Iranian Journal of Operations Research
Vol. 15, No. 1, 2024, pp. 12-27
DOI:

Causal relations of Collaboration in Supply chain 4.0

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Abstract

The basic purpose of this study is to investigate and display causal relationships among collaboration components in supply chain 4.0 using a fuzzy framework. After reviewing articles and extracting indicators, a collaboration model with trust, initiators, barriers, dimensions, and outcomes was designed. Then using the fuzzy DEMATEL method, the effect of each variable and its position were determined. To collect data targeted sampling and snowball methods were used. 20 questionnaires were distributed to supply chain and digital technologies experts. In this study, SCC 4.0 was examined by analyzing 27 primary factors categorized into 5 sections based on causal relationships. Among these, 20 factors were identified as influential factors, while 7 factors were deemed impactful factors. The trust value (D=2.36225) was found to have the most significant impact on other variables within the collaborative model. Trust (D+R=3.4111) and ICT infrastructure (D+R=3.1236) were closely linked and considered the foundational elements of the model. Implementing positive changes related to these two factors could result in more substantial and effective transformations in SCC 4.0, such as enhanced economic performance (D+R=3.1562) and social performance (D+R=2.5562). SC 4.0 managers can facilitate the development of collaborative trust across the SC By investing in communication and technology infrastructure.

Keywords: *Industry 4.0 technologies, Supply chain 4.0, Trust, Fuzzy DEMATEL.*

Manuscript was received on 02/12/2024, revised on 06/03/2024 and accepted for publication on 06/03/2024.

1. Introduction

The new world has undergone significant changes in the last decade with the growth of practical applications of Industry 4.0 [29]. The fourth industrial revolution has transformed processes, services, and products in many different industries. Industry 4.0 aims for continuous automation and data exchange, enabling seamless interaction between objects, machines, and humans to develop digital and intelligent business systems [19]. Supply chains (SCs), like other cases, have not been unaffected by these transformations. Implementing and accelerating Industry 4.0 technologies throughout the SC has led to gradual changes in supply chain processes [14]. The digitization of SC has improved profitability, efficiency, flexibility, agility, and responsiveness for companies. In this regard, SC 4.0

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refers to the use of the Internet of Things (IoT) and advanced data analytics in supply chain management as well as placing sensors on everything, networking, and automation to significantly improve performance and customer satisfaction [29]. The formation and sustainability of such a flow for SC components are only possible through modernization and reliance on the capabilities of Industry 4.0. The use of human capabilities such as collaboration is a fundamental requirement for stabilizing and implementing such ideas in SC [11] and it can effectively handle divergent objectives among the individuals within the chain [3].

Strategic collaboration is one of the key factors for the success of a modern SC [4]. Each type of relationship requires effective collaboration for survival [2]. Organized collaboration within companies, both internally and externally, improves communication among existing factors. Mutual collaboration to benefit SC network members requires serious investment in the competitive environment of the modern industry [32]. This collaboration increases the ability of companies to respond quickly and efficiently to environmental changes, and companies can configure resources to develop products that fit the market and increase revenue. The presence of collaboration eliminates misunderstandings among different levels within an organization structure which serves as a starting point for mutual understanding within an organization from a larger set or an SC [20].

In the absence of collaboration in SC, each level will only seek to increase its profitability [18]. This is even though without considering the demands, needs, conditions, and dependencies between other levels, SC lacks its proper functioning. The current use of digital technologies has strengthened information exchange towards improving supply chain collaboration (SCC) and facilitating sustainable benefits between companies and can give a competitive advantage to organizations from environmental, economic, and social perspectives [27]. The use of Industry 4.0 technologies towards process digitization and automation leads to a supportive approach for SCC.

Knowing the main components of collaboration and understanding how the components influence the supply chain leads to the creation of a collaborative platform to improve the performance of organizations. To form collaboration in SC, it is necessary to identify and investigate the factors affecting collaboration and the relationships between them. For this purpose, in this research, 5 main sections including Trust, Initiators, Barriers, Dimensions, and Outcomes are analyzed. Initiators include drivers' and enablers and examine changes in management actions for better collaboration. Barriers prevent changes and freeze an organization in its current state. To increase collaboration among SC members, managers must identify and understand the nature of Initiators and Barriers. Collaborative changes occur when managers strengthen Initiators and control and weaken Barriers. Dimensions represent the index and criterion of collaboration estimation and Outcomes are considered as the results of the implementation of collaborative performance in SC. Also, the concept of Trust as an independent factor plays a role in improving Initiators and reducing Barriers. Examining each of these parts in this research is important, but the way each group of factors affects other parts is also significant because all aspects interact with each other to create a collaborative output in SC; therefore, the main purpose of the research is to examine the causal relationships between the 5 sections.

2. Literature Review

Industry 4.0 started to transform businesses, products, and services in many different manufacturing and service industries. SC 4.0 is defined as the new generation of digital SCs that utilize Industry 4.0 technologies such as Artificial Intelligence (AI), IoT, and blockchain to improve performance and customer satisfaction [38]. Digital technologies have major impacts on the SCs [6] such as improving profitability, productivity, agility, and responsiveness [23]. Digitization of an SC is one of the great opportunities for businesses and organizations to growth possibility in the future and improve their business reputation [15]. Therefore, SC parties collaborate and manage organizational processes and common resources to achieve efficient flows [30].

