Strategic Decision-Making for Shipping Line Selection using Fuzzy AHP and MOLP

Sheryn Dian Permata[1] and Moses Laksono Singgih[2]

[1,2] Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
sheryn.permata@gmail.com

Abstract. Transportation is a crucial element in the supply chain. Over 80% of international trade goods by volume are transported by sea. The critical role of maritime transportation underscores the importance of strategic decision-making in selecting reliable and efficient shipping lines. The Tobacco Company (TC) case, which produces and distributes tobacco products globally, has been taken as an illustration of the lack of standardized criteria for selecting shipping lines, leading to significant delivery delays. This study aims to develop these standardized criteria by surveying five internal experts who assessed four shipping companies based on four main criteria and twelve sub-criteria. Analytical Hierarchy Process with Fuzzy logic accommodates subjectivity in decision-making and provides a clear and systematic approach to prioritizing factors. Subsequently, Multi-Objective Linear Programming was employed to identify the optimal shipping line that best met the company's priorities while addressing trade-offs between different factors. The analysis reveals that reliability in on-time delivery, total transit time, and space availability are the top priorities in shipping line selection, with transportation cost being the least prioritized. As a result, Shipping Line C emerged as the optimal choice, supporting the company's strategic goals.

Keywords: Decision-Making, Shipping Line, Supply Chain

1 Introduction

Transportation is a crucial element in the supply chain, particularly for the shipment of goods in the trade industry. Transportation and trade are closely interrelated, with transportation supporting the distribution of trade and trade sustaining the transportation industry [1]. According to UNCTAD, over 80% of the volume of international trade goods is transported by sea, which is even higher in developing countries due to relatively low shipping costs [2]. The tobacco company (TC) produces and distributes tobacco products to various countries. To optimize the supply chain and achieve customer satisfaction, TC partners with shipping service providers for export-import goods by sea. Choosing the right partners is crucial in facing global market competition to ensure products arrive efficiently and on time according to consumer demand. TC, which serves customers in various countries with over 60 sea routes, must wisely select shipping partners to ensure efficient transportation, reduced shipping

T. Amrillah et al. (eds.), *Proceedings of the International Conference on Advanced Technology and Multidiscipline (ICATAM 2024)*, Advances in Engineering Research 245,
https://doi.org/10.2991/978-94-6463-566-9_21

subjective due to a lack of standardized evaluation criteria, leading decision-makers to rely on personal preferences. The absence of clear, standardized criteria has resulted in frequent requests to change shipping vendors even before contracts end, as previously selected vendors often fail to meet TC's needs and expectations. Selecting vendors primarily based on cost has led to delayed deliveries, affecting TC's supply chain performance. Delivery performance on this route has declined by 12% due to average delays of nearly two weeks. Mid-contract vendor changes impact procurement strategies, budgets, and internal and external partnerships.

This study aims to evaluate TC's transportation procurement system, establish standardized criteria for selecting shipping lines, and determine optimal allocations for each chosen vendor. It employs a Multi-Criteria Decision Making (MCDM) approach using Fuzzy Analytical Hierarchy Process (FAHP) and Multi-Objective Linear Programming. MCDM helps identify the best alternative among suitable options and allows for the simultaneous assessment of numerous strategic and operational factors involving multiple decision-makers [3].

2 Literature Review

2.1 Decision Making

The decision-making process is one of the most essential elements in management within organizations today, mainly because it affects the success or failure of the entity [4]. Decision-making is a process undertaken by individuals, groups, or organizations to reach conclusions about future actions, considering a set of goals and constraints on available resources. This process is often iterative, involving issue formation, information gathering, reaching conclusions, and learning from experience [5]. Making decisions without errors in real life is unrealistic because every decision has some side effects. However, considering various determining factors and the pros and cons of each option significantly increases the likelihood of making the right decision [6].

