Evaluating Agricultural Food Supply Chain Resilience in the Context of the COVID-19 Pandemic

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ABSTRACT

With the spread of the global COVID-19 pandemic, agricultural food supply chains (AFSC) have suffered from unprecedented challenges and disruption. AFSC must possess extremely high levels of resilience when confronted by the pandemic. In this study, the authors have identified six important resilience criteria and 18 sub-criteria of AFSC in the context of COVID-19. The research presents the conceptual mixed multi-criteria decision-making (MCDM) technology to prioritize the resilience criteria based on understanding their interrelationships. Results identify three essential resilience criteria, namely “coordination and collaboration in the supply chain,” “efficiency,” and “strategic management” and the top five key sub-criteria as “velocity,” “visibility,” “continuity management,” “connectedness,” and “collaborative planning and replenishment.” The framework proposed in this study contributes to the interdisciplinary understanding towards building resilience within AFSC and has the potential to be extended to other types of supply chains in response to COVID-19.

KEYWORDS

Agricultural Food Supply Chain, ANP, COVID-19, Criteria Identification, Fuzzy-DEMATEL, MCDM, Network Structuring Model, Supply Chain Resilience

INTRODUCTION

Since COVID-19 was declared a global pandemic by the World Health Organization (WHO), the virus has rapidly spread to almost every country in the world (WHO, 2020). Due to the high transmissibility of the virus, governments worldwide have implemented inhibition and control measures to contend against the outbreak, including self-isolation and maintaining social distance. However, these measures have caused severe border restrictions and blockades (Grida et al., 2020). At the same time, consumption has been suppressed in the short-term, and cross-border investment has been significantly delayed.

The outbreak of COVID-19 and the suppression measures taken by countries have put the global food system at an unprecedented risk (FAO, 2020). Taking China as an example, the blockade policy was implemented in Wuhan on 23 January 2020. On 29 January, 31 provinces and municipalities in China launched a Level I response. During this period, offline agricultural product stores were generally closed or semi-closed, resulting in a sharp decline in agricultural product sales in the short term (Figure 1). Small-scale producers were hardest hit by the loss of income (Workie et al., 2020). Simultaneously, the supply of agricultural products was suspended due to logistics and road blockages.

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The epidemic also restricted labor movement, leading to a shortage of labor that disrupted planting, harvest, and other agricultural activities, and resulting in further economic losses (Balwinder-Singh et al., 2020).

The various problems caused by the epidemic pose significant challenges to supply chain resilience. The definition of supply chain resilience is the ability of the supply chain to resume operation after being disrupted (Reyes Levalle & Nof, 2017). Many studies have been carried out to explore supply chain resilience (White & Censlive, 2020). However, there have been some specific changes in the resilience structure of Agricultural Food Supply Chains (AFSC) affected by the epidemic. Therefore, in order to reduce the negative impact of the COVID-19 epidemic on AFSC, companies need to identify and analyze the main criteria that affect the resilience of AFSC. This research aims to answer three research questions: (1) In the context of the COVID-19 pandemic, what are the criteria for enhancing the resilience of AFSC? (2) What are the interrelationships between these criteria? (3) Which criteria have the greatest impact on the resilience of AFSC and require further analysis to support the future development of enterprises?

The organization of the remaining paper is as follows. The methodology for evaluating the resilience criteria and sub-criteria is discussed in Section 2. In Section 3, the procedures and results of the fuzzy Decision-making Trial and Evaluation Laboratory (DEMATEL) and the Analytic Network Process (ANP) are analyzed comprehensively. Section 4 introduces the key findings and managerial implications. Section 5 presents the conclusion of this article.

**Figure 1.** Decline in sales of agricultural products in China during the COVID-19 outbreak. Notes: Data from National Data Service Platform of Agricultural and Rural Response to COVID-19, http://snsj.agri.cn/market-operation.

