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A HYBRID MCDM METHOD TO EVALUATE SUPPLY-CHAIN DEVELOPMENT STRATEGIES

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ABSTRACT

Global logistics and outsourcing have become an irreversible industrial development trend in today's technology industry. Previous studies differ on supplier selection, supplier development, and supply-chain performance assessment evaluation methods. Research suggests that outsourcing is not only a program of options, but also results in different operating performances based on varying company supply-chain strategies. To build a competitive supply chain, companies must conduct a comprehensive assessment and develop a clear and explicit supply-chain development strategy. This research derives a composite method for assessing supply-chain strategy. A decision-making trial and evaluation laboratory method first clarify six major areas of supply-chain strategy assessment, and then draw a network impact-relationship map based on the direction of influence and extent of the impact in each area. An analytic network process then captures the interdependence between the evaluating factors, and identifies the relative weight of these criteria for each major factor in the supply-chain development strategy. Finally, the study develops an effective supply-chain strategy decision-making assessment model to help companies select an optimal strategy. Examining the world's top 4 TFT-LCD factories validates the results of this study.

KEYWORDS

Supply-chain development strategy; analytic network process; multiple criteria decision making; decision-making trial and evaluation laboratory method.

1. INTRODUCTION

With a gradual increase in the liberalization of global trade competition in a dynamic business environment, competitive advantages often result in the efficient use of existing resources. Whereas companies consider the overall use of resources or potential resources available, suppliers often play a major role as external resource providers in increasing company competitiveness, especially in a company group where the scale of intergroup competition is more significant. Supplier competitiveness has a positive influence on business performance because poor supplier management has adverse effects on long-

term business performance and market value (Williamson 1985, Buvik 2000, Burke et al. 2006, Chow et al. 2008). Logistics costs significantly undermine the comparative advantages of international trade and limit the attraction to FDI (Liao and Hu, 2012)

Many studies focus on suppliers or supply-chain management. Studies that examine supplier selection process discuss methods, criteria, or guidelines used in choosing suitable suppliers. A number of studies have investigated supplier development. By understanding how supplier performance affects enterprise competition, appropriate and effective measures can be taken to improve the overall performance of suppliers and business, contributing positively to enterprise competitiveness. (Hoecht and Trott 2006, Liou et al. 2007). Creating or building a supply chain is time consuming and often requires months or even years. Therefore, appropriate use of methods or models to develop supply chains that meet a company's short-, medium-, and long-term operational requirements are crucial factors in strengthening and maintaining operational competitiveness. (Huang et al. 2003)

Unlike previous research on the development of individual suppliers, this study proposes a method to guide the electronic manufacturers to evaluate an effective development strategy and build a comprehensive supply chain. This study incorporates the decision-making trial and evaluation laboratory (DEMATEL) method and an analytic network process (ANP) to establish the evaluation methods in the development of a supply-chain strategy. This reduces the gap between desire and expectation levels in each implementation and enhances competitive standards.

2. LITERATURE REVIEW

Many issues surround the role of suppliers in supply-chain management.

2.1 Make or buy

Culliton (1942) and Gambino (1980) determined that a company should explore internal and external procurement-related costs and quantitative indicators. Based on the data collected, the company can then respond appropriately to the solution with the lowest costs. Hubler (1966) found that applying break-even and marginal cost analysis to internal and external procurements can result in optimal decisions. Cost-related research has been conducted on non-cost factors, such as R&D and technology. Hippel (1988) indicated that obtaining external R&D technology or resources can reduce R&D investment costs, labor requirements, and equipment requirements.

2.2 Supplier Selection

The literature on methods of selecting suppliers in various fields is abundant. Sanjay (2007) applied the ANP to develop 23 crucial criteria for logistics service providers. Lee et al. (2001) discovered that factors affecting management are quality, cost, delivery, and service standards, which are also the main criteria for supplier selection, supplier performance, and the subsequent assessment of supplier performance. Gunasekaran et al. (2001) proposed a process-based performance evaluation system, and provide a convenient form of evaluation.

