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Analysis of Critical Success Factors of Logistics 4.0 using D-number based Pythagorean Fuzzy DEMATEL method

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ABSTRACT

Logistics 4.0 is a concept related to Industry 4.0, encompassing skills and notions of supply chain organization, integrating logistics with advanced technology in order to satisfy consumer demand for customized goods and services. Industry 4.0 is transforming businesses and supply chains through advanced technologies like analytics, big data, Internet of things, and cyber-physical systems, enhancing warehousing, manufacturing, and logistics. Logistics 4.0 can be regulated by properly analyzing specific Critical Success Factors using a Multi-Criteria Decision Making model in uncertain or ambiguous circumstances. Hence, it is necessary to explore the CSFs while bringing logistics 4.0 into action. These CSFs are interlinked, and this interlinkage is examined through the D-number-based Pythagorean fuzzy Decision Making Trial and Evaluation Laboratory method, which is suitable for group decision-making in incomplete and uncertain data. The proposed research paradigm incorporates the abilities of Trapezoidal Pythagorean Fuzzy Numbers for dealing with fuzziness and D-Numbers for getting an improved and further precise decision from a heterogeneous group of decision-makers using their linguistic choices. Additionally, it is adaptive and versatile in managing the intrinsic uncertainty brought on by ambiguous and subjective information.

1. Introduction

Industry 4.0 or the Fourth Industrial Revolution is gaining popularity among executives, managers, and government representatives because of its ability to develop intelligent firms and supply chains (SC) through the use of sophisticated technologies like as big data, analytics, Internet of Things (IoT), and cyber-physical systems (CPS) [1, 2]. These technologies improve SC components like warehousing, manufacturing, and logistics, with logistics 4.0 being a crucial part that could profit from SC digitalization [3, 4].

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Logistics 4.0 is a new paradigm that is interconnected with Industry 4.0. It can be viewed as short- and medium-term viewpoints, with short-term viewpoints focusing on firm processes using large amounts of data. Medium-term perspectives see logistics 4.0 as autonomous, self-organizing systems within other systems, equipped with smart technologies like big data, smart sensors, IoT, and CPS. These technologies create highly data-driven ecologies that meet customized demands more effectively [5]. Logistics 4.0 is also defined as a logistics structure consisting of autonomous subsystems, whose behavior depends on surrounding subsystems. It encompasses CPS monitoring of physical processes, generating virtual replicas of the real world, and implementing decentralized decision-making [6, 7]. Real-time communication with machines and humans is enabled through IoT, and data mining supports decision-making. However, this transformation is challenging due to high technological costs, infrastructure costs, global participation, complex SC networks, and privacy and security concerns [8].

Implementation issues for Logistics 4.0 must be taken into account by both the industrial and academic sectors. Identifying and analyzing Critical Success Factors (CSFs) for logistics 4.0 adoption is essential for ensuring a seamless and effective execution. By properly analyzing specific CSFs using a Multi-Criteria Decision Making (MCDM) method problem in uncertain or ambiguous circumstances, logistics 4.0 can be regulated. Hence, it is required to explore the CSFs while bringing logistics 4.0 into action. For successful administration, managers need to be aware of the structural interdependencies between the chosen CSFs. By focusing on these objectives, this study aims to bridge existing knowledge gaps and support policymakers in the efficient adoption of logistics 4.0. There are a number of significant factors that affect how conventional logistics will change to logistics 4.0 for businesses. This study is being conducted as a result to fulfill the aforementioned objectives. This study aims to overcome the following research gaps and aid officials in the effective deployment of logistics 4.0:

1. To pick out the main CSFs of the implementation of logistics 4.0;
2. To organize the CSFs according to the cause-and-effect rating and build causal links among the finalized CSFs to help implement logistics 4.0.
3. To involve multiple heterogeneous decision-maker (DM) groups in the decision-making process.

To determine how to achieve the above-mentioned goal, a thorough literature study is carried out with the help of an expert to point out the CSFs of logistics 4.0. These CSFs are interlinked, and this interlinkage is examined through the D-number based Pythagorean fuzzy Decision Making Trial and Evaluation Laboratory (D-PFDEMATEL) technique, which is suitable for group decision-making (GDM) in incomplete and uncertain data. The proposed research paradigm incorporates the abilities of Trapezoidal Pythagorean Fuzzy Numbers (TrPFN) for dealing with fuzziness and D-Numbers for getting an improved and precise decision from a non-homogeneous group of DMs along with their linguistic choices. Additionally, it is adaptive and versatile in managing the inherent uncertainty brought on by ambiguous and subjective information.

