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Evaluation of the Environmental Performance of Supply Chain in the Automotive Industry

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ABSTRACT

In today's competitive business environment, supply chain management (SCM) has become a critical factor for organizations seeking to increase market share and enhance customer satisfaction. The nature of competition has shifted from being limited to individual companies to encompassing entire supply chains. Consequently, supply chain evaluation has emerged as one of the most vital elements in SCM, requiring continuous refinement of assessment methods and criteria. Previous studies have introduced a variety of models and approaches to evaluate supply chains; however, many of these frameworks lack comprehensiveness and fail to adequately address the evolving needs of organizations, particularly regarding environmental considerations. This study aims to fill this gap by employing Shannon's entropy technique to evaluate and rank companies operating within the automotive industry, with a specific focus on environmental performance indicators. By integrating environmental factors into the assessment process, this research contributes to a more sustainable and holistic evaluation of supply chain effectiveness. The findings indicate that Company A3 outperforms other firms in the sample, positioning itself as the most effective organization according to the selected criteria. The results provide both theoretical insights and practical implications, highlighting the importance of adopting integrated evaluation models to strengthen competitive advantage and promote sustainable practices across supply chains.

1. INTRODUCTION

The automotive industry plays a pivotal role in global economies but is also a major contributor to environmental degradation through its complex supply chains, encompassing raw material extraction, manufacturing, distribution, and end-of-life management [1]. With increasing regulatory pressures and consumer demand for sustainability, evaluating the environmental performance of automotive supply chains has become essential for reducing emissions, waste, and resource consumption [2]. Green supply chain management (GSCM) practices, such as eco-design, green

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procurement, and reverse logistics, are increasingly adopted to enhance environmental performance while maintaining economic viability [3].

Studies have shown that internal and external GSCM activities significantly impact environmental and operational performance in the automotive sector [4]. For instance, in developing countries, GSCM implementation correlates positively with firm performance, contributing to both environmental sustainability and business outcomes [5]. Process-oriented reviews highlight the integration of sustainability across supply chain stages, identifying gaps in social aspects and stakeholder collaboration [6]. Moreover, fuzzy multi-criteria decision-making methods have been employed to prioritize GSCM practices and assess their influence on performance under uncertainty [7].

Institutional pressures, including regulations and market demands, moderate the relationship between GSCM practices and environmental performance, emphasizing the need for tailored strategies [8]. In Brazil, GSCM practices align with global trends, enhancing environmental outcomes through qualitative and quantitative approaches [9]. Composite indices for sustainable supply chain performance provide integrated tools for evaluation, combining economic, environmental, and social indicators [10].

Despite these advancements, challenges remain in standardizing metrics and addressing ESG factors comprehensively [11]. This study aims to evaluate the environmental performance of supply chains in the automotive industry, proposing a framework that integrates key indicators and methodologies to guide sustainable practices.

2. LITERATURE REVIEW

Suppliers, the core (or focal) company, and customers are interconnected through the flow of information, materials, and finances. Along the value-creation path during product manufacturing, environmental and social pressures emerge at various production stages [12]. The main external drivers of the supply chain are pressures and incentives from distinct stakeholder groups primarily end consumers and regulatory authorities. When the focal company experiences environmental pressures, it often transfers part of this burden to its upstream suppliers. Environmental considerations significantly influence the sustainability of the entire supply chain. Therefore, assessing supply chain performance using the aforementioned indicators can greatly enhance production efficiency, increase customer satisfaction, and mitigate environmental anomalies.

Given the limited research in this domain, the present study seeks to evaluate the supply chain performance of automotive manufacturers based on environmental criteria by employing modern multi-criteria decision-making (MCDM) methods. The earliest foundational work on supplier selection was conducted by Dickson [13], who identified and ranked 23 evaluation criteria. According to Dickson's study, the most critical criteria were price, quality, and timely delivery [13]. Subsequently, Weber et al. (1991) conducted a comprehensive review of 74 studies and categorized the findings based on Dickson's criteria [14].

Furthering this line of research, Ho et al. (2010) [15] emphasized that the most crucial economic criteria for supplier selection include quality, followed by delivery time, price, supplier capacity, and service performance. Similarly, Liao and Kao (2011) found that quality, price, and on-time delivery are the most significant economic indicators [16]. Some studies have exclusively focused on environmental indicators. For example, Handfield and Nichols (1999) [17] gathered expert opinions using the Delphi method and utilized the Analytic Hierarchy Process (AHP) to develop decision-making criteria for buyers.

