_i \sum_s \sum_f L_{tisf} X_{tisf} + \sum_t \sum_j \sum_f \sum_d L_{tjfd} X_{tjfd} \leq L_{max} \quad (14)$$

$$\sum_t \sum_i \sum_s \sum_f S_{tisf} X_{tisf} + \sum_t \sum_j \sum_f \sum_d S_{tjfd} X_{tjfd} + \sum_t \sum_j \sum_d \sum_r S_{tjdr} X_{tjdr} \geq R_{min} \quad (15)$$

$$\sum_t \sum_i \sum_s \sum_f W_{tisf} X_{tisf} + \sum_t \sum_j \sum_f \sum_d W_{tjfd} X_{tjfd} + \sum_t \sum_j \sum_d \sum_r W_{tjdr} X_{tjdr} \geq W_{min} \quad (16)$$

$$\sum_s X_{tisf} \leq K_{max}, \quad \forall i, t, f \quad (17)$$

$$\sum_r X_{tjdr} C_{tjdr} \leq T_{tdj}, \quad \forall d, t, j \quad (18)$$

$$\sum_r X_{tjdr} \leq S_{tdj}, \quad \forall t, j, d \quad (19)$$

$$X_{tisf}, X_{tjfd}, X_{tjdr} \geq 0, \quad \forall t, i, j, f, d, s, r \quad (20)$$

The quantity of product j dispatched from distribution center d to retailer r within time period t. Constraints in the multi-objective optimization model for sustainable supply chain networks are essential for ensuring that the produced solutions are feasible and aligned with real-world operational realities. These constraints are intended to represent the numerous limitations frequently faced in supply chain systems, including production capacity restrictions, carbon emission thresholds, market demand, and social welfare criteria. The constraints in this model are categorized into several primary types: demand and production constraints, environmental constraints, social constraints, capacity and infrastructure constraints, and logistics and transportation restrictions. Demand and production limitations are designed to align the quantity of products manufactured with market requirements while remaining within the limits of available capacity. Environmental regulations impose maximum thresholds on carbon emissions, waste, and resource consumption to guarantee that manufacturing and distribution processes are ecologically sustainable. Simultaneously, societal limitations guarantee that worker welfare considerations are included throughout the entire supply chain process. Conversely, limitations in capacity and infrastructure inhibit the excessive utilization of raw resources, transportation, and storage facilities. Ultimately, logistical and transportation limitations guarantee that product distribution is executed efficiently, in alignment with available capacity and transportation expenses. By taking into account these diverse restrictions, the formulated model can generate optimal solutions that are both economically efficient and conducive to overall environmental and social sustainability.

The comparison of the Multi-Objective Optimization Model for Sustainable Supply Chain Networks utilizing Mixed-Integer Linear Programming (MILP) and the Multi-Objective Optimization Model employing Genetic Algorithm (GA) by Ehtesham Rasi and Sohanian (2020) reveals distinct methodologies and efficacy in attaining supply chain sustainability. The MILP model presented in this article aims to deliver exact optimal solutions by incorporating five objective functions: maximizing profit, decreasing carbon emissions, minimizing industrial waste, boosting social welfare, and optimizing resource use. This approach is highly appropriate for systems with constant parameters and well-defined solution spaces, although it becomes less effective when utilized for large-scale or dynamic issues. The model created by Ehtesham Rasi and Sohanian (2020) employs genetic algorithms and MOPSO as adaptable metaheuristic techniques for addressing large-scale and intricate optimization challenges, and it can generate Pareto solutions that provide diverse compromise options between profitability and pollution mitigation. According to the evaluation results, evolutionary algorithms and MOPSO exhibit superior efficiency regarding computing time and solution diversity, particularly for NP-hard instances, however the MILP model is more adept at delivering deterministic solutions that comply with constraint restrictions. The selection of the optimal model is contingent upon the application context: MILP excels in stable situations with stringent precision demands, whereas GA is preferable for dynamic systems characterized by numerous variables and uncertainties.

The optimization results derived from this study can be juxtaposed with data or industry benchmarks to evaluate the model's feasibility. This model's cost efficiency, carbon emission reduction, and welfare enhancement can be juxtaposed with the tangible outcomes reported by firms in automobile industry sustainability reports. The implementation of the MILP approach in extensive supply chain networks encounters considerable computational difficulties, including prolonged processing durations and substantial data demands. To address these limitations, future model development could include integration with heuristic algorithms, the application of real-time data, and more adaptive dynamic approaches, thereby producing faster and more flexible solutions in real-world conditions.

4. CONCLUSION

The research findings indicate that the formulated multi-objective optimization model effectively attained equilibrium among economic, environmental, and social dimensions in sustainable supply chain networks. The Mixed-Integer Linear Programming (MILP) method was employed to concurrently create five target functions: maximizing profit, minimizing carbon emissions, eliminating manufacturing waste, enhancing worker welfare, and optimizing resource utilization. This model's efficiency is demonstrated by its potential to produce solutions that adhere to actual restrictions, like production capacity, carbon emission limits, and social welfare requirements, while simultaneously maximizing profit according to the specified parameters.

This methodology generates plans for supplier selection and distribution routes that account for cost efficiency and environmental effect. Supplier selection considers not just the lowest price but also emissions and social welfare, thereby balancing economic efficiency with sustainability. The efficacy of the model is significantly contingent upon the quality of input data, including actual costs, pollution levels, and production capacity. Consequently, this model requires calibration using precise and regularly updated industry data. When properly calibrated, this model possesses significant potential to aid Mega Motor Company in strategic decision-making concerning eco-friendly raw materials, efficient distribution, and sustainable labor practices, thereby improving the company's operational efficiency and competitiveness in the increasingly sustainability-oriented global market.

Therefore, further research may investigate the incorporation of stochastic or dynamic components into the model to more effectively address uncertainty, along with the implementation of hybrid approaches that merge MILP with heuristic methods or machine learning. The extensive implementation of the concept in the industry could potentially gain from a modular variant, facilitating modifications according to supply chain configuration or particular sustainability objectives.

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