Journal of Industrial and Systems Engineering
Vol. 14, No. 3, pp. 149-167
Summer (July) 2022

Lean supply chain based on IoT and blockchain: Quantitative analysis of critical success factors (CSF)

Hamed Nozari[1], Alireza Aliahmadi[1]

[1]*School of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran*

ham.nozari.eng@iauctb.ac.ir, aaliahmadi@iust.ac.ir

Abstract

Today, due to industrial development in the world, the variety of products has increased and products have special complexities. Lean supply chain is an approach aimed at producing and delivering products in the fastest possible time with the least production waste. The lean supply chain approach is one of the most important strategies to help managers in the organization due to the nature of its activities and the volume and variety of products, suppliers, and customers within the organization, with very diverse needs and very high geographical dispersion. This approach can, as an effective tool, play a very functional role in reducing waste from the supply chain and reducing organizational costs. Today, evolving technologies such as the Internet of Things and blockchain play a significant role in facilitating lean supply chain creation. The Internet of Things (IoT), along with blockchain technology, provides instant insight into every move of the goods made in the supply chain and more responsibility than ever before. In addition, IoT eliminates many of the paperwork requirements prone to supply chain management error and simplifies processes for less efficient product management from warehouse to final destination. In this study, a framework for a lean supply chain based on these technologies was first proposed. Then, the critical success factors in this lean supply chain were extracted using the literature and expert opinions. In order to evaluate these factors and study their internal relationships, a nonlinear fuzzy approach and fuzzy DEMATEL method were used. The results show that quick response to customer needs is one of the most important critical factors for the success of the lean IoT-blockchain based supply chain.

Keywords: Lean supply chain, IoT based chain, blockchain technology, critical success factors, fuzzy DEMATEL

1-Introduction

In order to carry out the main mission and achieve the desired goals, each organization must have the appropriate logistics and operational support and meet all the needs of its operational units so that these units can perform their assigned tasks in an appropriate and acceptable manner. Accordingly, the quality of provision and support of the main organizational operations has a very important role in achieving the goal and any weakness and progress in this area, will have its effects on the performance of activities and missions of operational units of the organization (Alemsan et al., 2022).

*Corresponding author
ISSN: 1735-8272,

The turning point and the winner of today's global competition in the field of business, are undoubtedly the companies and organizations that can with the highest efficiency create value for their main and key stakeholders, according to their wishes and opinions. Organizations that can offer their products and services with high quality, low prices and in a timely manner according to the requests and tastes of their customers in different markets. Elimination of waste and optimal use of resources has always been one of the main goals in any organization, which is specifically focused on the concept of dismantling the organization and is implemented (Mahdavisharif et al., 2022).

Nowadays, the benefits and advantages of applying a lean approach have been identified for many leaders and managers of enterprises and as a pure management paradigm in productive and non-productive organizations, it paves the way for companies to move forward. The idea of lean manufacturing, which started in the manufacturing sector, quickly spread to the organization level in terms of benefits, benefits and improvements, and pushed the boundaries of the organization, encompassing suppliers, contractors, partners and customers, and paving the way for its formation (Anand & Kodali, 2008). Value chains became internal and external to organizations. The transformation of the supply chain into a lean supply chain begins with identifying the current situation and determining the distance from the desired situation. Purpose that is made possible by the use of lean supply chain models and tools (Arif-Uz-Zaman & Ahsan, 2014).

Lean supply chain is the rule of lean principles and thinking at the bottom and top of the value stream. That is, not only must pure thinking and principles be extended to the entire chain, but it must transcend the boundaries of the organization to optimize the overall value flow in the supply chain as a whole. Lean supply chain is the rule of lean principles and thinking at the bottom and top of the value stream, that is, not only lean thinking and principles should extend to the whole chain, but also beyond the boundaries of the organization to the total value flow in the optimal supply chain Be. The lean supply chain approach also helps organizations and businesses identify, analyze, and then eliminate process losses using a philosophy of continuous improvement and a culture of teamwork (Jasti & Kodalin, 2015).