The article is organized as follows: Section 2 provides a brief literature review on logistics 4.0 and the DEMATEL method. Section 3 introduces the proposed DEMATEL model utilizing TrPFN and D numbers. The execution of the study is discussed in Section 4. Section 5 delves into the analysis of the results, and, lastly, Section 6 offers the conclusion.

2. Literature Review

The logistics 4.0 paradigm comprises three aspects: external, technological, and human factors. The external aspect is primarily concerned with the paradigm shifts brought on by customer requirements for high-quality products, Industry 4.0 innovations, globalization, and sustainability. It also includes changes in societies, such as work-life balances [9, 10]. The technology aspect includes the technological underpinnings of the paradigm shift, such as social media apps, cloud computing, and digital transformation. This aspect could be viewed as a drive towards "4.0" systems [9]. The third aspect emphases on logistics, focusing on tasks, areas, and human influences. Tasks include management and execution actions, which can be distributed into four domains: supply logistics, production logistics, distribution logistics, and reverse logistics [11]. Human factors, such as physical limits, psycho-social interactions, decisions, and motivation all have an impact on logistics both in terms of effectiveness and quality. In Logistics 4.0, humans will not be replaced by machines, but new technology and human-machine interaction impact and support their job. Humans play a significant role in the adoption or denial of new technology because of how they perceive its pros and cons. [12].

Logistics 4.0 initiatives have been shown to help the economy by dropping costs, increasing productivity, improving customer satisfaction, and improving information accuracy [13, 14]. However, phase of logistics 4.0 has received little attention in the available research. Most studies emphasis on the technical aspects of logistics 4.0, such as the role of robots in logistics, the execution of block chain technologies in the automotive production, and the development of fresh technological solutions like big data, CPS, IoT, and mobile-based systems. In logistics, robots have a critical function to play, particularly in Industry 4.0, as they aid in selection, operations, and logistics awareness. 'Cobots', collaborative robots, can be useful in smart logistics systems [15]. Block chain technologies are also being implemented in the automotive industry, creating significance in logistics 4.0 [16]. Research has acknowledged chances for sustainable logistics and SCs in logistics 4.0 [17]. The application of a logistics 4.0 framework for identifying future strategies and technologies for sustainable operations and the development of new technological solutions like big data, CPS, IoT, and mobile-based systems are explored [18]. A few studies also examined practitioners' multidimensional approach to Industry 4.0 projections in logistics, influenced by operational, financial, and human resources changes in various industries [19].

The DEMATEL method is extensively employed as a technique for decision-making in real-world scenarios, analyzing interdependencies between factors and their significance. It can be effectively used in uncertainty situations by fuzzy sets and extensions.

The DEMATEL model finds application in diverse fields, including global management, prioritization of SWOT matrix in the insurance firms, and GDM, and supply chain management (SCM). Recent models have used fuzzy sets, intuitionistic fuzzy sets (IFS), and Pythagorean fuzzy sets to address these issues [20–23]. Table 1 delivers a detailed overview of recently developed models for the DEMATEL Method.

Table 1
Comparison of the proposed methodology in contrast to latest literature on DEMATEL

Author	Crisp number	Fuzzy number	Interval-valued IFS	PFN	D-number	GDM
Gabus and Fontela [24]	√					
Wu and Lee [20]		√		√		
Giri et al. [23]	√	√		√		
Lin et al., [25]	√				√	√
Yavas and Ozkan-Ozen [22]		√				√
Abdullah et al., [26]			√			
Pribicevic et al., [27]		√			√	√
Yuksel and Dincer [28]				√		
Proposed method	√	√	√	√	√	√