Collaboration is referred to as the driving force behind supply chain management and may be the ultimate core capability [24]. However, there is a widespread belief that few firms have truly capitalized on their potential to change their situation [22]. SCC is the network of various entities that work cohesively to make up Procedures and processes. SCC prompted companies to implement data analytics functions to improve SC efficiency [1]. To deal with the increasing world challenges, SCs must become smarter and take advantage of collaboration with partner relationships [6].

The conditions that Industry 4.0 technologies have created for industries and services [29] have affected the way of communication management and information sharing in the supply chain. Therefore, collaboration is considered an essential factor in the direction of stability and control of conditions to develop SC goals. Identifying collaboration alone is not a driving factor because the components of this concept have various aspects. The 5 main sections (Trust, Initiators, Barriers, Dimensions, and Outcomes) discussed in the introduction cover different basics. To create a better understanding of the impact of collaboration on SC 4.0, the relationships between the 5 main sections are analyzed to finally improve the performance of the SC with a more accurate description of the aspects of collaboration. So, the main research question is how the causal relationships between the collaboration components are. Relevant research is shown in Table 1.

Table 1: Relevant articles

	Authors	Source Title	Method	Findings	Supply chain 4.0
1	[16]	A conceptual digital collaborative SC model based on Industry 4.0 technologies	A deep review analysis and identifying the main factors to affect collaborative SC	Conceptualized a framework by developing a new digital collaborative SC model that be used as a referential guide for all SC actors.	Blockchain, IoT, and cloud computing
2	[35]	The Effect of Blockchain on SCC	Systematic review	Proposing a conceptual model for a blockchain-based information collaboration system and potential applications of blockchain technology to enhance SCC	Blockchain
3	[31]	SCC in the era of blockchain technologies	Conceptual approach	Relevance of the antecedents of the SCC in the era of blockchain technologies and highlighting the opportunities and challenges for blockchain technologies implementation in SC networks	Blockchain

	Authors	Source Title	Method	Findings	Supply chain 4.0
4	[10]	Improving SCC through operational excellence approaches	Analytic Hierarchy Process (AHP) and TOPSIS	Strengthening the integration of management information systems, improving information transparency and large data processing abilities are the measures of IoT in improving SCC	IoT
5	[19]	A digital platform for Industry 4.0 SME collaboration	Design Science Research (DSR) method	Presented the architecture design and implementation of the DIGICOR collaborative	Industry 4.0 platform
6	[7]	Effects of big data analytics capabilities, technological dynamism, and competitive intensity on SCC	Structural Equation Modelling	Collaboration has a direct effect on organizational performance, mediated by big data analytics capabilities and moderated by technological dynamism and competitive intensity	Big Data
7	[4]	A Design-Science Research in SCC	System Dynamics Approach	Understanding all aspects of sustainability, development, and optimization of future digital, collaborative SC and the underlying information systems through the application of AI	AI
8	[8]	Highly-integrated SCs in collaborative manufacturing	Implemented proof of concept based on a Hyper ledger Sawtooth application with Python	Devising a secure solution for block-chain interoperability	Blockchain
9	[9]	Perspective on SCC in the Context of SC Management 4.0	A systems theory and Action Design Research (ADR) approach	Using ADR for developing the implementation model as the interconnectedness of SC networks to enable a comprehensive system innovation and digitalization	Industry 4.0 platform

	Authors	Source Title	Method	Findings	Supply chain 4.0
10	[37]	Value enablement of collaborative SC environment	Confirmatory Factor Analysis (CFA)	presenting the impact of IoT origins on real-time data on a collaborative SC model	IoT
11	[33]	A new paradigm for SC integration and collaboration	Review	Blockchain may facilitate SCC and integration. Applications of blockchain including information sharing, traceability, and automation can enable SCC.	Blockchain
12	This study	Causal Relationships of Collaboration in SC 4.0	Fuzzy DEMATEL	Analysis of causal relations among 5 collaboration sections in SC 4.0	Industry 4.0 platform

3. Methodology

The fuzzy Decision Trial and Evaluation Laboratory (DEMATEL) technique was applied to examine the causal relations of collaboration components in SC 4.0 to produce a causal relations map. DEMATEL, being a comprehensive approach, enables the analysis of a structural model that encompasses causal relationships between various factors and sheds light on the interdependencies among them [21]. To handle the complexity of human judgment situations in the decision-making process, DEMATEL considers probability (Fuzzy) environments [28]. DEMATEL is used to verify the interdependence between variables and define the relations that reflect the characteristics of the basic system and the related trends over time [17]. DEMATEL technique can convert the relations among the causes and effects of criteria into an intelligible structural model of a system [34].