The digital revolution has had a profound impact on delivery logistics and supply chain management. The Internet of Things (IoT) has changed the way companies deliver and manage their operations. In the modern supply chain, the Internet of Things makes this process more efficient. These technologies can connect products that each convey their own position and situation. Because of this, there is a better chance of converging back office systems and avoiding the need for dedicated hardware. By connecting products, businesses will also have the opportunity to collect data on product performance and consumer use of products that have never been seen before (Lian-yue, 2012). Blockchain also allows users to track all types of transactions more securely and transparently to improve supply chain visibility. China blockchain technology is used to increase supply chain visibility, which is required for the legal functioning of the supply chain (Perboli et al., 2018).

The simultaneous presence of these technologies can increase the strength of the supply chain in the path of lean development. For these reasons, in this study, the dimensions, components and key performance indicators of a lean supply chain have been analyzed. In addition to providing a conceptual framework, the critical success factors in a lean supply chain based on IoT and blockchain are evaluated.

The framework of this research is as follows. The second section reviews the literature. The third section provides a conceptual framework and discusses the critical success factors of the smart lean supply chain. In the fourth section, the research method is presented. In the fifth section, the computational results are shown. Finally, a conclusion is presented in the sixth section.

2-Literature review

Lean supply chain management is the application of lean thinking across the supply chain. Traditionally, lean manufacturing was applied to the four walls of a manufacturing company - from receiving docks to shipping docks and everything in between. Lean supply chain management extends the application of lean upstream in supplier management, downstream in distribution network management and upward in overall supply chain integration and management (Reyes et al., 2021). The dimensions of the lean supply chain are shown in figure 1. The application and management of lean principles and practices at the supply chain level is much more complex than the application of lean management within the company, because it requires more coordination and management of physical, information and financial flows between different factors (Mahdavisharif et al., 2022). In this regard, digitalization is defined as the use of computer technology and the Internet for the process of creating economic value more efficiently and effectively. Digitization by evolving technologies such as artificial intelligence, the Internet of Things, and blockchain not only changes the business processes and products of the company, but also the processes of the entire supply chain (Takeda-Berger et al., 2021). This leads to major changes in what is called digital transformation. In the digital transformation, Internet technologies and connectivity, which make them more powerful, play a major role in the deployment and use of more traditional information technology and more innovative or emerging information technology. This shared use of different technologies using the connection allowed by the Internet has created the concept of information technology and digital (Vlachos et al., 2021).

Fig 1. Lean supply chain dimensions(Sony, 2019)

Production processes must be built on an integrated, high-maneuverability standard platform and a shared global information platform that understands lean management. IoT can integrate internal and external information, a summary of the supply chain management information platform, providing perceived information for each node company, product knowledge, company and supply chain. Understand customer needs in timely and effective communication and share available information to achieve regular interaction between internal and external management. Real-time, diversity and richness of information in lean supply chain management environment is very important, especially every company should focus on the market, also focus on upstream and downstream other companies in order to respond to changing customer demand over time (Vlachos et al., 2021). The benefits of IoT and blockchain technology are multidimensionality and the acquisition of information through various channels, through large-scale sensor networks and the collection of information terminals from a variety of infrastructures and access objects that are sent to the cloud for storage, computing and processing. Which provides lean supply chain management decision support. IoT computing mode allows each of the supply chain loops to be self-organizing, calculation, feedback function makes the supply chain management system smarter through information exchange, more powerful information processing ability, improve information accuracy, reduce distortion It should be noted that it is a solution in the direction of lean supply chain (Abd Rahman et al., 2021).

In recent years, increasing attention to transformationaltechnologies and lean approaches such as the Internet of Things and blockchain as an emerging field has led to an increase in the number of literature contributions, especially in the form of Literature Review. The review of the previous literature mainly examines the relationship between Lean and Industry 4.0 with a focus on the manufacturing process, without considering other key supply chain processes, such as logistics (Buer et al., 2018). However, the impact of lean digital supply chains must be studied by addressing the complexity of supply chains made up of several processes and levels based on different technologies. Each of these technologies has specific features and characteristics that make it suitable for use in a clean environment. Therefore, it is important to explore the relationships between IoT and blockchain technologies and the pure principles of supply chain management with a focus on each. In addition, supply chain members need to be aware of the benefits and capabilities of each digital technology at both operational and organizational levels, as well as its impact on decisions to address network complexity. In addition, choosing the right technologies is a strategic task in Industry 4.0, because the wrong choice can prevent it instead of helping pure achievement. Therefore, due to the high cost of investment associated with transformational technologies, supply chain members must identify the most practical ones that are compatible with the pure context to determine implementation priorities (Bamakan et al., 2021).