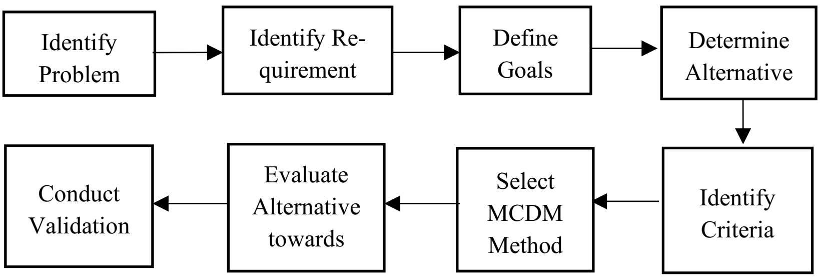

Fig. 1. Decision-Making Process

Multi-Criteria Decision Making (MCDM) is a well-known branch of decision-making that evaluates alternatives based on two or more criteria [7]. One complexity and controversy in MCDM is determining the decision-making criteria. No single alternative will be the best for all objectives, necessitating a comparison among alternatives. The best alternative will be the one that most closely meets the desired objectives.

2.2 Criteria of Shipping Line Selection

Vendor selection decision-making involves a series of complex steps. Technology plays a role in providing data support and analysis in vendor selection decisions. Digital platforms and data analytics can provide better insights and understanding to support more informed decisions [8]. Monczka et al. present that selected suppliers should align with the company's business strategy and long-term goals [9]. Many companies struggle to identify essential criteria in supplier selection to improve their supply chain performance [10]. Based on a literature review by previous researchers, the following are the criteria identified as determinants in shipping line selection. Table 1 shows the criteria used by previous researchers to select shipping lines.

Table 1. Criteria and Sub-criteria of Shipping Line Selection.

Criteria	Subcriteria	Article
Transportation Reliability	On-Time Reliability	[10], [11], [12], [13], [14], [15]
	Cargo Security	[10], [11], [12], [13], [14], [15]
	Historical Operational Performance	[12], [16]
	BL Accuracy	[11], [12], [15]
Quickness and Service Quality	Total Transit Time	[10], [11], [12], [14], [15], [16], [17], [18]
	Schedule Frequency	[11], [12], [13], [15], [17]
	Container Quality	[12], [13], [15], [16], [17]
	Ability to Handle Special Requests or Emergencies	[10], [11], [17], [18]
Capacity	Container Availability	[11], [15], [17]
	Space Availability	[11], [12]
	Demurrage and Detention Free Time	[11], [13], [15]
Cost	Shipping Cost	[10], [12], [14], [15], [16], [17], [18]

2.3 Fuzzy Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is a decision-making method developed by mathematician and management scientist Thomas L. Saaty in 1980 [19]. AHP is used to address complexity and uncertainty in decision-making by involving multiple criteria and alternatives. Some problems require quick decisions, but the available data is not always quantitative; it can also be qualitative, based on perception, experience, and intuition. Zadeh introduced the fuzzy set theory using linguistic terms and membership degrees to handle the inherent uncertainty in human judgment during decision-making.

Therefore, Saaty developed a value scale to express pairwise comparisons [20]. This scale is a range of numbers from 1 to 9, with each number expressing relative importance. Saaty created a pairwise comparison scale, as shown in Table 2 below.

Table 2. Intensity Scale of Pairwise Comparisons.

Intensity of Importance	Interpretation
1	Both elements are equally important
3	One element is slightly more important than the other
5	Judgments and experience indicate that one element is much more important than the other
7	One element is very strongly or significantly more important than the other
9	One element is more important than the other
2,4,6,8	Intermediate values between the two adjacent judgments

2.4 Multi-Objective Linear Programming

Multi-Objective Linear Programming (MOLP) is an optimization approach that considers multiple objectives [21]. A linear programming model consists of three essential components: decision variables to be determined, optimization objectives (maximizing or minimizing), and constraints that the solution must satisfy. The general form of an MOLP problem can be expressed as,

$$Max\ (or\ Min)\ Z = \ (Z_1, Z_2, \ldots, Z_k) \tag{1}$$

subject to:

$$Ax \leq \ b \tag{2}$$

$$x \ \geq \ 0 \tag{3}$$

where,
Z_1 represents the ith objective function.
A is a matrix of coefficients for constraints.
$\boldsymbol{x}$ is the vector of decision variables.
b is the vector of constraints' right-hand side values.
k is the number of objective functions.