This research created a conceptual model in 5 sections by collecting data from the literature review of SCC articles. Then analysis of the causal relationships network between the collaboration components was done with the fuzzy DEMATEL method. The statistical population of research was formed by experts who are proficient in digital technologies in SC. The questionnaire was completed by 20 experts using non-probability and snowball sampling methods. Most of the respondents to the questionnaire had more than 5 years of work experience. In terms of education, half of the people had a doctorate. Since the obtained CVR was equal to 1 for all the factors, the experts confirmed the validity of the indicators and considered the determined factors to be necessary. To measure the reliability, the retest method was used based on the criterion of access to experts. The questionnaire was sent to five experts for re-checking and the correlation between the answers in the first and second stages was equal to 0.901, 0.882, and 0.793. Considering that the correlation of answers was more than 0.7, the reliability of the questionnaire is acceptable.

4. Finding

The relations map of SCC is shown in Fig. 1. In this conceptual model Trust as an independent factor in improving Initiators and reducing Barriers is on the right side of the model. One of the factors of high importance factor in accelerating the formation of the collaboration process in SC is trust [5]. Trust as a facilitating factor, on the one hand, can improve the speed of the initiators' effect on the SCC flow and, and the other hand, prevent the intensity of collaboration barriers. Initiators in 8 categories, barriers in 8 categories, dimensions in 7 categories, and finally outcomes in a general category including 3 sections were classified.

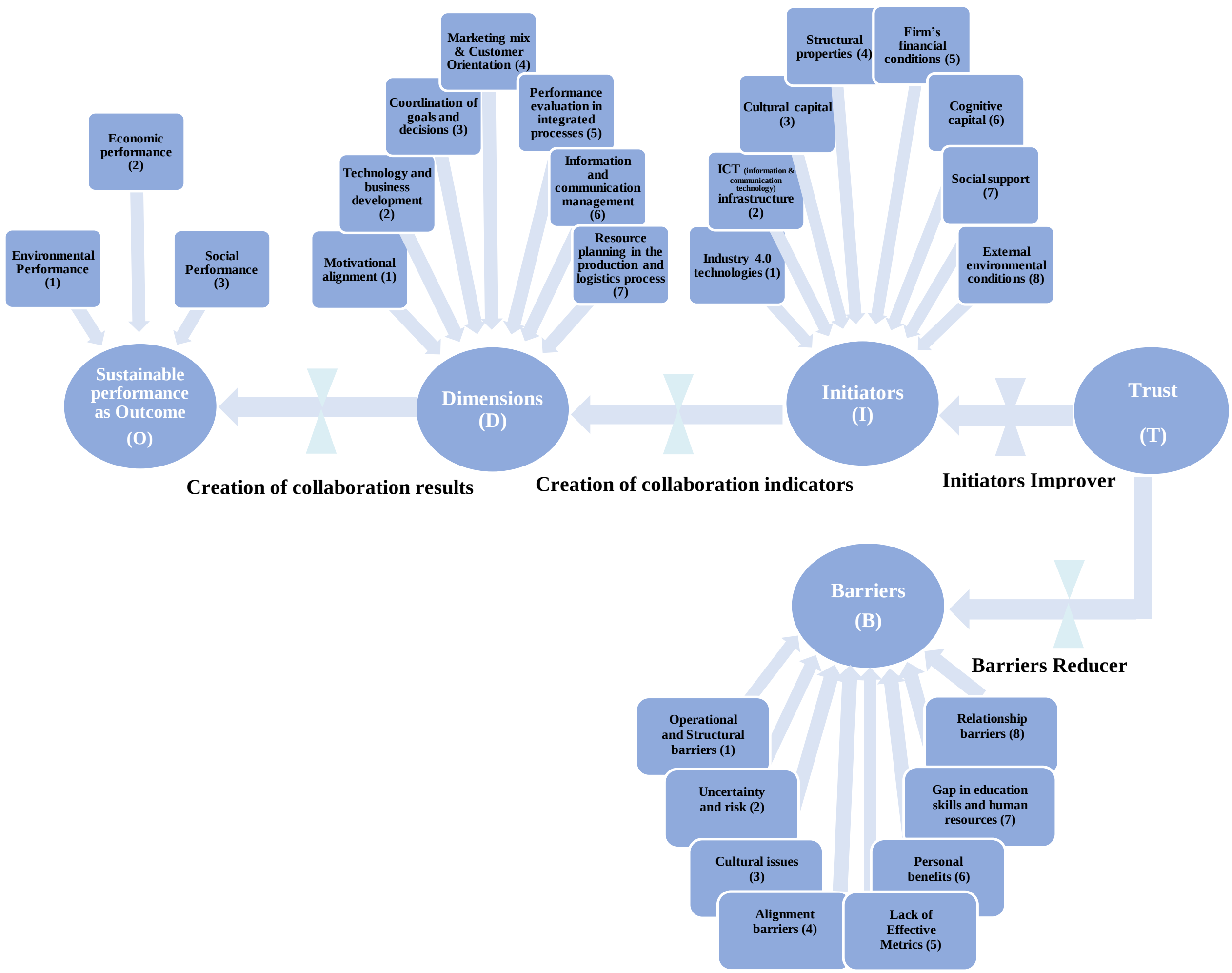

Fig.1. Conceptual model of collaboration components in supply chain 4.0

Causal relations made in 5 Steps based on Fig. 1 with the Fuzzy DEMATEL technique:

Step 1) Designing the fuzzy verbal scale to face the ambiguity of human judgment (Table 2). Fuzzy numbers have been used to express experts' preferences.