Prior research has primarily concentrated on fuzzy numbers, concentrating solely on membership functions and assuming a homogeneous group of DMs, which may not be optimal for various situations. To encompass the benefits of non-membership functions, we adopt Pythagorean fuzzy sets (PFS), a more comprehensive concept in uncertain decision-making processes. Implementation of logistics 4.0 entails the amalgamation of diverse management areas, making it more pragmatic to incorporate expertise from various domains in decision-making procedure. This complexity can be effectively managed by D-numbers. Hence, by assimilating D-numbers and PFS theory into DEMATEL, we create a framework capable of handling uncertainty and fuzziness within the data, elucidating the interrelationships between criteria and their influences. This study advances the theoretic framework for GDM using the DEMATEL method, employing PFS and D-numbers. Our work appropriately addresses the limitations of previous studies. Firstly, PFS introduces membership and non-membership values, effectively addressing realistic problems characterized by fuzzified and uncertain information. Secondly, the application of D-numbers proves to be a robust approach for grouping DMs' linguistic evaluations and achieving consensus among both homogeneous and non-homogeneous expert groups. Lastly, D-numbers are able to process DMs' preferences (or confidence levels) articulated through probability along with fuzzy linguistic variables (FLV), providing a realistic representation of ambiguities. Consequently, the DEMATEL method is enhanced to adeptly manage intricate decision-making scenarios in a realistic means.

3. Methodology

3.1 DEMATEL method for GDM [29]

Step 1. A team of m DMs divided into two panels $G1$ and $G2$, analyses the n different criteria and expresses their opinion using PFLVs. The PFLVs used for comparison are expressed as TrPFN $l = \{l_b, b = 1,2, \dots, k\}$, where each term l_b is represented as TrPFN $\langle(a_1, a_2, a_3, a_4); \mu, \nu\rangle$ and k reflects the number of FLVs. Each expert panel determines the extent to which criterion i influences criterion j. The expert group's judgement of the i^{th} and j^{th} criteria is provided via the D number D_{ij}, which is indicated by

$$
\begin{aligned}
D_{ij}^{1} &= \left\{(l_{ij(1)}^{1}, v_{ij(1)}^{1}), \dots, (l_{ij(i)}^{1}, v_{ij(i)}^{1}), \dots, (l_{ij(k)}^{1}, v_{ij(k)}^{1})\right\} \\
D_{ij}^{2} &= \left\{(l_{ij(1)}^{2}, v_{ij(1)}^{2}), \dots, (l_{ij(i)}^{2}, v_{ij(i)}^{2}), \dots, (l_{ij(k)}^{2}, v_{ij(k)}^{2})\right\}
\end{aligned}
\tag{1}
$$

where k denotes the quantity of PFLVs utilized for judgement and D_{ij}^1, and D_{ij}^2 denote the D numbers used to characterize, respectively, $G1$ and $G2$'s preferences. By doing this, we are able to create dual $n \times n$ matrices, $\Omega^1 = \left[D_{ij}^1\right]_{n\times n}$ and $\Omega^2 = \left[D_{ij}^2\right]_{n\times n}$, where each element of each matrix corresponds to a D number.

Step 2. Converting D matrices into a single PFLV matrix is done in three phases.

Phase I involves combining initial expert preferences' uncertainties using the combination rule for D numbers, $D_{ij} = D_{ij}^1 \odot D_{ij}^2$ as given below

$$
\begin{aligned}
&D(\phi) = 0 \\
&D(B) = \frac{1}{1 - K_D} \sum_{B_1 \cap B_2 = B} D_1(B_1) D_2(B_2), B \neq \phi
\end{aligned}
\tag{2}
$$

with

$$K_D = \frac{1}{Q_1 Q_2} \sum_{B_1 \cap B_2 = \phi} D_1(B_1) D_2(B_2)$$
$$Q_1 = \sum_{B_1 \subseteq \theta} D_1(B_1)$$
$$Q_2 = \sum_{B_2 \subseteq \theta} D_2(B_2)$$

Phase II converts uncertainties at intersections of PFLVs into single PFLVs using the proportion between intersection surfaces and corresponding area of PFLVs.

$$D_{FLVT}(H_i) = D(H_i) + D(H_i, H_{i+1}) \frac{\frac{S_{i,i+1}}{S_i}}{\frac{S_{i,i+1}}{S_i} + \frac{S_{i,i+1}}{S_{i+1}}} \tag{3}$$

$$D_{FLVT}(H_{i+1}) = D(H_{i+1}) + D(H_i, H_{i+1}) \frac{\frac{S_{i,i+1}}{S_{i+1}}}{\frac{S_{i,i+1}}{S_i} + \frac{S_{i,i+1}}{S_{i+1}}} \tag{4}$$

where the intersection area between the PFLV l_i and l_{i+1} is characterized by $S_{i,i+1}$, while the area of the PFLV l_i and l_{i+1} is represented by S_i and S_{i+1}, respectively. Afterwards, we attain a D matrix $\Omega = [D_{ij}]_{(n \times n)}$.