Moreover, Hsu and Hu (2009) [18] introduced new supplier evaluation metrics, particularly relevant for hazardous materials management, which include: clean material procurement, hazardous material tracking and labeling, eco-friendly product design capabilities, hazardous material volume and inventory, and regulatory compliance. Lee (2009) identified key criteria for supplier selection in high-tech industries, including pollution control capability, provision of green products, and environmental management practices [19].

3. SHANNON'S ENTROPY

Entropy theory is a fundamental concept used in decision-making studies, particularly in addressing uncertainty within multi-criteria decision-making (MCDM) problems. The entropy weight method quantitatively reflects the degree of dispersion or variation among different alternatives with respect to a particular attribute. A higher entropy value indicates lower differentiation among alternatives on that attribute, implying limited useful information and consequently a lower weight assigned to that criterion. Conversely, attributes with lower entropy values exhibit greater discriminative power and thus receive higher weights, signifying their importance in the decision-making process.

To determine the weights of the criteria using the entropy method, the following computational steps are adopted:

Step1: Normalize the decision matrix.

Set: $for\ x_{ij} > 0 \ \rightarrow \ P_{ij} = \frac{x_{ij}}{\max_{j=1} x_{ij}}$

$for\ x_{ij} \le 0 \ \rightarrow \ P_{ij} = \frac{x_{ij}}{\min_{j=1} x_{ij}}$

To ensure comparability among different criteria, the raw data must first be normalized. This step is essential for eliminating inconsistencies arising from varying measurement units and scales across the dataset. Normalization transforms all criteria into dimensionless values within a common scale, thereby enabling objective comparison among alternatives. This process ensures that no single criterion disproportionately influences the analysis due to its unit or scale.

Step2: Compute entropy h_i as

$h_i = -\ h_0 \sum_{j=1}^{m} p_{ij}.Ln\ p_{ij}$ i=1,2,…,n

where h_0 is the entropy constant and is equal to $(Ln\ m)^{-1}$ and $p_{ij}.Ln\ p_{ij}$ is defined as 0 when p_{ij} =0.

Step 3: Set $d_i = 1 - h_i$,i = 1,2,…,n as the degree of diversification.

Step 4: Set $w_i = \frac{d_i}{\sum_{s=1}^{n} d_s}$ i=1,2,..,n as the degree of importance of attribute i.

4. TOPSIS

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is widely recognized as one of the most effective Multi-Attribute Decision-Making (MADM) methods for addressing complex, real-world decision problems [20]. Introduced by Hwang and Yoon (1981) [21], TOPSIS is based on the idea that the optimal choice should be the alternative that lies closest to the Positive Ideal Solution (PIS) and simultaneously farthest from the Negative Ideal Solution (NIS) [22].

The Positive Ideal Solution serves as a hypothetical reference point that maximizes benefit criteria while minimizing cost criteria. In contrast, the Negative Ideal Solution represents the scenario that minimizes benefit criteria and maximizes cost criteria [23]. Put simply, the PIS consists of the most favorable values achievable across all criteria, whereas the NIS corresponds to the least favorable values [24].

The application of TOPSIS involves the following procedural steps:

Step 1: Formation of the normalized decision matrix.

This initial step standardizes the varying attribute values into dimensionless quantities, thereby enabling a consistent basis for comparison across different criteria.

Step 2: Development of the weighted normalized decision matrix.

Here, the normalized values are adjusted by multiplying them with the assigned weights of each respective criterion. The weighted normalized value vij is computed as:

$$r_{ij} = X_{ij} / \sqrt{\sum_{i=1}^{n} X_{ij}^2}\ , \forall i, j \quad (1)$$

Where w_j is the weight of the jth criterion, and $\sum_{i=1}^{m} w_j = 1$

$$v_{ij} = w_j . r_{ij} \ , \forall i,j \quad (2)$$

Step 3: Determine the ideal and negative-ideal solution.

$$A^{*}=\{v_1^{*}, \dots, v_m^{*}\}=\left\{\left(\max_i v_{ij} \,\middle|\, j\epsilon C_h\right), \left(\min_i v_{ij} \,\middle|\, j\epsilon C_c\right)\right\} \quad (3)$$

$$A^{-}=\{v_1^{-}, \dots, v_m^{-}\}= \left\{\left(\min_i v_{ij} \,\middle|\, j\epsilon C_h\right), \left(\max_i v_{ij} \,\middle|\, j\epsilon C_c\right)\right\} \quad (4)$$

Where C_b corresponds to benefit criteria and C_c corresponds to cost criteria.