2.3 Supply-chain development strategy

Porter (1980) combined competitive analysis and supply-chain strategy to identify the different forms of competition and the three related supply-chain strategies. The first supply-chain strategy is full integration, where an enterprise meets their own demands through internal resources and procedures, and not through external or market mechanisms. The second strategy is tapered or partial integration, where a company supplies its core or specific requirements by using internal resources and mechanisms. Following normal procurement procedures and obtaining resources externally or from markets meets the remaining requirements of the company. The third strategy is quasi-integration, where a company adopts a specific strategy and establishes a close, strategic relationship with upstream and downstream suppliers in the supply chain.

3. DEVELOPMENT OF A HYBRID DECISION EVALUATION METHOD BY COMBINING THE DEMATEL METHOD WITH AN ANP

According to the literature review, the formulation of a supply-chain development strategy must consider the effect of numerous factors, and the association between these factors must be examined and verified. This study develops a hybrid multi-criteria-decision-making model by incorporating the DEMATEL and ANP, and provides a decision-making evaluation tool for businesses when evaluating supply-chain development strategies.

The DEMATEL method identifies the correlation between decision-making criteria (Hwarng et al. 2005, Huang and Tzeng 2007, Liou et al. 2007), eliminating the effects of decision-making methods that assume that no inefficiencies occur among the decision-making criteria. The ANP identifies the degree of the impact of each influential criterion from a number of decision-making guidelines, and captures the effects of complex inter-organizational and interpersonal interactions effectively (Saaty 2003).

This study applies the model to confirm its validity. The hybrid model includes five major steps, and addresses supply-chain strategy assessment problems. ***1.*** *Identify the evaluation criteria of the supply-chain development strategy,* ***2.*** *Find major criteria for each factor,* ***3.*** *Identify the relationship between factors using the DEMATEL method,* ***4.*** *Decide the weight of criteria and factors by ANP.*

4. EMPIRICAL STUDY OF THE TFT-LCD INDUSTRY AND TOP FOUR TFT-LCD PANEL MANUFACTURERS

Empirical data obtained from the world's top four manufacturers of TFT-LCD panels validates the hybrid evaluation method of supply-chain development strategy.

This study investigates the growth and decline of competitiveness, the strategy used in the development of supply chains, and the performance associated with business strategies through the development of the hybrid decision-making model.

4.1 Construct the supply-chain strategy evaluation system

Complex decision-making processes form corporate strategy, particularly in the highly competitive TFT-LCD market environment. Internal and external factors are

crucial to these decision-making processes. This study is based on information obtained through in-depth interviews with experts; two senior managers working for different TFT-LCD manufacturers, and an experienced researcher who works in a nonprofit organization. Through this process, supply-chain development decision-making criteria in TFT-LCD manufacturers collected, considering 32 influential criteria. These 32 criteria then clarified. The data compared with the responses obtained from the three experts, and necessary adjustments made according to this comparison. The six finalized decision-influential factors are market (D1), supplier (D2), competitors (D3), enterprise (D4), government (D5), and supply chain performance (D6).

4.2 Identify major criteria of each dimension

The questionnaire data obtained through interviews with eight experts. They were five managers from supply chain and procurement organizations from the top three TFT-LCD panel manufacturers, two experienced senior researchers from a nonprofit R &D institute, and one professor from the management school of a university. The interview process divided into two phases. First, the respondents asked to provide scores for the 32 influential criteria across the six factors. During this rating process, the factors were only used as a guide to provide the respondents with the classification and cognitive understanding to rate criteria. If more than three respondents identified the same influential criteria (not part of the 32 criteria), these criteria were included as additional criteria, and these novel criteria appraised. Once the first phase was completed, respondents proceeded to the next phase and provided appraisals of the degree of factor impact.

Based on the questionnaire results, criteria with average ratings of three and more selected. At least one criterion in each of the six factors had a rating greater than or equal to three. Table 1 shows the 15 criteria that selected. The other 17 criteria had an average score of less than three because they influenced decision-making in supply-chain development less than the other criteria. Therefore, they excluded from the list of influential criteria and the rest of this research. The respondents also identified other influential factors during the interview process; however, they are not included in this research because fewer than three respondents identified the same additional criteria.