**METHODOLOGY**

This study is divided into three stages to evaluate the resilience criteria and sub-criteria of AFSC in the context of the COVID-19 pandemic. In the first stage, the critical resilience criteria and sub-criteria of AFSC were determined through literature review and expert opinions. In the second stage, the fuzzy DEMATEL method was used to evaluate the interrelations between eighteen sub-criteria, and the Influence Relationship Matrix (IRM) was obtained according to their interrelations. The IRM was used as a network relation map for the ANP process. In the final phase, the ANP method was adapted to evaluate the weights of resilience criteria and sub-criteria.
Delphi Method

The Delphi method is a process of obtaining consensus through the repeated collection, feedback, and modification of expert opinions (Schulze & Bals, 2020). The more rounds conducted in the Delphi method, the less feedback from experts we can obtain. Therefore, this study carried out two rounds of expert surveys.

Firstly, through literature review, the definition of AFSC was obtained, and the impact of COVID-19 on AFSC was analyzed. This preliminary phase clarified the important criteria and sub-criteria of AFSC in the context of COVID-19. Secondly, according to Winkler & Moser (2016), the principle of selecting experts is that each expert represents an aspect of AFSC in the context of the COVID-19 pandemic. Therefore, the ability of experts, rather than the number of participants, are the most important factors in qualitative research. The researchers proposed that the expert panel should include academic experts, business practitioners, and practical experts in related fields. The composition of the expert panel should enable the researchers to collect opinions widely and efficiently. Furthermore, the expert panel participants were determined after comprehensive analysis, as shown in Table 1. Finally, in order to analyze the interactions and weights of the resilience criteria and sub-criteria, two rounds of Delphi surveys were conducted. The first round of the Delphi survey was implemented from September to October 2020, and the second round was implemented from October to November 2020.

Table 1. Expert panel characteristics

<table>
<thead>
<tr>
<th>Expert</th>
<th>Practitioner or Academic</th>
<th>Position or research field</th>
<th>Job Experience</th>
<th>Educational background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expert A</td>
<td>Practitioner</td>
<td>AFSC senior manager</td>
<td>11 years</td>
<td>International Business Administration</td>
</tr>
<tr>
<td>Expert B</td>
<td>Practitioner</td>
<td>AFSC manager</td>
<td>9 years</td>
<td>Business</td>
</tr>
<tr>
<td>Expert C</td>
<td>Practitioner</td>
<td>Fruit and vegetable procurement director</td>
<td>5 years</td>
<td>Economics</td>
</tr>
<tr>
<td>Expert D</td>
<td>Practitioner</td>
<td>Consultant supply chain planning</td>
<td>6 years</td>
<td>Economics</td>
</tr>
<tr>
<td>Expert E</td>
<td>Practitioner</td>
<td>Distribution director</td>
<td>5 years</td>
<td>Logistics engineering</td>
</tr>
<tr>
<td>Expert F</td>
<td>Practitioner</td>
<td>Demand planning manager</td>
<td>8 years</td>
<td>Marketing</td>
</tr>
<tr>
<td>Expert G</td>
<td>Academic</td>
<td>Professor for supply chain management and risk management</td>
<td>10 years</td>
<td>Supply chain management; Management science and engineering</td>
</tr>
<tr>
<td>Expert H</td>
<td>Academic</td>
<td>Professor of agricultural food and environmentally supply chain</td>
<td>14 years</td>
<td>Management science and engineering;</td>
</tr>
</tbody>
</table>

During the interviews, a 4-point scale (from 0, no influence, to 4, very high influence) was used to determine the interactions between the criteria. Satty’s 1-9 scale (the relative importance of the two criteria goes from 1, which is equally important, to 9, where one is extremely important than the other) was used to assess their weights. In the second round of the Delphi survey, experts were invited again to evaluate the criteria and sub-criteria, and they were permitted to change their previous views if they wished. Simultaneously, the results of the first round of Delphi surveys were provided to experts to promote understanding. After the second round, the Delphi survey was considered complete.
Identifying the Criteria and Sub-Criteria

A comprehensive framework analysis was constructed for the evaluation of supply chain resilience. When faced with sudden public safety incidents, the AFSC managers must consider the following aspects to enhance resilience: Stability (Shao & Jin, 2020), Coordination and collaboration in the AFSC (Aggarwal et al., 2020), Strategic control (Wong et al., 2020), Agility (Brusset, 2016), Efficiency (Garofalo et al., 2015), and Sustainability (Melkonyan et al., 2017). The details of the sub-criteria identified from the literature to support the development of a resilient AFSC in the context of COVID-19 and relevant sources are presented in Table 2.