Phase III involves converting the D matrix components to a unique direct relational matrix $Z = [z_{ij}]_{(n \times n)}$ by means of the expected values, where,

$$z = \sum E(v_i) D(v_i) \tag{5}$$

The expected values are determined using the equation,

$$E(A) = \frac{(a_1 + a_2 + a_3 + a_4)}{4} \sqrt{\mu^2 + \nu^2} \tag{6}$$

where, $A = \langle (a_1, a_2, a_3, a_4); \mu, \nu \rangle$ is a TrPFN and $a_1, a_2, a_3, a_4 \in \mathbb{R}$.

Step 3. The elements of the normalized matrix $N = [n_{ij}]_{n \times n}$ are calculated by means of the equation,

$$N = g \times Z \tag{7}$$

where,

$$g = \frac{1}{\max_{1 \le i \le n} \sum_{j=1}^{n} z_{ij}} \tag{8}$$

Step 4. The PF total matrix, $T = [t_{ij}]_{n \times n}$, is calculated as

$$T = N(I - N)^{-1} \tag{9}$$

where I is an identity matrix.

Step 5. Determine the matrix's row sum vector D and column sum vector R.

$$R = \left[\sum_{j=1}^{n} t_{ij} \right]_{1 \times n} \text{ and } D = \left[\sum_{i=1}^{n} t_{ij} \right]_{n \times 1} \tag{10}$$

The significance factor index (D-R) and influence strength index (D+R) are employed to create a meaningful relationship map within cause-and-effect categories. The D-R values indicate the net impact on the organization. Criteria are characterized into cause-and-effect groups. DMs can examine the outcomes to gain a deeper understanding and focus on important CSFs. Fig. 1 depicts the flow diagram of the method.

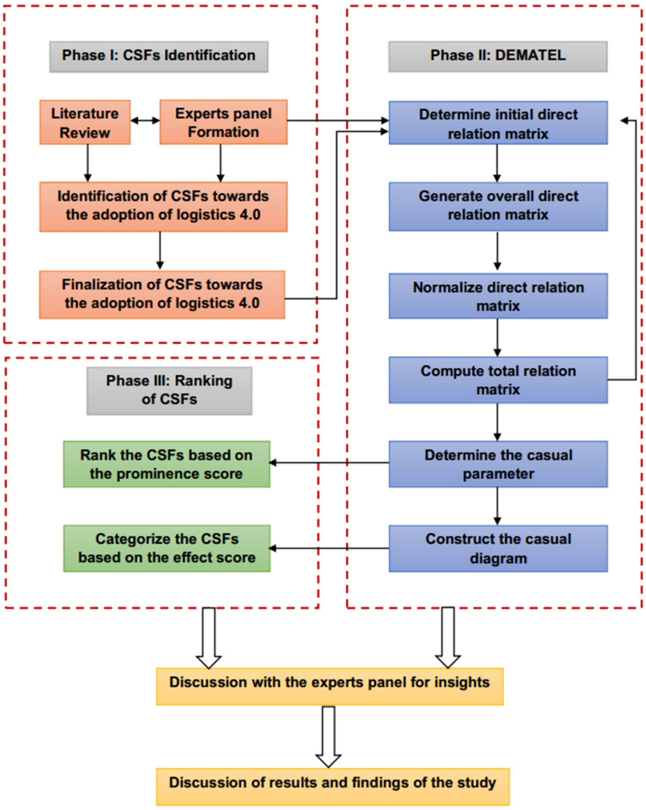

Fig. 1. Flow diagram of the proposed method

4. Case Study

A thorough literature study is conducted to identify the CSFs of logistics 4.0. Ten criteria are finalized suitable for logistics 4.0, which are: coordination of logistics 4.0 goals with company strategies (F1), managerial dedication (F2), acquisition of analytical skills (F3), investment availability (F4), education and training (F5), research atmosphere (F6) technological framework (F7), knowledge transfer (F8), trust and partnership (F9), and intelligent workplace (F10). The research is grounded in insights gathered from a panel of three industry experts and three academic experts, all of whom have collaborations with the industry. These professionals are affiliated with different academia specializing in logistics management, holding doctoral degrees and possessing expertise in logistics. An assessment form was meticulously crafted and distributed to the DMs via email. The form comprises two parts: the initial segment captures the DMs' biographical data, while the second part includes a comparative table featuring 10 criteria. Each expert was tasked with evaluating the pairwise causal relationships of the 10 logistics 4.0 criteria, utilizing the PFL scale outlined in Table 2. For clarity, an illustration of a linguistic valuation provided by an expert is furnished in Table 3.