Table 1: Major Factors and Supply-Chain Strategy Criteria

Factor	Criteria
Market Factor (D_1)	initial capital (C_1)
	technology life cycle (C_2)
	ROI of leading suppliers (C_3)
Supplier Factor (D_2)	competition advantage of manufacturing capability (C_4)
	alignment of technology roadmap (C_5)
	cost-down capability (C_6)
Competitor Factor (D_3)	the bargaining power with suppliers (C_7)
	possible supply-chain strategy of major competitors (C_8)
Corporate Factor (D_4)	cost structure (C_9)
	technical gap between company and leading component or device provider (C_{10})
	field application capability gap between company and leading component or device provider (C_{11})
	risk of discontinuous supply (C_{12})
	organizational culture (C_{13})
Government Factor (D_5)	support of infrastructure for global logistics (C_{14})
Supply Chain Performance Factor (D_6)	gross margin (C_{15})

4.3 Identify the relationship between factors using the DEMATEL method

This section explores the direction of the direct and indirect factor and criteria affects and demonstrates these relationships with an NIRM diagram.

4.3.1 Find average influence matrix ***A***

In the second phase of the interview process, eight experts focused on the level of impact of the six factors D_1-D_6 by sequentially selecting two factors and comparing them with each other. Using Table 1 as a base rate indicator, a_{ij} represents the average rating the eight experts assigned to the effect that factor D_1 has on factor D_2, and a_{ii} represents the impact D_1 has on itself, which this study assumes is zero. Table 2 shows the results of the interviews. The degree of influence among all factors is demonstrated.

Table 2: Initial Average Influence Matrix A

	D_1	D_2	D_3	D_4	D_5	D_6
D_1	0	2.4	3.4	3.6	3.6	3.4
D_2	2.3	0	2.0	3.2	1.4	3.2
D_3	3.1	2.3	0	3.6	1.5	2.5
D_4	2.1	2.9	3.1	0	1.6	3.6
D_5	2.6	1.9	1.2	2.3	0	1.6
D_6	1.1	1.9	2.3	2.1	1.0	0

4.3.2 Decide initial direct influence matrix ***D***

According to the Normalization of the initial average influence matrix ***A,*** initial direct-relationship matrix *D*, shown in Table 3, is developed.

Table 3: Initial Direct-Influence Matrix *D*

	D_1	D_2	D_3	D_4	D_5	D_6
D_1	0.000	0.142	0.209	0.222	0.222	0.204
D_2	0.142	0.000	0.124	0.198	0.086	0.198
D_3	0.191	0.142	0.000	0.222	0.093	0.154
D_4	0.130	0.179	0.191	0.000	0.099	0.222
D_5	0.161	0.117	0.074	0.142	0.000	0.099
D_6	0.068	0.117	0.142	0.130	0.056	0.000

4.3.3 Derive the total influence matrix.

Table 4 shows total-influence matrix ***T***, which developed using Equations (1) to (5) to convert initial direct-influence matrix ***D***.

Table 4: Total-Influence Matrix *T*

	D_1	D_2	D_3	D_4	D_5	D_6
D_1	0.447	0.587	0.666	0.759	0.550	0.737
D_2	0.469	0.362	0.499	0.616	0.363	0.615
D_3	0.540	0.519	0.424	0.676	0.399	0.622
D_4	0.488	0.541	0.576	0.485	0.393	0.664
D_5	0.429	0.405	0.393	0.500	0.242	0.462
D_6	0.318	0.366	0.403	0.441	0.257	0.323

4.3.4 Conduct influence exerted and experienced

Using Equations (6) to (8), Table 5 shows the results derived from calculating $r_i + c_i$ values, which show that corporate factors (*D4*), market factors (*D1*), and competitor factors (*D3*) have significant and intense relationships among other factors. Calculating $r_i - c_i$ values shows that market factors (*D1*) have the highest ability to affect other factors, and supply-chain performance factors (*D6*) experience the highest impact from other factors. Interactions among the key impact factors clearly exist, and final decisions influenced indirectly by the impact exerted on other factors. Therefore, the interaction among key influential factors during the decision-making process should not ignore in practical business operations.

Table 5: Sum of Influence Exerted and Experienced

Factors	r_i	c_i	$r_i + c_i$	$r_i - c_i$
Market Factors (D_1)	3.746	2.691	6.437	1.055
Supplier Factors (D_2)	2.924	2.780	5.704	0.144
Competitor Factors (D_3)	3.180	2.961	6.141	0.219
Corporate Factors (D_4)	3.147	3.476	6.623	-0.329
Government Factors (D_5)	2.430	2.204	4.634	0.226
Supply-Chain Performance Factors (D_6)	2.108	3.423	5.531	-1.315

4.3.5 Set the threshold value to reduce the complexity of the relationship

By removing a_{ij} with a minor impact, the matrix focuses more on impact relations with more influence and avoids the complication of relationships that have zero or minor impact. Following discussions with experts in the first phase of this study, the threshold value has been set to 0.5, and all data below this value removed. Table 6 shows the result of this in matrix T *.