Fuzzy DEMATEL Method

The Basic of Triangular Fuzzy Numbers

Given that the expert views gathered through the Delphi process are rather ambiguous, so the triangular fuzzy number is used in this study to remedy the defects and elicit expert evaluation (Lin et al., 2018).

Definition: Suppose there is a universe of discourse $U$. If $\mu_A(x) : U \rightarrow [0,1], \mu_A(x)$ is defined as the membership of $x$ ($x \in A$). Let $M$ be a triangular fuzzy number on $U$, and its membership function $\mu_M : U \rightarrow [0,1]$ can be expressed as:

$$
\mu_M(X) = \begin{cases} 
\frac{x-l}{m-l} & x \in [l,m] \\
\frac{x-\mu}{m-\mu} & x \in [m,\mu] \\
0 & \text{other}
\end{cases}
$$

Where $m$ is the center, $l$ and $\mu$ represent the left and right bounds of $M$, respectively.

CFCS Method

During the Multi-Criteria Decision Making (MCDM) process, qualitative and vague information is often obtained, which requires defuzzification (Nazam et al., 2020). In this study, we used the CFCS method to convert triangular fuzzy numbers into crisp numbers (Kiani Mavi & Standing, 2018). Suppose $z_{ij} = (l_{ij}, m_{ij}, r_{ij})$ is the evaluation value given by the expert panel. It represents the influence degree of the i-th criterion on the j-th criterion. The defuzzification steps are as follows:

Step 1: Normalization.

$$x_l = (l_{ij} - \min l_{ij}) / \Delta_{\min}^{\max} \tag{1}$$

$$x_m = (m_{ij} - \min l_{ij}) / \Delta_{\min}^{\max} \tag{2}$$

$$x_r = (r_{ij}^k - \min l_{ij}^k) / \Delta_{\min}^{\max} \tag{3}$$
The purpose of normalization is to reduce the difference in the scores of various experts, where \( \Delta_{\min} = \max_{ij} r_{ij} - \min_{ij} l_{ij} \).