This study solves the MOLP problem using the Weighted Sum Method by assigning weights to each objective and combining them into a single objective function.

$$Max\ (or\ Min)\ Z = \sum_{i=1}^{k} (w_i Z_i) \tag{4}$$

3 Research Methodology

Fuzzy AHP requires expert judgment to determine the relative weights of each criterion and alternative. Therefore, this study used a questionnaire to collect data from experts with relevant backgrounds, knowledge, and experience, as shown in Table 3. Two kinds of questionnaires are used in this research: an initial questionnaire and a pairwise comparison questionnaire. The first questionnaire used a Likert scale, presenting a comprehensive list of criteria for shipping line selection. The pairwise comparison questionnaire is a more detailed survey used after refining the criteria based on the initial questionnaire's results. This questionnaire aims to determine the relative importance of each criterion by comparing them in pairs.

Table 3. Decision Makers and Work Experience.

Respondent	Work Experience
DM 1	17 years
DM 2	15 years
DM 3	10 years
DM 4	13 years
DM 5	17 years

The steps to do the analysis using an integrated Fuzzy Analytical Hierarchy Process and Multi-Objective Linear Programming are as follows:

1. Define the respondents as the decision makers containing a group of experts.
2. Identify criteria from previous research.
3. Design the initial questionnaire and conduct the survey.
4. Analyze responses to validate criteria to be used in the analysis.
5. Construct a hierarchical structure.
6. Create a pairwise comparison questionnaire based on the hierarchical structure.
7. Distribute the questionnaire and collect the data.
8. Transform the pairwise comparison data into fuzzy numbers.
9. Build a fuzzy comparison matrix and calculate the weights.
10. Calculate the inconsistency ratio (acceptable if below 10%)
11. Normalize weights and rank the criteria.
12. Evaluate shipping line alternatives.
13. Formulate a multi-objective linear programming model incorporating the criteria weights.
14. Define the objectives and constraints.
15. Solve Multi-Objective Linear Programming problems using the Weighted Sum method and obtain the optimal solution.

4 Analysis and Findings

4.1 Fuzzy Analytical Hierarchy Process

The fuzzy pairwise comparison among the criteria is a fundamental step in the FAHP process. This step involves comparing each criterion with every other criterion using linguistic terms that reflect their relative importance. By conducting fuzzy pairwise comparisons, decision-makers can capture subjective preferences more accurately, allowing for a more nuanced and realistic prioritization of criteria. The resulting fuzzy comparison matrices form the basis for calculating the fuzzy weights of each criterion, ultimately influencing the overall decision-making process (see Table 4).

Table 4. Weight Calculation for Main Criteria.

Criteria	Transportation Reliability	Quickness and Service Quality	Capacity	Cost	Weight
Transportation Reliability	1	2.35	4.11	6.55	0.51
Quickness & Service Quality	0.43	1	2.91	5.57	0.30
Capacity	0.24	0.34	1	4.96	0.14
Cost	0.15	0.18	0.20	1	0.05

Inconsistency Ratio = 0.076.

According to Table 4, it is known that transportation reliability is the highest priority criterion, as it has the most significant weight of 0.51, and the second priority is quickness and service quality, with a weight of 0.30. This weight indicates that the company prioritizes ensuring timely deliveries, essential for maintaining a responsive and dependable supply chain. The second priority, quickness and service quality, reflects the company's focus on speed and excellence in service delivery. This criterion enables the company to respond swiftly to dynamic market demands and changes, enhancing its ability to adapt and remain competitive.