Table 6 : Total-influence matrix *T**

	D_1	D_2	D_3	D_4	D_5	D_6
D_1	-	0.587	0.666	0.759	0.550	0.737
D_2	-	-	-	0.616	-	0.615
D_3	0.540	0.519	-	0.676	-	0.622
D_4	-	0.541	0.576	-	-	0.664
D_5	-	-	-	0.500	-	-
D_6	-	-	-	-	-	-

4.3.6 Construct a NIRM of criteria and factors.

Figure 1 is an NIRM that shows relationships in total influence matrix T* graphically. The two axes $r_i + c_i$ and $r_i - c_i$ not only graphically identify the weighting of the impact among the factors, but also show the impact direction of the factor interaction.

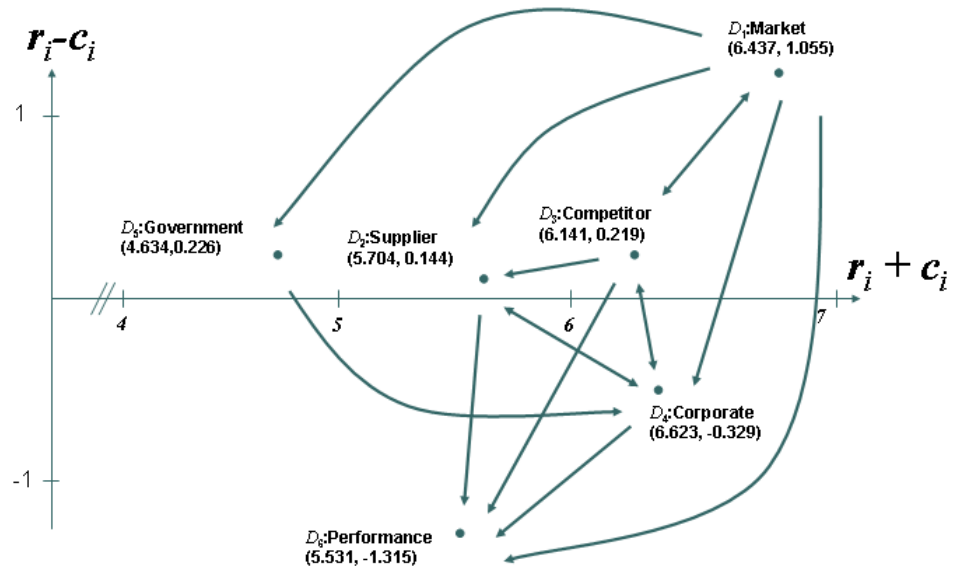

Figure 1. NIRM

4.4 Determine the weight of criteria using an ANP

This study uses the ANP to collect and calculate the impact weighting of criteria that affect decisions. The 15 criteria shown in Table 1 added to the factors listed in Table 6, forming a super matrix. The eight experts invited to participate in a second interview. Each expert asked to rate two criteria according to the relationship between the super matrix elements and the directional impact among factors listed in Fig. 1. The super matrix clearly identifies the impact of the 15 influential criteria on supply-chain development decisions. Criterion C_{15} (gross margin of supply-chain) has the largest impact weight at 12.6%. It demonstrates the strategic thinking that the whole supply-chain performance should consider instead of the local optimization of a single company of supply-chain. The second largest impact weight is C_8 (major competitors' strategies of supply chain), at 10.8%, followed by C_7 (competitor bargaining power with suppliers) at 10.3%. This shows that competitor supply-chain strategies are an influential criterion as the company evaluates the supply-chain development strategy. Any strategy that enforces supplier governance or supply-chain relationships that the company adopts directly affects competitor supply-chain development strategy. C_{14} (support for infrastructure for global logistics) has the lowest weight at 0.5%, indicating that global logistics is no longer a critical criterion in the supply-chain development process.