Table 2: Fuzzy Linguistic Scale

Linguistic Term	Influence Score	Triangular Fuzzy Number
No influence	0	(0, 0, 0.25)

Very low influence	1	(0, 0.25, 0.50)
Low influence	2	(0.25, 0.50, 0.75)
High influence	3	(0.50, 0.75, 1)
Very High influence	4	(0.75, 1, 1)

Step 2) A 27x27 non-negative matrix is established. 20 matrices with fuzzy values were obtained from experts' opinions and their average was calculated using the initial fuzzy matrix of direct relationships.

Step 3) Through the standardization relationship (1), the scale of indicators is converted into comparable scales. Relationship (2) is the fuzzy matrix of standardized direct relationships.

$$a_{ij} = (\sum_{j=1}^{i} l_{ij}, \sum_{j=1}^{i} m_{ij}, \sum_{j=1}^{n} u_{ij}) \qquad (1)$$

$$r = max_{1\le i\le n} (\sum_{j=1}^{n} u_{ij})$$

$$x_{ij} = \frac{z_{ij}}{r} = (l'_{ij}, m'_{ij}, u'_{ij}) \qquad (2)$$

Step 4) The fuzzy matrix of total relations T matrix is obtained (3). $x_{ij} = (l'_{ij}, m'_{ij}, u'_{ij})$, Values related to matrix entries of X_1, X_m, X_u respectively, included values l', m', u' in matrix X.

$$\tilde{T} = \lim_{k\to\infty} (\tilde{x}^1 + \tilde{x}^2 + \cdots + \tilde{x}^k) \qquad (3)$$

$$Xl = [l''_{ij}], Xm = [m''_{ij}], Xu = [u''_{ij}] \qquad (4)$$

According to the $t_{ij} = (l''_{ij}, m''_{ij}, u''_{ij})$:

$$[l''_{ij}] = X_I \times (1 - X_I)^{-1}, [m''_{ij}] = X_m \times (1 - X_m)^{-1} \qquad (5)$$

$$[u''_{ij}] = X_u \times (1 - X_u)^{-1} \qquad (6)$$

In this way, all values of T matrix entries were obtained as triangular fuzzy numbers. Then the values of $(D + R)$ and $(D - R)$ are obtained. Actually D *and* R respectively are the sum of rows and columns for each element in the matrix T. As a result, $[\tilde{D}_{n\times 1}], [\tilde{R}_{1\times n}]$ made with (7) and (8).

$$\tilde{D} = (\tilde{D}_i)_{n\times 1} = [\sum_{j=1}^{n} \tilde{T}_{ij}]_{n\times 1} \qquad (7)$$

$$\tilde{R} = (\tilde{R}_i)_{1\times n} = [\sum_{i=1}^{n} \tilde{T}_{ij}]_{1\times n} \qquad (8)$$

Table 3 shows the T matrix (total relationship matrix).

Table 3: Total relationship matrix

	T	I_1	I_2	…	O_2	O_3
T	(0.004, 0.015, 0.071)	(0.017, 0.031, 0.094)	(0.029, 0.052, 0.139)	…	(0.006, 0.041, 0.068)	(0.009, 0.64, 0.132)
I_1	(0.005, 0.010, 0.042)	(0.008, 0.019, 0.066)	(0.009, 0.014, 0.089)	…	(0.015, 0.028, 0.095)	(0.017, 0.031, 0.129)
I_2	(0.005, 0.013, 0.051)	(0.007, 0.029, 0.058)	(0.008, 0.018, 0.074)	…	(0.014, 0.039, 0.121)	(0.011, 0.029, 0.136)
…	…	…	…	…	…	…
O_2	(0.001, 0.011, 0.037)	(0.005, 0.008, 0.031)	(0.002, 0.008, 0.041)	…	(0.001, 0.005, 0.021)	(0.002, 0.009, 0.017)

$\boldsymbol{O_3}$	(0.001, 0.015, 0.047)	(0.006, 0.009, 0.069)	(0.001, 0.007, 0.030)	…	(0.002, 0.003, 0.018)	(0.001, 0.008, 0.019)

Then, the importance of the factors $(\tilde{D}_i + \tilde{R}_i)$ and the relationship between them $(\tilde{D}_i - \tilde{R}_i)$ are determined. If $(\tilde{D}_i - \tilde{R}_i > 0)$, the factor is an effective variable. If $(\tilde{D}_i - \tilde{R}_i < 0)$, the factor is an impressionable variable (Table 4).