Table 5. Weight Calculation for Transportation Reliability.

Subcriteria	On-Time Reliability	Cargo Security	Historical Operational Performance	BL Accuracy	Weight
On-Time Reliability	1	3.71	5.26	5.79	0.60
Cargo Security	0.27	1	0.65	3.47	0.16
Historical Operational Performance	0.19	1.54	1	2.61	0.17
BL Accuracy	0.17	0.29	0.38	1	0.07

Inconsistency Ratio = 0.069.

Table 5 shows the pairwise comparison of each subcriteria under the main criteria of transportation reliability. It confirms that on-time reliability, with a weight of 0.60, is the top criterion, aligning with the conclusion from Table 4. This result indicates that ensuring shipments consistently arrive on schedule is paramount for TC's supply chain strategy. Historical operational performance and cargo security, with weights of 0.17 and 0.16, respectively, are also important, reflecting the need for dependable past performance and secure transportation of goods.

Table 6. Weight Calculation for Quickness and Service Quality.

Subcriteria	Total Transit Time	Shipping Frequency	Container Quality	Ability to Handle Emergencies	Weight
Total Transit Time	1	2.60	2.46	2.37	0.42
Shipping Frequency	0.39	1	1.63	0.47	0.16
Container Quality	0.41	0.61	1	0.21	0.11
Ability to Handle Emergencies	0.42	2.11	4.79	1	0.31

Inconsistency Ratio = 0.085.

Table 6 highlights that TC prioritizes minimizing transit times and ensuring flexibility in handling emergencies, reflecting the need for speed and flexibility and quick response to unforeseen situations while transporting the cargo. Subsequently, Table 7 shows the pairwise comparison matrix of capacity. These priorities indicate that TC values having enough shipping space and container resources to maintain a smooth and cost-effective supply chain, ensuring that goods are shipped without delays or interruptions.

Table 7. Weight Calculation for Capacity.

Criteria	Container Availability	Space Availability	Demurrage & Detention Free Time	Weight
Container Availability	1	0.33	0.84	0.17
Space Availability	3	1	6.27	0.68
Demurrage & Detention Free Time	1.18	0.16	1	0.15

Inconsistency Ratio = 0.085.

Overall, the pairwise matrix analysis across different criteria reveals that inconsistency ratios are below the commonly accepted threshold of 10%. The relatively low inconsistency ratios suggest that the decision-makers' judgments are logically consistent and trustworthy, ensuring no significant contradictions exist in the assessment process and making the FAHP result of final rankings and priorities credible.

Table 8. Final Framework for Shipping Line Selection.

Criteria	Sub-Criteria	LW	GW	Rank
Transportation Reliability (0.51)	On-Time Reliability	0.595	0.302	1
	Cargo Security	0.162	0.082	6
	Historical Operational Performance	0.173	0.088	5
	BL Accuracy	0.069	0.035	8
Quickness and Service Quality (0.30)	Total Transit Time	0.425	0.125	2
	Shipping Frequency	0.161	0.047	7
	Container Quality	0.105	0.031	9
	Ability to Handle Emergencies	0.309	0.091	4
Capacity (0.14)	Container Availability	0.170	0.025	10
	Space Availability	0.682	0.100	3
	Demurrage & Detention Free Time	0.148	0.022	11
Cost (0.05)	Cargo Transportation Cost	0.050	0.003	12

The global weighting in the final framework reflects the company's focus on reliability, speed, and capacity while placing less emphasis on cost. The low priority given to cost in TC's shipping line selection is strategically aligned with the characteristics of their market. In a competitive environment where customers can easily switch brands if products are out of stock, ensuring reliable and timely deliveries is crucial to maintaining market trust. By prioritizing reliability over cost, TC mitigates the risk of stock-outs and avoids losing customer confidence, thereby supporting a more resilient and customer-focused supply chain.

Table 9. Weight and Ranking of Alternatives.