**Step 2:** Compute left and right normalized values.

---

**Table 2. Major identified AFSC resilience criteria and sub-criteria**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Sub-criteria</th>
<th>Literature</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability(A)</td>
<td>Supply-side stability (A1)</td>
<td>(Hobbs, 2020)</td>
<td>The ability to respond to supply-side shocks caused by problems such as labor shortages.</td>
</tr>
<tr>
<td></td>
<td>Process stability (A2)</td>
<td>(Dekker et al., 2013)</td>
<td>It includes attributes such as traceability, storage and transportation conditions, safety, packaging, etc.</td>
</tr>
<tr>
<td></td>
<td>Demand-side stability (A3)</td>
<td>(Cranfield, 2020)</td>
<td>The ability to respond to dramatic fluctuations in demand is caused by consumer panic or the cut-off of traditional offline channels.</td>
</tr>
<tr>
<td>Coordination and collaboration in AFSC (B)</td>
<td>Connectedness (B1)</td>
<td>(Ivanov, 2020)</td>
<td>It shows the level of synergy among supply chain partners.</td>
</tr>
<tr>
<td></td>
<td>Visibility(B2)</td>
<td>(Kiil et al., 2019)</td>
<td>It is the ability to monitor supply chain production, inventory, transportation and other data in real-time.</td>
</tr>
<tr>
<td></td>
<td>Collaborative planning and replenishment (B3)</td>
<td>(Fan et al., 2017)</td>
<td>It is the mechanism for cooperation and risk-sharing.</td>
</tr>
<tr>
<td>Strategic management (C)</td>
<td>Continuity management (C1)</td>
<td>(Ge et al., 2020)</td>
<td>It is an integrated management process, which enables the supply chain to recognize potential crises and formulate recovery plans.</td>
</tr>
<tr>
<td></td>
<td>Intellectualization and Digitalization (C2)</td>
<td>(Chiappetta Jabbour et al., 2020)</td>
<td>Intelligence and digitalization can improve information sharing capabilities and reduce time loss.</td>
</tr>
<tr>
<td></td>
<td>Cold chain management and security (C3)</td>
<td>(Wu &amp; Hsiao, 2021)</td>
<td>Manage cold chain issues, such as the perishability of agricultural products and the prolonged survival time of the new coronavirus in frozen environments.</td>
</tr>
<tr>
<td>Agility (D)</td>
<td>Volume flexibility (D1)</td>
<td>(Delic &amp; Eyers, 2020)</td>
<td>The ability to flexibly produce different quantities of products.</td>
</tr>
<tr>
<td></td>
<td>Mix flexibility (D2)</td>
<td>(Delic &amp; Eyers, 2020)</td>
<td>The ability to flexibly produce different kinds of products.</td>
</tr>
<tr>
<td></td>
<td>Distributed power (D3)</td>
<td>(Rajesh, 2019)</td>
<td>All departments can take countermeasures when emergencies occur.</td>
</tr>
<tr>
<td>Efficiency (E)</td>
<td>Velocity (E1)</td>
<td>(Yang et al., 2021)</td>
<td>Unnecessary time should be reduced to deal with fluctuations in demand and supply.</td>
</tr>
<tr>
<td></td>
<td>Aligning strategies (E2)</td>
<td>(Zhu &amp; Krikke, 2020)</td>
<td>The ability to transform supply chain strategies to prepare for risks such as disruption.</td>
</tr>
<tr>
<td></td>
<td>Standardization (E3)</td>
<td>(Rajesh, 2019)</td>
<td>Establish standards for the product or service process to obtain the best order.</td>
</tr>
<tr>
<td>Sustainability (F)</td>
<td>Economical (F1)</td>
<td>(Wong et al., 2020)</td>
<td>This includes factors that affect the supply chain economy, such as prices, and output growth.</td>
</tr>
<tr>
<td></td>
<td>Environmental (F2)</td>
<td>(Saberi, 2018)</td>
<td>This includes factors that affect the environment and cause pollution, such as carbon emissions.</td>
</tr>
<tr>
<td></td>
<td>Social (F3)</td>
<td>(Pu &amp; Zhong, 2020)</td>
<td>The social factors involved in the AFSC management include employee professionalism, employee safety.</td>
</tr>
</tbody>
</table>
\[ xls_{ij} = \frac{xm_{ij}}{1 + xm_{ij} - xl_{ij}} \quad (4) \]

\[ xrs_{ij} = \frac{xr_{ij}}{1 + xr_{ij} - xm_{ij}} \quad (5) \]

**Step 3:** Compute total normalized crisp value.

\[ x_{ij} = \frac{[xls_{ij}(1 - xls_{ij}) + xrs_{ij} xrs_{ij}]}{(1 - xls_{ij} + xrs_{ij})} \quad (6) \]

**Step 4:** Compute crisp values.

\[ z_{ij} = \min l_{ij} + x_{ij} \Delta_{\max}^{\min} \quad (7) \]

**Integrated CFCS and DEMATEL Method**

With the help of graph theory and matrix, the DEMATEL method can calculate the interactions of criteria and sub-criteria in the system. However, the traditional DEMATEL method is unsuitable for the MCDM process as the data is subjective and vague. Therefore, scholars have introduced the fuzzy theory (Quiñones et al., 2020). This method involves the following steps:

**Step 1:** In the process of expert evaluation, intuitive expressions of the interactions between criteria were used as follows: “very high influence, high influence, low influence, very low influence, and no influence”. Therefore, this expression mode is selected as the semantic transformation term, as shown in Table 3.