Table 2
Pythagorean fuzzy linguistics scale

Linguistic variable	Corresponding TrPFN
Absolutely low (AL)	⟨(0,0,0,0); 0,1⟩
Low (L)	⟨(0,0.1,0.2,0.3); 0.1,0.8⟩
Fairly low (FL)	⟨(0.1,0.2,0.3,0.4); 0.3,0.7⟩
Medium Low (ML)	⟨(0.3,0.4,0.5,0.6); 0.5,0.5⟩
Fairly high (FH)	⟨(0.5,0.6,0.7,0.8); 0.6,0.4⟩
High (H)	⟨(0.7,0.8,0.9,1); 0.8,0.2⟩
Absolutely high(AH)	⟨(1,1,1,1); 1,0⟩

Table 3
Evaluation of dimensions by DM 1

	F1	F2	…	F10
F1	(0,0)	(ML,0.3)	…	(ML,0.1)
F2	(FH,0.2)	(0,0)	…	(ML,0.6)
F3	(L,0.2)	(FL,0.2)	…	(ML,0.4)
F4	(L,0.2)	(ML,0.15)	…	(ML,0.4)
F5	(FL,0.5)	(L,0.20)	…	(FL,0.3)
F6	(L;FL,0.3)	(ML;FH,0.25)	…	(ML,0.6)
F7	(FH,0.2)	(FL,0.25)	…	(FL,0.3)
F8	(L;FL,0.3)	(L;FL,0.6)	…	(L;FL,0.4)
F9	(L,0.15)	(ML,0.1)	…	(ML,0.5)
F10	(FL,0.25)	(FH,0.3)	…	(0,0)

Step 1. The study involved six DMs from two groups, $G1$ and $G2$, working in Transportation and Logistics Management and Sustainable SCM respectively. They compared ten criteria for logistics 4.0 implementation using a 7-point PFL scale and expressed their opinions using D numbers.

Step 2. Phase I involves combining uncertainties from DMs' groups to obtain accumulated preferences, using rule (2).

Phase II involves transforming uncertainties at joining of two PFLVs into single PFLVs using equations (3) and (4), resulting in a unique Pythagorean fuzzy D matrix, Ω.

In Phase III, the TrPFNs are substituted with expected values from Table 3, and equation (6) is used to alter matrix Ω into a unique direct relational matrix, Z, as shown in Table 4.

Table 4
Single direct relational matrix

	F1	F2	F3	F4	…	F10
F1	0.000	0.361	0.462	0.354	…	0.318
F2	0.452	0.000	0.504	0.392	…	0.354
F3	0.156	0.161	0.000	0.373	…	0.287
F4	0.153	0.394	0.272	0.000	…	0.287
F5	0.266	0.199	0.229	0.245	…	0.390
F6	0.136	0.431	0.214	0.160	…	0.603
F7	0.445	0.217	0.446	0.272	…	0.390
F8	0.201	0.169	0.288	0.151	…	0.212
F9	0.127	0.258	0.174	0.118	…	0.341
F10	0.217	0.446	0.217	0.191	…	0.000

Step 3. Using equations (7) and (8), direct relational matrix, Z, is normalized, to obtain normalized relational matrix, N.

Step 4. The PF total matrix T is calculated by means of Eq.(9) and is depicted in Table 5.

Table 5
Pythagorean fuzzy total relation matrix

	F1	F2	F3	F4	...	F10
F1	0.203	0.339	0.376	0.306	...	0.374
F2	0.360	0.292	0.437	0.356	...	0.440
F3	0.184	0.219	0.179	0.245	...	0.280
F4	0.206	0.299	0.279	0.169	...	0.309
F5	0.244	0.265	0.280	0.244	...	0.350
F6	0.222	0.334	0.286	0.231	...	0.414
F7	0.340	0.337	0.403	0.309	...	0.431
F8	0.180	0.197	0.235	0.173	...	0.236
F9	0.196	0.259	0.246	0.196	...	0.318
F10	0.242	0.332	0.287	0.240	...	0.260

Step 5. The step involves calculating the column sum, R, and the row sum, D, and then calculating the values $D + R$ and $D - R$, representing 'prominence' and 'relation', respectively. If $D - R > 0$, the criteria are ranked as the cause, influencing other criteria, while if $D - R < 0$, they are classified as the effect. The cause-effect diagram is then plotted using these values, with the x-axis representing the $D + R$ value and the y-axis representing the $D - R$ value, indicating the cause-and-effect set, as shown in Fig. 2. The prominence and relation values and the rankings of the factors are given in Table 6.