Alternative	Weight	Ranking
Shipping Line A	0.268	3
Shipping Line B	0.178	4
Shipping Line C	0.278	1
Shipping Line D	0.276	2

The analysis of the weights for each shipping line alternative shows that Shipping Line C has the highest weight of 0.278, making it the top choice among the alternatives. Shipping Line D is a close second with a weight of 0.276. Shipping Line A and B rank third and fourth with weights of 0.268 and 0.178, respectively. This ranking indicates that Shipping Line C is the most favorable option based on the weighted criteria, closely followed by Shipping Line D, while Shipping Line A and B are less preferable. These rankings are derived from the overall weighting and prioritization of various criteria when selecting a shipping line.

4.2 Multi-Objective Linear Programming

To determine the optimal choice among the four ranked shipping lines, further analysis was conducted using MOLP with the following objective functions.

Z_1 maximizes on-time reliability

$$Max\ Z_1 = 0{,}5x_1 + 0{,}74x_3 + 0{,}56x_4 \quad (5)$$

Z_2 minimizes total transit time

$$Min\ Z_2 = 23x_1 + 35x_2 + +21x_3 + 19x_4 \quad (6)$$

Z_3 maximises demurrage and detention

$$Max\ Z_3 = 28x_1 + 21x_2 + +28x_3 + 28x_4 \quad (7)$$

Z_4 minimises transportation cost

$$Min\ Z_4 = 2994x_1 + 2492x_2 + +1526x_3 + 2035x_4 \quad (8)$$

Subject to,

$$x_1 + x_2 + x_3 + x_4 = 150 \quad (9)$$

$$x_1, x_2, x_3, x_4 \geq 0 \quad (10)$$

where,
x_1 = total containers per year allocated to Shipping Line A
x_2 = total containers per year allocated to Shipping Line B
x_3 = total containers per year allocated to Shipping Line C
x_4 = total containers per year allocated to Shipping Line D

The MOLP analysis results in Table 10 show that the optimal solution for shipping line allocation is to select Shipping Line C exclusively, with a total allocation of 150 containers. This decision yields an optimum value of 1973.35. The allocation effectively utilizes the chosen shipping line to maximize the overall objective, reflecting Shipping Line C's superior performance in meeting the criteria established for the selection process. This conclusion supports the earlier findings that Shipping Line C is the most suitable option, aligning with TC's strategic focus on reliability and efficiency.

Table 10. Weight and Ranking of Alternatives.

x_1	x_2	x_3	x_4	Optimum Value
0	0	150	0	1973.35

5 Conclusion

The analysis reveals that the most critical criteria for selecting a shipping line are reliability of on-time delivery (GW=0.302), total transit time (GW=0.125), and space availability (GW=0.10). The other criteria considered in the selection of shipping line are the ability to handle special requests or emergencies (GW = 0.091), historical operational performance (GW = 0.088), cargo security (GW = 0.082), shipping frequency (GW = 0.047), the accuracy of Bill of Lading (GW = 0.035), container quality (GW = 0.031), container availability (GW = 0.025), free time demurrage and detention (GW = 0.022), and the lowest priority criterion is cargo transportation cost (GW = 0.003). Notably, cargo transportation cost is the least essential criterion, indicating that the ability to maintain supply chain reliability and responsiveness outweighs cost considerations for TC. This strategic approach ensures that the company can meet consumer demands promptly while maintaining operational stability and stock levels in the market. Shipping Line C, scoring highest at 0.278, reflects an optimal solution, ensuring efficient resource use and a responsive approach to market needs, strengthening TC's supply chain strategy.

Acknowledgments. The authors would like to express their gratitude to all those who contributed to the completion of this study. Special thanks are extended to the respondents for their expertise and valuable insights throughout the research process.

Disclosure of Interests. The authors declare no conflicts of interest. The research was conducted independently, and the results presented in this article reflect the authors' analyses and conclusions. No external funding was received for this study.