**Step 2:** Initial direct relationship fuzzy matrix. An initial fuzzy direct relationship matrix, named as fuzzy matrix A, is established by N respondents, as shown in Equation (8).

<table>
<thead>
<tr>
<th>Scale</th>
<th>Linguistic variable</th>
<th>Triangular Fuzzy Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No influence</td>
<td>(0,0,0.25)</td>
</tr>
<tr>
<td>1</td>
<td>Very low influence</td>
<td>(0,0.25,0.25)</td>
</tr>
<tr>
<td>2</td>
<td>Low influence</td>
<td>(0.25,0.5,0.75)</td>
</tr>
<tr>
<td>3</td>
<td>High influence</td>
<td>(0.5,0.75,1.0)</td>
</tr>
<tr>
<td>4</td>
<td>Very high influence</td>
<td>(0.75,1.0,1.0)</td>
</tr>
</tbody>
</table>
In the matrix, the $a_{ij}$ represents the degree of influence of criteria i to criteria j. The direct relation fuzzy matrix $X$ can be obtained by normalizing $A$, as shown in Eq. (9):

$$
\tilde{X} = \begin{bmatrix}
\tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\
\tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \tilde{x}_{nn}
\end{bmatrix}
$$

(9)

Where

$$
\tilde{x}_{ij} = \frac{a_{ij}}{\max_{1 \leq j \leq n} \sum_{j=1}^{n} a_{ij}} = \left( \frac{a_{ij}}{\max_{1 \leq j \leq n} \sum_{j=1}^{n} a_{ij}}, \frac{a_{ij}}{\max_{1 \leq i \leq n} \sum_{i=1}^{n} a_{ij}}, \frac{a_{ij}}{\max_{1 \leq j \leq n} \sum_{j=1}^{n} a_{ij}} \right)
$$

(10)

Step 3: Calculate the fuzzy total-influence matrix. The fuzzy total-influence matrix $\tilde{T}$ can be obtained as Eq.(11), where $I$ is the identity matrix:

$$
\tilde{T} = \lim_{k \to \infty} (\tilde{X}_1 + \tilde{X}_2 + \cdots + \tilde{X}_k) = X \times (I - X)
$$

(11)

Through the CFCS method, the total-influence matrix $T$ after defuzzification can be obtained.

Step 4: Determine the causal degree through Eq.(12) and (13):

$$
T_r = \sum_{i=1}^{N} t_{rij}
$$

(12)

$$
T_c = \sum_{j=1}^{N} t_{cij}
$$

(13)

Step 5: Obtain centrality and cause degree using Eq. (14) and (15):
\[ D_i = \sum_{i=1}^{N} t_{ij} + \sum_{j=1}^{N} t_{ij} \]  

(14)

\[ R_i = \sum_{i=1}^{N} t_{ij} - \sum_{j=1}^{N} t_{ij} \]  

(15)

When \( R_i \) is positive, criterion \( i \) is classified into cause group, and criterion \( i \) is classified into effect group if \( R_i \) is negative. Compared with the effect criterion, the change of the cause criterion has a greater impact on the system. In addition, the effect criterion can be changed by affecting its cause criterion.

**ANP Method**

The ANP method is often applied to MCDM processes that cannot be expressed in a hierarchical structure. In the ANP method of this study, the relationship network graph is constructed by setting a threshold for the IRM and then deleting the network relation less than the threshold value. Additionally, the weights of the criteria and sub-criteria are obtained on this basis. The steps of ANP method are summarized as:

**Step 1:** Construct the network structure according to IRM and threshold.

**Step 2:** The expert questionnaire obtained from the Delphi method is converted into a pairwise comparison matrix shown in Eq. (16):

\[
A = [a_{ij}]_{n \times n} = \begin{bmatrix}
1 & \ldots & a_{i1} & \ldots & a_{in} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
a_{i1} & \ldots & 1 & \ldots & a_{in} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
a_{n1} & \ldots & a_{nj} & \ldots & 1
\end{bmatrix}
\]  

(16)

Where \( a_{ij} = \frac{1}{a_{ji}}, (i, j = 1, 2, \ldots, n) \).