4.5 Obtain a performance index of the supply-chain development strategy

Considered the types of corporate strategies and supplier governance capabilities, this study classifies ten supply-chain strategies by the intensity of cooperative relationships between a company and their suppliers or supply source. The cooperative relationship with the most intensity and highest governance is the in-house capacity when a company establishes internal production and has the capacity to supply its own requirements. Pure purchase has the most loosely cooperative relationship.

Strategy 1 (S_1): Internal: Companies construct their capability of producing and supplying raw materials, semi-finished products, or services required internally.

Strategy 2 (S_2): Supply by subsidiary: The company uses their subsidiaries to supply necessary raw materials, semi-finished products, or services.

Strategy 3 (S_3): Supply by group companies: The company uses affiliated businesses of the same enterprise group for supply of raw materials, semi-finished products, or services required.

Strategy 4 (S_4): M & A: By financial means, such as acquisitions and mergers, the enterprise is able to hold partial or entire supplier equity, allowing the business to have the greatest influence on business decisions, influencing suppliers to meet business requirements.

Strategy 5 (S_5): Equity investment: By investing in suppliers or acquiring supplier stock, the company takes a position on the board of directors and becomes an influential stakeholder or forms an alliance at management levels with suppliers.

Strategy 6 (S_6): In-house supplier capacity: The close strategic cooperation formed between companies and suppliers encourages suppliers to create exclusive production or service facilities within a company and directly supply business requirements.

Strategy 7 (S_7): By plant: Suppliers build non-exclusive production or service facilities in a location close to the company factory and directly supply business requirements.

Strategy 8 (S_8): Business alliance: The company and suppliers form a strategic alliance by cooperating in professional or commercial affairs, bringing both parties to various degrees of cooperation in the market, particularly in the fields of the R&D, manufacturing, and logistics.

Strategy 9 (S_9): Advance payment: The company ensures the stability of supply (including aspects of delivery, supply, price, or supply conditions) by making partial or full payment in advance.

Strategy 10 (S_{10}): Pure purchase: The company purchases products or services from suppliers through a simple procurement contract.

Each expert examined the performance of key criteria C_1-C_{15} in each of the ten supply-chain strategies. Table 8 shows the performance rating derived for the ten supply chain strategies. When assessing the performance rating in the TFT-LCD supply-chain development strategy, the highest performance rating is equity investment of 0.694. In-house supplier capacity is second with a performance rating of 0.678, followed by M&A at 0.618. This shows that strategic performance is relatively high when maintaining supply-chain development through financial operations or working closely with an exclusive supply alliance. It is better than using subsidiaries and affiliated companies, which are more capable of governing suppliers on the performance of supply-chain development strategy. In-house production performance ratings are less than expected. This finding shows that the supply chain contributes more to enterprise performance than in-house production. Pure purchasing has the lowest performance rating at 0.409, followed by advance payment at 0.518. Hence, the company with the lowest ability to govern suppliers also performs worse.

Table 7: Performance Index of Strategy

Strategy	Performance Indices
S_1: Internal	0.546
S_2: Supply by subsidiary	0.592
S_3: Supply by group companies	0.579
S_4: M&A	0.618
S_5: Equity investment	0.694
S_6: In-house supplier capacity	0.678
S_7: By Plant	0.541
S_8: Business alliance	0.576
S_9: Advance payment	0.518
S_{10}: Pure purchase	0.409

4.6 Use the performance index to evaluate the top four TFT-LCD manufacturer supply-chain strategies

Comparing data from 2003 and 2008 validates this study. Data drawn from the actual performance of the world's four leading TFT-LCD panel manufacturers in the three main components of supply-chain development strategy in 2003 and 2008 and changes in the

supply-chain strategy. Various supply-chain tactics of color filter and backlight modules are key components of TFT-LCD panel used during this process. Findings in 2008 confirm that evaluating the performance of strategies individually results in better outcomes. However, the color filter supply-chain strategy received lower performance scores in the internal production strategy in 2003, and thus, gradually became the main supply source in 2008. Consultations with experts showed that, since 2005, TFT-LCD development has faced logistics challenges because of the increase in manufacturing sizes, which means that specific components such as color filters must increase in size. This transformation forces the TFT-LCD manufacturer to consider internal or in-house supplier capacity and other strategies. Because of the capital investment required, suppliers are reluctant to build dedicated production facilities within LCD factories, forcing TFT-LCD factories to consider the internal strategy. This trend requires the performance weight of the original assessment of the strategies to be re-evaluated.