Table 4: influence of factors (fuzzy numbers)

Factors	$\boldsymbol{\tilde{D}_i + \tilde{R}_i}$	$\boldsymbol{\tilde{D}_i - \tilde{R}_i}$
$\boldsymbol{T}$	(1.5556 3.0023 6.0113)	(0.8136 1.0245 2.4141)
$\boldsymbol{I_1}$	(2.0302 2.8401 3.8723)	(1.1001 1.2003 1.4023)
$\boldsymbol{I_2}$	(2.3526 3.3569 3.5865)	(0.9532 1.5009 1.6332)
$\boldsymbol{I_3}$	(1.4856 1.9986 2.1865)	(-0.9523-0.8569 0.1596)
$\boldsymbol{I_4}$	(1.3265 1.2965 2.0652)	(0.8236 0.9265 1.0256)
$\boldsymbol{I_5}$	(1.9865 2.1265 2.5689)	(0.2345 0.4632 0.7962)
$\boldsymbol{I_6}$	(0.5986 0.7658 0.9865)	(0.1236 0.2689 0.5192)
$\boldsymbol{I_7}$	(0.4258 0.6598 1.9632)	(0.5632 0.7896 1.1869)
$\boldsymbol{I_8}$	(0.8956 1.1862 2.0326)	(0.8963 1.1236 1.6596)
$\boldsymbol{B_1}$	(1.7896 2.2865 2.8598)	(0.3563 0.4898 1.1695)
$\boldsymbol{B_2}$	(1.9865 2.7595 2.9695)	(0.1265 0.3589 0.5865)
$\boldsymbol{B_3}$	(1.6329 2.5986 2.9685)	(0.6589 0.9685 1.8698)
$\boldsymbol{B_4}$	(1.2568 1.3698 2.3658)	(-0.9589-0.2256 0.1096)
$\boldsymbol{B_5}$	(0.9856 1.0956 1.9865)	(0.2458 0.5698 1.0685)
$\boldsymbol{B_6}$	(1.7896 2.5658 2.9985)	(0.0562 0.2695 0.3698)
$\boldsymbol{B_7}$	(0.2329 0.5986 0.9965)	(0.0326 0.1265 0.5586)
$\boldsymbol{B_8}$	(1.5689 1.9865 2.8985)	(0.5693 1.1006 1.7652)
$\boldsymbol{D_1}$	(1.3269 1.5986 2.7685)	(0.8596 1.2623 1.8962)
$\boldsymbol{D_2}$	(0.5863 0.9685 1.9598)	(-1.5632 -0.9563 0.2532)
$\boldsymbol{D_3}$	(0.3569 0.8965 1.1598)	(-0.8563 -0.2368 0.1896)
$\boldsymbol{D_4}$	(0.9685 1.4568 2.6632)	(0.12365 0.2689 0.6589)
$\boldsymbol{D_5}$	(0.5698 1.3236 1.7685)	(0.2659 0.3256 0.7489)
$\boldsymbol{D_6}$	(0.9685 1.8698 2.9396)	(0.4589 0.7895 1.2693)
$\boldsymbol{D_7}$	(0.2659 0.3985 0.7596)	(0.2589 0.5698 1.1685)
$\boldsymbol{O_1}$	(0.5896 1.6659 2.9625)	(-2.9685-1.5696 -0.5896)
$\boldsymbol{O_2}$	(2.7635 3.1869 3.4653)	(-1.6589 -0.75980.2658)
$\boldsymbol{O_3}$	(1.5898 2.4589 3.5686)	(-1.9685 -1.1358 -0.1895)

Step 5) For numbers defuzzification, the values of $(D + R)$ and $(D - R)$ are used. The value of $(D + R)$ is always positive and indicates the significance of that factor. Also if $(D - R)$ is positive; the factor is effective on other factors and otherwise, it is impressionable. The $(\tilde{D}_i + \tilde{R}_i)$ and $(\tilde{D}_i - \tilde{R}_i)$ fuzzy numbers are defuzzified based on (9). The B number is the defuzzification of $\tilde{A}$ number.

$$B = \frac{(a_1 + a_3 + 2 \times a_2)}{4} \quad (9)$$

$\tilde{A} = (a_1, a_2, a_3)$

The defuzzification numbers are shown in Table 5.

Table 5: influence of factors (defuzzification numbers)