**Step 3:** Consistency check. When \( CR \leq 0.1 \), the assessment results of the expert panel are consistent. CR (consistency ratio) and CI (consistency index) are calculated as Eq. (17) and Eq. (18).

\[ CR = \frac{CI}{RI} \]  

(17)

\[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \]  

(18)
Where $\lambda_{\text{max}}$ is the maximum eigenvalue in matrix A, and RI is average random consistency index.

**Step 4:** Obtain the unweighted supermatrix. The eigenvectors of each dimension criteria are integrated into a matrix, and the matrix is an unweighted supermatrix, as shown in Eq.(19):

$$
W = \begin{bmatrix}
W^{11} & \ldots & W^{ij} & \ldots & W^{in} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
W^{ni} & \ldots & W^{nj} & \ldots & W^{nn}
\end{bmatrix}
$$

(19)

**Step 5:** Obtain the weighted supermatrix by multiplying the eigenvectors obtained from the unweighted supermatrix and the pairwise comparison matrix. $W_{ij}$ is the matrix formed by the eigenvectors obtained by pairwise comparison between the sub-criteria in criteria i and the sub-criteria in criteria j, as shown in Eq. (20).

$$
W_{ij} = \begin{bmatrix}
w^{i1}_{j1} & \ldots & w^{i1}_{jk} & \ldots & w^{i1}_{jm} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
w^{ik}_{j1} & \ldots & w^{ik}_{jk} & \ldots & w^{ik}_{jm} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
w^{in}_{j1} & \ldots & w^{jn}_{jk} & \ldots & w^{jn}_{jm}
\end{bmatrix}
$$

(20)

Furthermore, a stable limiting matrix can be obtained by multiplying the weighted supermatrix multiple times, and the weights of the criteria and the sub-criteria can be obtained.

**RESULTS**

Considering the complexity of the AFSC in the context of the COVID-19 pandemic, many organizations use the MCDM methods to support the management process (Zhang et al., 2020). In this process, the Delphi method is widely used to collect expert opinions. In this method, the opinions of experts are repeatedly consulted and modified until a consensus is derived. And the experts’ consistent views are finally summarized, which are taken as the basis of analysis.

**Construct the Network Structure Based on Fuzzy-DEMATEL**

**Step 1:** The initial fuzzy direct relation matrix is generated by evaluating the questionnaire results from the Delphi expert panel for sub-criteria, as shown in Table 4.
**Step 2:** Obtain the IRM. Through the integration of DEMATEL and CFCS methods, the total-influence matrix is obtained after defuzzification. Furthermore, the threshold value is set to 0.07 for sub-criteria through expert panel discussion and literature review. The influence relations smaller than the threshold will not be expressed. The IRM is obtained after deleting those influence relations with a smaller threshold in the total-influence matrix, as shown in Table 5 (Lin et al., 2018).
Table 4. Initial fuzzy direct relation matrix of the sub-criteria

<table>
<thead>
<tr>
<th></th>
<th>A 1</th>
<th>A 2</th>
<th>A 3</th>
<th>B 1</th>
<th>B 2</th>
<th>B 3</th>
<th>C 1</th>
<th>C 2</th>
<th>C 3</th>
<th>D 1</th>
<th>D 2</th>
<th>D 3</th>
<th>E 1</th>
<th>E 2</th>
<th>E 3</th>
<th>F 1</th>
<th>F 2</th>
<th>F 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
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<tr>
<td>A 3</td>
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Next, influential network relation maps of criteria and sub-criteria can be graphed as shown in Figure 2, according to the $D_i$ and $R_i$ values shown in Table 6.