5. DISCUSSIONS AND IMPLICATIONS FOR MANAGEMENT

The results of this study verify that the DEMATEL method can assist decision makers to distinguish between and prioritize key criteria that influence the decision-making process. The NIRM provided information on the directional impact of decisions among variables and relative degree of impact. This graph clearly quantifies the relationships between the impact factors of the decision-making process and the degree of influence within the interaction. Decision makers are able to understand complex business decisions and interlacing influential factors as well as types of interaction mechanisms and the weights of the impact occurring among variables. The complex models used in assisting organizations with the assessment of their business strategies in the competitive environment exclude effects of interactions between influential factors. Human intuition in decision-making is vulnerable because of the interference caused by an insufficient number of decision-making strategies applied in real scenarios. This is particularly true in supply-chain strategy assessment because, with the development of supply-chains, companies must consider many external variables, including suppliers upstream and downstream of the supply chain, competitors, product replacements in the market, and potential competitors. Companies do seek better decision-making strategies to navigate many influential variables. The DEMATEL method is specialized in determining and prioritizing key factors affecting the decision-making process, and assists decision-makers in understanding this complex decision-making process.

ANP analysis not only consists of AHP characteristics, showing an assessment model of simple decision variables of alternatives, but also excludes assumptions on the independence of decision-making variables, analyzing the phenomenon of interdependency and impact among variables together. Through the process of this analysis, the findings show that interactions between supply-chain development and influential variables exist, this cannot ignore. The results from this analysis are more closely to the actual management environment that businesses currently encounter. Hence, the company making supply-chain development decisions should not disregard interactions between variables identified by the MCDM method. It may be impossible to resolve the difficulties encountered in the actual decision-making process without solving these problems with scientific calculations.

This study applies the hybrid MCDM method to an empirical study of the TFT-LCD industry. It resolves issues encountered by businesses during the evaluation of supply-

chain development strategies. By using these quantitative methods, companies can solve strategy decisions that include many complex variables.

This study combines previous research results and actual practices in the technology industry, and defines ten strategies of supply-chain development based on the methods with which businesses govern their suppliers. They are internal, supply by subsidiary company, supply by group company, M&A, equity investment, in-house supplier capacity, by plant, business alliance, advance payment, and pure purchasing. Instead of adopting a single, stand-alone strategy, this study explores that most businesses use a strategy set that includes multiple strategies for supply-chain development. Hence, the supply-chain development strategy developed in this research should serve as a reference for other industries and studies.

From evaluating the character and impact of the competitive advantage of individual supply-chain strategies, the current study findings show that dynamic transformation in the composition of various supply-chain strategies has occurred. Changes occurred among strategies adopted by businesses in 2003 and 2008, and businesses adjusted the type of chosen supply-chain strategies. This study shows that strategy adjustments occurred dynamically, and that no specific pattern was present. Thus, companies are driven to make adjustments to strengthen their competitive advantage in a dynamic business environment. The hybrid decision-making model developed in this study also considers key factors in assessing the performance score of various supply-chain strategies. This strategy performance score fluctuates with changes in competition or the external business environment. It forces a company to change the supply-chain development strategy by reviewing the performance score regularly.

6. CONCLUSIONS

This study details the hybrid MCDM decision-making assessment model by combining the DEMATEL and ANP methodologies. It also proves the applicability of the model in the emerging TFT-LCD industry through empirical verification, showing the practical value of the model. The DEMATEL methodology clarifies the direction and impact of the interactions between complex variables that affect decision-making. It provides an NIRM, which provides decision makers with an overall view of the interactions among influential decision-making variables by using graphical and quantitative methods derived from the analysis. The ANP accounts for variables and the interdependency between variables during the performance appraisal of decision-making, and provides an effective decision-making assessment for decision makers as they confront the many different characteristics and properties of decision variables.

The complete integration of the DEMATEL and ANP methods reduces the problem of theory deviating from practice because of empirical and general assumptions in theoretical research. Decision makers can apply this hybrid decision-making model, combining it with dynamic factors over time, to decision-making in supply-chain development and other business decisions. Subsequent research can combine dynamic factors with time and improve this model or develop a dynamic MCDM model. Researchers can also develop a computer-based system or create software for the hybrid MCDM model. This model is an efficient decision-making tool.

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