Factors	Rank	D	R	$D+R$	$D-R$
Trust (T)	1	2.3622	1.0488	3.4111	1.3134
Industry 4.0 technologies (I_1)	4	2.0685	0.8546	2.9231	1.2139
ICT infrastructure (I_2)	2	2.3124	0.8911	3.2035	1.4213
Cultural capital (I_3)	13	0.6497	1.2825	1.9322	-0.6328
Structural properties (I_4)	18	1.1705	0.2506	1.4212	0.9199
Firms financial condition (I_5)	10	1.3595	0.8716	2.2311	0.4879
Cognitive capital (I_6)	25	0.5020	0.2001	0.7022	0.3019
Social Support (I_7)	23	0.9026	0.0825	0.9852	0.8201
External environmental conditions (I_8)	19	1.2700	0.0535	1.3235	1.2165
Operational and Structural barriers (B_1)	9	1.4626	0.8395	2.3021	0.6231
Uncertainty and risk (B_2)	5	1.4895	1.1200	2.6095	0.3695
Cultural issues (B_3)	7	1.7791	0.6770	2.4561	1.1021
Alignment barriers (B_4)	16	0.6616	0.9942	1.6559	-0.3326
Lack of Effective Metrics (B_5)	21	0.9114	0.3105	1.2219	0.6009
Personal benefits (B_6)	8	1.3266	1.0944	2.4211	0.2322
Gap in education skills and human resources (B_7)	26	0.4092	0.2035	0.6128	0.2057
Relationship barriers (B_8)	11	1.6271	0.4939	2.1211	1.1332
Motivational alignment (D_1)	14	1.5669	0.2443	1.8112	1.3226
Technology and businesses development (D_2)	22	0.1558	0.9564	1.1122	-0.8006
Coordination of goals and decisions (D_3)	24	0.2899	0.5130	0.8029	-0.2231
Marketing mix & Customer Orientation (D_4)	17	0.9945	0.6617	1.6562	0.3328
Performance evaluation in integrated processes (D_5)	20	0.8388	0.4167	1.2556	0.4221
Information and communication management (D_6)	12	1.3927	0.5605	1.9532	0.8322
Resource planning in the production and logistics process (D_7)	27	0.5337	-0.0775	0.4562	0.6112
Environmental Performance (O_1)	15	0.0467	1.7088	1.7556	-1.6621
Economic performance (O_2)	3	1.2173	1.9388	3.1562	-0.7215
Social Performance (O_3)	6	0.7269	1.8292	2.5562	-1.1023

Step 5) factors relationships map is shown in Fig. 2.

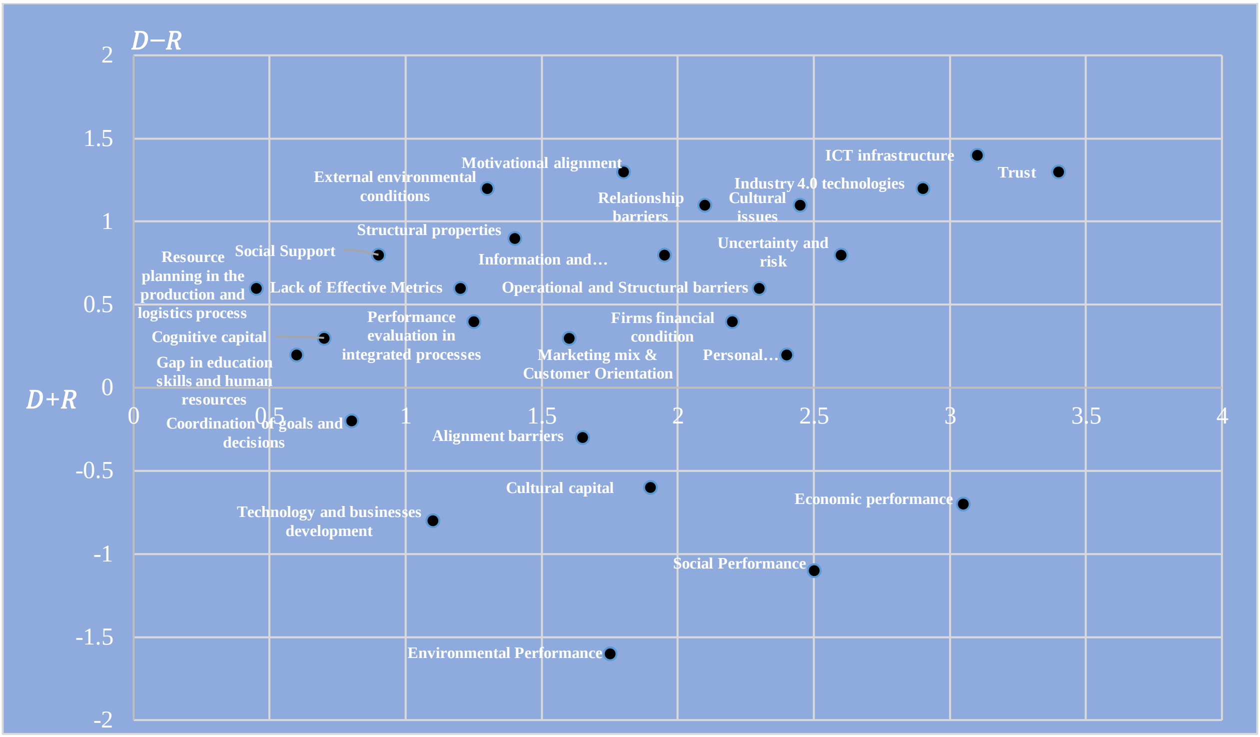

Fig. 2. DEMATEL relationships map of SCC 4.0

The causal relationships of SCC 4.0 are shown in Fig. 3.