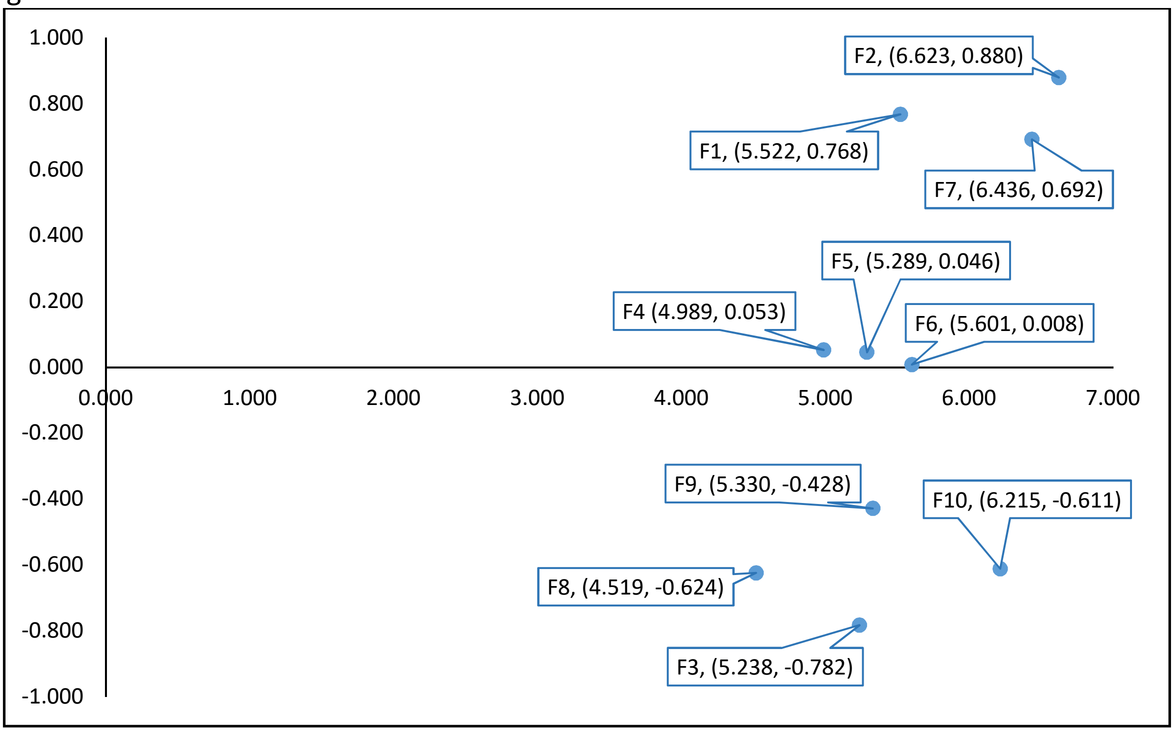

Fig. 2. Cause and Effect Diagram

Table 6
Final rankings

	D	R	D + R	D - R	Rank
F1	3.145	2.377	5.522	0.768	2
F2	3.751	2.872	6.623	0.880	1
F3	2.228	3.010	5.238	-0.782	10
F4	2.521	2.468	4.989	0.053	4
F5	2.668	2.622	5.289	0.046	5
F6	2.805	2.797	5.601	0.008	6
F7	3.564	2.872	6.436	0.692	3
F8	1.947	2.571	4.519	-0.624	9
F9	2.451	2.879	5.330	-0.428	7
F10	2.802	3.413	6.215	-0.611	8

The variations in DMs' judgments for 10 criteria are also computed using the normalized Euclidean Difference Measure. We compare the D+R values that were acquired for each panel. The dissimilarity measure serves as a numeric indicator of the degree of distinctiveness between two data points. It is between 0 and ∞. Here, a difference of 7.11 in opinions is established. This indicates that there isn't much difference between the expert groups' perspectives [30].