References

1. BPS. Impor Menurut Moda Transportasi 2019-2020. BPS- Indonesia, Jakarta (2021)
2. UNCTAD. Review of Maritime Transport 2023. United Nations Publications, New York (2023)
3. Saghafian, S. & Hejazi, S. R. Multi-criteria Group Decision Making Using A Modified Fuzzy TOPSIS Procedure. in International Conference on Computational Intelligence for Modelling, Control, and Automation, and International Conference on Intelligent Agents, Web Technologies and Internet Commerce (CIMCA-IAWTIC'05) (2005)
4. Kozioł-Nadolna, K. & Beyer, K. Determinants of the decision-making process in organizations. in Procedia Computer Science vol. 192 2375–2384 (2021)
5. Schoemaker, P. J. H. & Russo, J. E. Decision-Making. in The Palgrave Encyclopedia of Strategic Management (2017)
6. Taherdoost, H. & Mitra Madanchian. Decision Making: Models, Processes, Techniques. Cloud Computing and Data Science 1–14 (2023)
7. Wang, R. & Kwong, S. Active Learning with Multi-Criteria Decision Making Systems. Pattern Recognit 47, 3106–3119 (2014)
8. Chopra, Sunil. Supply Chain Management : Strategy, Planning and Operation. Pearson Education (2019)
9. Monczka, R. M. and H. R. B. and G. L. C. and P. J. L. Purchasing and Supply Chain Management. Cengage Learning (2015)
10. Shen, L., Mathiyazhagan, K., Kannan, D. & Ying, W. Study on Analysing the Criteria For Selection of Shipping Carriers in Chinese Shipping Market Using Analytical Hierarchy Process. International Journal of Shipping and Transport Logistics 7, 742–757 (2015)
11. Wen, C.-H. & Huang, J.-Y. A Discrete Choice Model of Ocean Carrier Choice. Journal of the Eastern Asia Society for Transportation Studies 7, 795–807 (2007)

12. Lu, J. L. Investigating Critical Factors that Influence Shippers' and International Freight Forwarders' Preferences in Carrier Selection Using Integrated Hierarchical Information Integration Approach. Journal of Marine Science and Technology (Taiwan) 21, 182–190 (2013)
13. Fanam, P. D. & Ackerly, L. Evaluating Ocean Carrier Selection Criteria: Perspectives of Tasmanian Shippers. Journal of Shipping and Trade 4 (2019)
14. Hsu, C. L. & Ho, T. C. Evaluating Key Factors of Container Shipping Lines from the Perspective of High-Tech Industry Shippers. Journal of Marine Science and Technology (Taiwan) vol. 29 30–41. Preprint (2021)
15. Ergin, T. H. O. R. S. A., Feizollahi, M. J. & Kutlu, C. Ocean Container Carrier Selection Using Fuzzy TOPSIS Method: Customers' Perspective. Mar Technol Soc J 56, 59–71 (2022)
16. Jumandono, M. & Singgih, M. L. Selection of Shipping Container Vendors Using Analytical Hierarchy Process (AHP). in IPTEK Journal of Proceedings Series (2019)
17. Solakivi, T. & Ojala, L. Determinants of Carrier Selection: Updating the Survey Methodology into the 21st Century. In Transportation Research Procedia vol. 25 511–530. Elsevier BV (2017)
18. Cahoon, S., Fanam, P. D. & Nguyen, H. O. An Empirical Analysis of the Critical Selection Criteria of Liner Operators: The Perspective of Freight Forwarders. International Journal of Shipping and Transport Logistics 10, 567 (2018)
19. Liu, Y., Eckert, C. M. & Earl, C. A Review of Fuzzy AHP Methods for Decision-Making with Subjective Judgements. Expert Systems with Applications vol. 161. Preprint (2020)
20. Saaty, R. W. The Analytic Hierarchy Process-What It Is and How It Is Used. vol. 9 (1987)
21. Sakawa. M. Fuzzy Sets and Interactive Multi-objective Optimization. (1993)