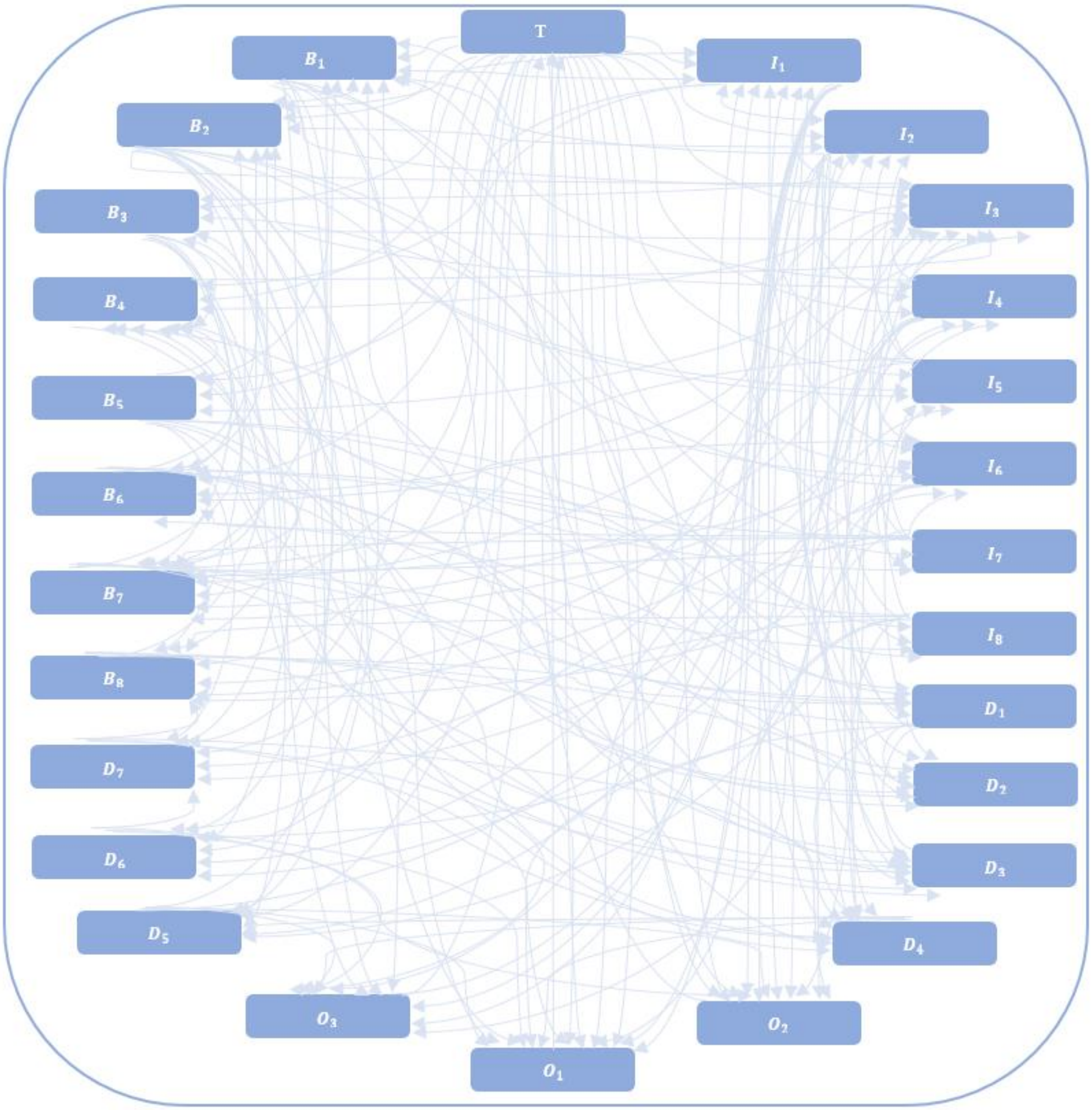

Fig. 3. Causal relationships of SCC 4.0

A sensitivity analysis was conducted to validate the results by adjusting the weights assigned to various experts. The initial weight was assigned to the first expert, with the remaining experts receiving equal weights. This variation in weights was implemented to assess the model's robustness. The ranking of impediments before and after the sensitivity analysis can be found in Table 6.

Table 6: Comparison of ranks before and after sensitivity

Factors	Rank before sensitivity analysis	Rank after sensitivity analysis
Trust (T)	1	1
Industry 4.0 technologies (I_1)	4	2
ICT infrastructure (I_2)	2	4
Cultural capital (I_3)	13	15
Structural properties (I_4)	18	17
Firms financial condition (I_5)	10	12
Cognitive capital (I_6)	25	22
Social Support (I_7)	23	21
External environmental conditions (I_8)	19	18
Operational and Structural barriers (B_1)	9	11
Uncertainty and risk (B_2)	5	3
Cultural issues (B_3)	7	7
Alignment barriers (B_4)	16	20
Lack of Effective Metrics (B_5)	21	27
Personal benefits (B_6)	8	6
Gap in education skills and human resources (B_7)	26	25
Relationship barriers (B_8)	11	9
Motivational alignment (D_1)	14	13
Technology and businesses development (D_2)	22	24
Coordination of goals and decisions (D_3)	24	26
Marketing mix & Customer Orientation (D_4)	17	19
Performance evaluation in integrated processes (D_5)	20	16
Information and communication management (D_6)	12	10
Resource planning in the production and logistics process (D_7)	27	23
Environmental Performance (O_1)	15	14
Economic performance (O_2)	3	5
Social Performance (O_3)	6	8

It can be noticed that the rank of the Trust, Industry 4.0 technologies, and ICT infrastructure before sensitivity analysis is the same after sensitivity analysis. It reflects the idea that these are the most significant among all the components.