### Assessing the Weights by ANP Method

**Step 1:** According to the IRM obtained by the DEMATEL method, the network structure in the ANP method is constructed. On this basis, multiple pairwise comparison matrices are formed by evaluating the results of the expert panel. Then, the consistency of these matrices is checked through the CR value. If the test fails, the matrix is fed back to the expert group for re-evaluation until all the matrices are acceptable.

**Step 2:** According to Eq. (19) and Eq. (20), unweighted supermatrix and weighted supermatrix are obtained, and the limit supermatrix is further calculated. Furthermore, the limited weights and global weights of the criteria and sub-criteria can be obtained, as shown in Table 7.

### Managerial Implications and Discussion

This study combines the fuzzy-DEMATEL method and the ANP method to carry out the analysis. The results show that “Velocity”, “Visibility”, “Continuity management”, “Connectedness”, and “Collaborative Planning and Replenishment” are the most critical sub-criteria to enhance the resilience of AFSC. Due to the shocks caused by the COVID-19 epidemic to both the supply and demand side, traditional methods to improve velocity, such as zero inventory, are unsuitable for AFSC management in the COVID-19 epidemic. In response to this problem, managers can use time and location delay...
|       | A1    | A2    | A3    | B1    | B2    | B3    | C1    | C2    | C3    | D1    | D2    | D3    | E1    | E2    | E3    | F1    | F2    | F3    |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| A1    | 0.000 | 0.000 | 0.073 | 0.000 | 0.000 | 0.117 | 0.000 | 0.088 | 0.000 | 0.000 | 0.126 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| A2    | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.117 | 0.000 | 0.088 | 0.000 | 0.000 | 0.125 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| A3    | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.086 | 0.000 | 0.000 | 0.000 | 0.000 | 0.081 | 0.000 | 0.000 | 0.000 | 0.000 | 0.076 | 0.000 |
| B1    | 0.191 | 0.202 | 0.227 | 0.095 | 0.212 | 0.163 | 0.206 | 0.088 | 0.080 | 0.159 | 0.181 | 0.135 | 0.190 | 0.112 | 0.152 | 0.103 | 0.117 |
| B2    | 0.168 | 0.223 | 0.265 | 0.194 | 0.202 | 0.241 | 0.000 | 0.155 | 0.159 | 0.137 | 0.166 | 0.184 | 0.075 | 0.158 | 0.126 | 0.127 |       |
| B3    | 0.082 | 0.089 | 0.095 | 0.143 | 0.168 | 0.000 | 0.093 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.092 | 0.000 | 0.000 |
| C1    | 0.173 | 0.172 | 0.225 | 0.000 | 0.072 | 0.111 | 0.088 | 0.000 | 0.000 | 0.000 | 0.158 | 0.157 | 0.115 | 0.000 | 0.000 | 0.126 |       |
| C2    | 0.098 | 0.129 | 0.085 | 0.000 | 0.102 | 0.100 | 0.000 | 0.150 | 0.000 | 0.000 | 0.077 | 0.000 | 0.000 | 0.088 | 0.081 | 0.105 |       |
| C3    | 0.074 | 0.082 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| D1    | 0.000 | 0.000 | 0.119 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| D2    | 0.000 | 0.000 | 0.124 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.083 | 0.000 | 0.074 | 0.000 |
| D3    | 0.000 | 0.000 | 0.121 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.073 | 0.000 |
| E1    | 0.000 | 0.079 | 0.089 | 0.136 | 0.142 | 0.000 | 0.101 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| E2    | 0.000 | 0.128 | 0.120 | 0.000 | 0.000 | 0.103 | 0.000 | 0.090 | 0.090 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| E3    | 0.000 | 0.123 | 0.000 | 0.000 | 0.073 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.107 | 0.070 | 0.000 | 0.000 | 0.000 | 0.000 |
| F1    | 0.094 | 0.120 | 0.159 | 0.000 | 0.000 | 0.000 | 0.107 | 0.070 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| F2    | 0.000 | 0.000 | 0.097 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| F3    | 0.115 | 0.123 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
strategies to improve velocity. The time delay strategy mainly refers to the measure that the manager delays the logistics activities with the help of supply chain management until the order is generated. The location delay strategy is realized by delaying the distribution of upstream companies in the supply chain. This will concentrate inventory in upstream companies as much as possible, thereby achieving economies of scale. In general, this strategy delays the order generation time to achieve the precise supply to meet the customers’ demand. Hence, the delay strategy can reduce unnecessary pipeline time and improve velocity.