5. Result Discussion

The CSFs are analyzed for the execution of logistics 4.0 using the proposed D-PFDEMATEL model, which successfully captured the overall impact on one another. The proposed methodology is applied to categorize the ten CSFs into cause-and-effect categories. Out of which, six factors - managerial dedication (F2), coordination of logistics 4.0 goals with company strategies (F1), technological framework (F7), investment availability (F4), education and training (F5), and research atmosphere (F6) belong to cause category while remaining four factors - trust and partnership (F9), intelligent workplace (F10), knowledge transfer (F8), and acquisition of analytical skills (F3) belong to effect category. The DEMATEL method ranks CSFs for logistics 4.0 into cause-and-effect categories based on prominence value, aiding in enhanced decision-making. Cause group members are more significant, while effect group members are prone to be influenced by others, causing them minimal qualified for system enhancements. This approach helps analyze relationships between criteria and enhances system improvement.

A strategic map, illustrated in Figure 3, delineates the significant structural relationships between the criteria for conducting an in-depth analysis. To ensure precision and meaningfulness, the establishment of a threshold value is crucial to filter out less important connections between the criteria. The threshold value, denoted as α, is computed using the mean value for matrix T, yielding a calculated α of 0.279. Relationships with values less than α were eliminated from the map. For visual clarity, different types of arrows were employed to represent varying echelons of relations among the criteria based on their strength. A red-colored arrow with dashes indicates a medium relationship, a blue-colored thin lined arrow indicates a strong relationship, and a green-colored thick lined arrow signifies an extremely strong relationship. These arrow types were determined by scrutinizing the total relational matrix, T. Following the calculation of the threshold value and the elimination of values below α, the extreme values in the matrix T were identified. Relations were then categorized on a three-point measure: values between 0.279 and 0.333 were considered to have a 'medium relationship', those between 0.333 and 0.387 were classified as a 'strong relationship', and values ranging from 0.387 to 0.440 were designated as having an 'extremely strong relationship'.