Step **4:** Calculate the separation measures of each alternative from the Positive Ideal Solution (PIS) and the Negative Ideal Solution (NIS) using the following formulas:

$$S_i^{*} = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^{*}\right)^2} \ , \forall i \quad (5)$$

Similarity, the separation from the negative-ideal solution is given as

$$S_i^{-} = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^{-}\right)^2} \ , \forall i \quad (6)$$

Step 5: Calculate the relative closeness of each alternative A_i to the Positive Ideal Solution A^* using the formula below:

$$CC_I^{*} = \frac{S_i^{-}}{S_i^{*} + S_i^{-}} , \forall i \quad (7)$$

Step 6: Determine the Ranking of Alternatives.

The relative closeness index values, denoted as CC_I^*, fall within the range of 0 to 1. A higher value signifies that the alternative is closer to the positive ideal solution, indicating a greater preference or suitability.

5. 4APPLICATION

This study aims to evaluate the environmental performance of the supply chains of four automotive companies. Initially, relevant environmental indicators are calculated for each firm. To assign objective weights to both the primary criteria and their sub-criteria, Shannon's entropy method is utilized. Subsequently, the TOPSIS technique is employed to analyze and rank the automotive firms' environmental performance based on the weighted criteria.

Table 1. classified indicators for confirmation by experts

Indicators
Cooperation with research institutes and laboratories
Green operational efficiency
Green transportation
Green recycling facilities
Carbon reduction initiatives
The company's environmental commitment
Green operating method
Reducing material and energy consumption through better product design
Developing products with design features that facilitate ease of reuse and recyclability
Designing energy efficient products

According to Shannon method, we calculate the values of h_i ,d_i and w_i, which are presented in Table 2.

Table 2. Values of h_i ,d_i and w_i for Each Criterion

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A1	1	1	0.83	1	1	1	0.84	0.59	0.29	0.17
A2	0.68	0.64	1	0.72	0.72	0.38	1	0.4	0.55	0.64
A3	0.09	0.09	0.18	0.45	0.33	0.18	0.81	0.6	0.62	1
A4	1	1	0.63	0.26	0.18	0	0.86	0.4	1	1
E	-0.47	-0.50	-0.48	-0.94	-0.91	-0.67	-0.19	-0.81	-0.36	-0.06
d	1.47	1.50	1.48	1.94	1.91	1.67	1.19	1.81	1.36	1.06
W	0.095743	0.097256	0.09634	0.125983	0.123714	0.108521	0.077344	0.117495	0.088446	0.06916

Following the determination of criteria weights via Shannon's entropy method, the criterion values for each firm are computed. Within the TOPSIS framework, the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) are established by selecting the maximum and minimum values for each criterion, respectively. Subsequently, the distances of each firm from the PIS and NIS are calculated using Equations (5) and (6). The closeness coefficient for each firm is then derived according to Equation (7), which serves as the basis for ranking the firms. The resulting rankings of the automotive companies are summarized in Table 3.

Table 3. Rankings of Automotive Firms Based on CC_i Values

firms	CC_i	Ranking
A1	0.53	3
A2	0.72	2
A3	0.81	1
A4	0.39	4

6. CONCLUSION

According to the findings and results obtained from this research, practical suggestions can be made as follows: • Considering the importance and wide effects of the issue of evaluating the supply chain of automotive companies based on environmental indicators, it is suggested that industrial units in the research and development department or in the department of communication with their universities and scientific centers, look for the structure and criteria for the evaluation of the supply chain. Automobile companies should be least influenced by conditions, personal interests and even individual opinions of experts. • The people involved in the supply chain assessment process should be controlled and, if possible, have maximum impartiality and minimal relationships. • Also, the design of software expert systems that can test the ranking of options based on different ranking methods by surveying experts regarding options based on specified indicators and preferably provide the required sensitivity analysis.

Declaration

We acknowledge that we used ChatGPT to enhance the academic writing of our manuscript while ensuring the originality and integrity of our work.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

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Declaration of Interest

The authors declare that they have no competing interests.

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