In order to achieve visibility, managers should create a visual operation model through end-to-end data traceability. Timely feedback of relevant information is conducive to supply chain monitoring and makes the supply chain management more flexible. Simultaneously, strengthening information collaboration through digitization is an important support for improving supply chain efficiency. The digitization of the supply chain can be achieved by multiple information integrations such as procurement, production and operation, sales, payment and settlement. Continuity management is a comprehensive management process, which mainly includes short-term response plans and long-term risk management plans. The realization of the short-term plans requires monitoring the changes in supply and demand brought about by the COVID-19 epidemic. These short-term plans should include formulating the rapid response plan and recognizing the management of unknown factors. The realization of long-term planning needs to be forward-looking. Therefore, managers should

![Table 6. Centrality degree and cause degree of criteria and sub-criteria](image-url)
focus on the implementation of the sustainable operation goals of the supply chain, supplemented by diversified models, to achieve the leap of the industrial chain and the value chain.

For the purpose of promoting the smooth flow of supply to demand, companies need to strengthen their close contact, coordination and cooperation with upstream and downstream partners in the supply
chain. When collaborating with upstream companies, managers should reinforce the rational allocation of resources through collaborative production. In selecting new suppliers, it is particularly important that directors carefully evaluate the company’s supply capacity and stability, and fully prepare for the risk of insufficient supply caused by force majeure factors. When collaborating with downstream companies, managers should build an integrated supply chain service platform to balance supply and demand. Due to the ripple effect of the supply chain, enterprises in the supply chain often share risks and benefits. Therefore, enterprises can establish a collaborative sharing mechanism to achieve horizontal expansion of the supply chain, and then realize the collaborative planning and replenishment between enterprises. Shared resources include not only the sharing of physical objects, but also the sharing of information and employees. It should be noted that among the five most important sub-criteria, “Velocity” belongs to the effect group. The effect criterion is more susceptible than the cause criterion, which requires managers to avoid looking at the effect criterion in isolation. Thus, when managers implement optimization strategies for velocity, they should pay full attention to the other sub-criteria that affect velocity and make decisions based on understanding their interrelationships.

**CONCLUSION**

The evaluation and development of resilience in the AFSC play a vital role in reducing loss and restoring operation. For this reason, managers should be familiar with the criteria for improving supply chain resilience and their interactions. This research has attempted to answer the three questions stated in the introduction as follows. For the first question, this study summarized six criteria and eighteen key sub-criteria as an evaluation system based on a thorough review of the literature and the consensus.
of experts developed through the Delphi method. The second question was answered by the fuzzy-DEMATEL method. According to the results of the fuzzy-DEMATEL method, the interrelationships between these criteria and the sub-criteria were established, as shown in Figure 2. The third research question was analyzed by the ANP method to obtain the key criteria and sub-criteria in the evaluation system. Generally, this research integrated the fuzzy-DEMATEL method and the ANP method to undertake a novel analysis of the AFSC. The analysis shows that “Velocity”, “Visibility”, “Continuity management”, “Connectedness”, and “Collaborative Planning and Replenishment” are the main factors towards improving the resilience of the AFSC. Moreover, managers should not consider the effect criteria in isolation. In order to facilitate understanding, this study visualized the interrelations between these criteria. Since a change in one factor will trigger a change in another factor, it is necessary to analyze the global weight of the sub-criteria based on determining their interrelations. These results will help managers to determine their priorities and directions before making decisions, which can also help reduce the vulnerability of the AFSC as a whole.

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REFERENCES


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