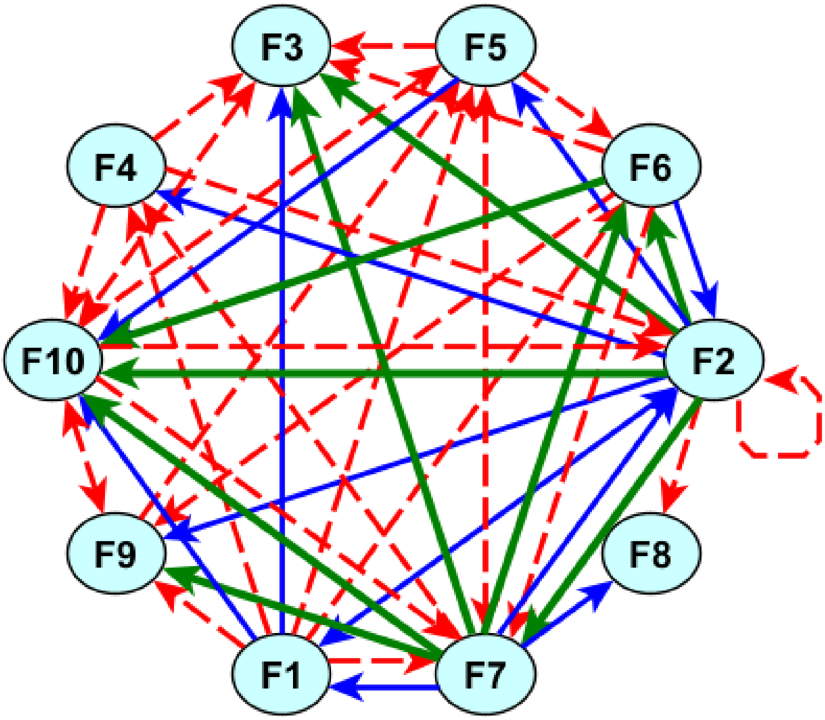

Fig. 3. Strategic map

5.1 Cause Criteria Analysis

Performance in the cause group has an impact on the complete system. The cause group criteria are therefore given additional attention in the implementation of logistics 4.0. According to our findings, six of the ten CSFs, managerial dedication (F2), coordination of logistics 4.0 goals with company strategies (F1), technological framework (F7), investment availability (F4), education and training (F5), and research atmosphere (F6), belong to the cause group. In the cause category, 'managerial dedication' (F2) received the highest D-R rating. With a prominence value of 5.075, F2 stands out among the KSFs as a prominent factor. Managerial dedication, thus has the biggest effect on the whole system, as logistics 4.0 necessitates the integration and coordination of smart technologies. Organizations must provide monetary and technological support to successfully adopt logistics 4.0. 'Coordination of logistics 4.0 goals with company strategies' (F1) is the second most influencing factor, motivating management to develop policies and guidelines for its adoption. This includes initiatives like IoT, big data analytics, CPS, and traceability. 'Technological framework' (F7), including virtual interfaces, high-speed data transfer systems, and real-time status monitoring, is essential for logistics 4.0 adoption. This infrastructure impacts factors like intelligent work culture and analytical skills. 'Investment availability' (F4) is a critical component for logistics 4.0 adoption because it necessitates significant investment from stakeholders. For logistics professionals to develop an intelligent culture and transfer knowledge, 'education and training' (F5) are just as crucial. Workshops and seminars can be used to provide training, developing a smart workplace culture. Another influencing factor for the adoption of logistics 4.0 is the 'research atmosphere' (F6), which aids in the development of processes and technology support. Through various incentives, top management should encourage research while also supporting knowledge transfer, an intelligent workplace culture, and the acquisition of analytical skills. These factors are vital for logistics 4.0 to be implemented successfully.

5.2 Effect Criteria Analysis

The effect category is subjective to four factors: trust and partnership (F9), intelligent workplace (F10), knowledge transfer (F8), and acquisition of analytical skills (F3). The acquisition of analytical skills is influenced by elements including managerial dedication, the research atmosphere, and the technological framework (F3). Knowledge transfer (F8) is impacted by education, training, and research, and an intelligent workplace (F10) is produced by managerial dedication. The managerial dedication also affects trust and partnership (F9). These elements might become more potent as cause group CSFs advance.

5.3 Implications

Logistics 4.0 is a rapidly growing concept that organizations are pursuing a decision support system to facilitate its adoption. This study provides a list of CSFs for implementing logistics 4.0, providing organizations with a well-informed position. To successfully adopt logistics 4.0, managers should concentrate on influencing elements including managerial dedication, financial as well as non-financial. The effect of logistics 4.0 on the company's success ought to inspire top management. A technological framework, developed through public-private partnerships, is also essential for successful adoption. Managers should be prepared to invest in developing this framework. Prioritizing factors such as invest availability in logistics 4.0, education and training, and research atmosphere is crucial. The causal map explains the causal linkages between the components, which aids policy planners in developing implementation strategies. Overall, logistics 4.0 adoption is a challenging task that requires careful planning and investment.

6. Conclusions

DEMATEL analysis ranked CSFs into influential and influenced groups, with influencing factors significantly impacting logistics 4.0 adoption. Advancements in influencing factors lead to improvements in influenced factors, requiring initial focus on these factors. The results suggest managerial dedication is the crucial CSF for logistics 4.0 adoption, as it requires smart technologies, integration, and coordination. Therefore, organizations must provide financial and technological support. Coordinating logistics 4.0 goals with company strategies, such as big data analytics, IoT, traceability, and CPS, is essential. Technological framework, including high-speed data sharing, real-time condition monitoring, and virtual interfaces, also influences smart work culture and analytical capabilities. With a dependent relationship, four of the influenced group's factors are impacted by the influencing factors. As cause group CSFs improve, these parameters could also get better. While this research addresses a notable gap in the existing literature, additional research would be necessary in the future to build upon these findings. The model's validity and effectiveness are evaluated by executing it to information acquired from DMs, followed by a comparison study. By giving a list of CSFs that are important for the implementation of logistics 4.0, this study proves beneficial for industrial practitioners, academic professionals within the field, and offers valuable insights for future recommendations.. Organizations can make well-informed decisions about the deployment of logistics 4.0 after evaluating these criteria. The findings of this study also help managers as they can concentrate just on influential elements as it is difficult to focus on all of the factors at once. The study's reliance on expert opinions introduces potential biases influenced by their management roles, geographical locations, and organizational affiliations. Additionally, equal weight was assigned to the opinions of each expert group. Furthermore, the study involved a relatively small group of DMs. As part of future research endeavors, our developed method will be employed to analyze MCDM problems associated with logistics. The proposed methodology could also be seamlessly combined with Interpretive Structural Modeling (ISM) to establish a rational grading amongst factors, categorizing challenges based on their causal relationships. This integration aims to enhance decision-making processes.

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Conflicts of Interest
The authors declare no conflicts of interest.

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