5. Conclusion

In this research, SCC 4.0 was investigated with 27 main factors in 5 sections in the form of causal relationships. The purpose of relationship analysis was to examine all the factors in one framework, and analysis of each 5 section's effect compared to other categories was not intended. In this way, 20 factors are placed above the horizontal line of Fig. 1 and identified as effective factors. Also, 7 factors below the horizontal line were selected as impressionable factors. In Fig.1 factors with higher levels are more effective. Lower factors are more impressionable. Also, as the factors move to the right side of the chart, they become more important; because they have a greater effect and impression. The factor that interacts more with other variables, is more important.

5.1. Main conclusion

According to the explanation in the last paragraph, *Trust* was ranked first as an effective factor. Trust has the role of strengthening initiators and reducing the barriers that affect collaboration. It also helps to form the dimensions of collaboration in SC 4.0. Reliability, predictability, and fairness define the concept of trust. Trust is the key factor of collaboration which points to the importance of social relationships in SC [25]. Trust value ($D = 2.36225$) has the greatest effect on other variables in the collaboration model. Trust ($D + R = 3.4111$) and *ICT infrastructure* ($D + R = 3.1236$) are closely related to each other and are considered the most fundamental factors of the model, and creating constructive changes related to these two factors can lead to more serious and effective changes in SCC 4.0 such as improved *Economic performance* ($D + R = 3.1562$) and *Social Performance* ($D + R = 2.5562$). ICT significantly and positively improves responsiveness, reliability, and management efficiency, which further translates into SC performance [36]. Sustainability is considered as important for SC 4.0 performance and is used as the kernel for improving organizations [12]. Social SC practices influence the firm's performance. Most firms are not informed of their role and responsibility to develop the community. The sustainability framework raises awareness of sustainable actions that drive organizations to implement leverage social performance and sustainable social SC 4.0 practices. By being socially responsible, organizations can gain improved brand awareness, enhanced customer loyalty, increased sales, and observed firm growth [13]. Economic performance improvement needs to establish relationships & trust with SC partners. Collaboration & reciprocity with customers is needed for organizations to gain economic performance [39]. *Industry 4.0 technologies* and *Uncertainty and risk* have closed relationships in the fourth and fifth ranks, respectively. In the Industry 4.0 environment, SCs have become prone to various risks due to process digitalization and the growth of technology. The uncertainties that are internal to SC networks and external to the environment of an organization about global SCs are regarded as SC risks. SC 4.0 risks are behavioral, operational, and manufacturing process, demand, financial, governmental and organizational, product recovery, safety, social and environmental, disruption, and cyber security. SC managers should focus on cyber security and safety risks in the current Industry 4.0 environment [26].

5.3. Managerial insight

There are key aspects concerning the practical implications of this research. Supply chain partners are limited in their collaboration efforts beyond their operational boundaries when it comes to project co-development. Moreover, the current level of coordinated collaboration is relatively low, indicating a lack of close ties among supply chain partners to potentially outsource non-core activities. Introducing a model that emphasizes collaboration as a driving force can address this issue. The utilization of Industry 4.0 technologies, such as digital twins, AI, IoT, and blockchain, plays a crucial role in enhancing supply chain collaboration. These technologies are transforming the way supply chains operate by improving transparency and efficiency. Managers need to embrace these tools to maintain competitiveness in the market. The use of active voice in supply chain communication promotes clarity and directness in managerial interactions. Managers are encouraged to employ an active voice when conveying instructions and expectations, as direct communication among supply chain partners facilitates better understanding and collaboration. SC 4.0 managers can facilitate the development of collaborative trust across the SC by investing in communication and technology infrastructure. Collaborative relationships between different SC departments are possible by increasing the speed of data transfer, and this is made possible by facilitating the digital platform.

5.3. Research limitations

A constraint encountered during this study was the absence of an opportunity to examine the supply chain of a technology firm that consistently employs Industry 4.0 technologies in its day-to-day activities. Gaining insights into the operational processes of such a company and obtaining input from experts in the field would have greatly enhanced the comprehensiveness of the dimensions and indicators of collaboration derived from the existing research literature.

5.4. Future research directions

Classification and analysis of causal relationships of variable categories with each other, examination and testing of the research conceptual model in the form of a studied company, and comparative analysis of collaboration factors as players in game theory conditions, would be interesting for future research. The integration of collaboration within the supply chain not only fosters trust but also influences the dynamics of collaboration itself. This reciprocal relationship between collaboration and trust highlights the importance of understanding both dimensions. Future research could explore these dynamics further by replicating the study within a Fast-Moving Consumer Goods (FMCG) company. Additionally, delving into other aspects of collaboration could enhance the existing model and contribute to a more holistic understanding of collaboration within the context of Supply Chain 4.0. For instance, identifying and incorporating dimensions and indicators for assessing partner collaborative relationships could be a valuable avenue for exploration.

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