There has been a lot of research on the lean supply chain in recent years. Table 1 shows some of the research done in recent years and the research gap.

Table 1. Some on the research conducted in the study area

Author and year	Lean supply chain	IoT	Blochchain	Conceptual Framework	Analysis of critical success factors
(Mahdavisharif et al., 2022)	✓	✓	✓	×	×
(Chang & Huang, 2022)	✓	×	×	✓	×
(Jha, & Prashar, 2022)	✓	✓	×	×	×
(Makinde et al., 2022)	✓	×	×	×	×
(Kale et al., 2022)	✓	✓	×	✓	×
(Núñez-Merino et al., 2020)	✓	✓	✓	×	×
(Lian-yue et al., 2012)	✓	✓	×	✓	×
(Perboli et al., 2018)	✓	×	✓	×	×
(Alvim, 2020)	✓	✓	×	×	×
(Raji, 2021)	✓	✓	✓	×	×
(Zarrar, 2021)	✓	✓	×	×	×
(Reyes et al., 2021)	✓	✓	✓	×	×
(Wang, 2015)	✓	✓	×	×	×
Current study	✓	✓	✓	✓	✓

Researchs show that the critical indicator of lean supply chain success based on IoT and blockchain technologies has not been studied so far, and this study can be necessary and important given the digital developments in today's world.

3-Lean supply chain based on IoT and blockchain

3-1- Features of the smart lean supply chain

The modern supply chain is a huge network, and just one problem connecting a company to it can be catastrophic. Losing track of a shipment can delay its delivery, destroy inter-organizational relationships, and completely derail reporting information available to control organizational processes. With the power of the Internet of Things, data can now be relied on from a wide range of sources, as well as a clear picture of the route the consignment is taking, allowing any stroke to be quickly dealt before it can affect business. Let it be solved. IoT sensors can send real-time information not only about the physical location of the package, but also about how it is transported, proper temperature control, arrival time, and more (Raji et al., 2021).

Real-time tracking with an IoT-enabled smart tracker provides stunning connectivity and in-depth coverage of all aspects of the supply chain. Using decentralized record keeping by blockchain technology increases the accuracy and reliability of the data. These technologies minimize costly errors and allow supply lines to be merged and separated as needed to maximize storage and cargo space and minimize waste. Technologies such as active and inactive RFID tags, which provide data on the items to which they are attached, are just an example of how IoT can be used in inventory management. In terms of fleet management, companies use IoT technology to move and deliver physical assets, consumer transportation, and field service vehicles. This makes their processes more efficient, and like warehouse and inventory management, the solutions include tracking technologies such as GPS to collect various data in real time when trucks or vehicles are on the road (Mahdavisharif et al., 2021).

The Internet of Things enhances product visibility in the supply chain and allows managers to view important data on material handling equipment, packages, vehicles and warehouses from any device. Some of these devices include GPS and RFID readers. With advanced technologies, sensors and a supply chain that knows how to make these tools work properly, businesses will be able to anticipate, correct and prevent supply chain problems. The simultaneous presence of IoT and blockchain technologies along with the analytical capability of artificial intelligence can increase the quality of the lean supply chain (Zekhnini et al., 2021).

Investing in IoT-based logistics solutions and blockchain technology provides agile innovations in smart tracking, real-time data unloading, and the opportunity to dramatically improve the customer experience while building a robust, clean logistics system. Once you have secure data, the next step is effective data management, which is provided by these evolving technologies and creates a lean supply chain. Figure 2 provides a framework that illustrates the key elements of a lean supply chain.

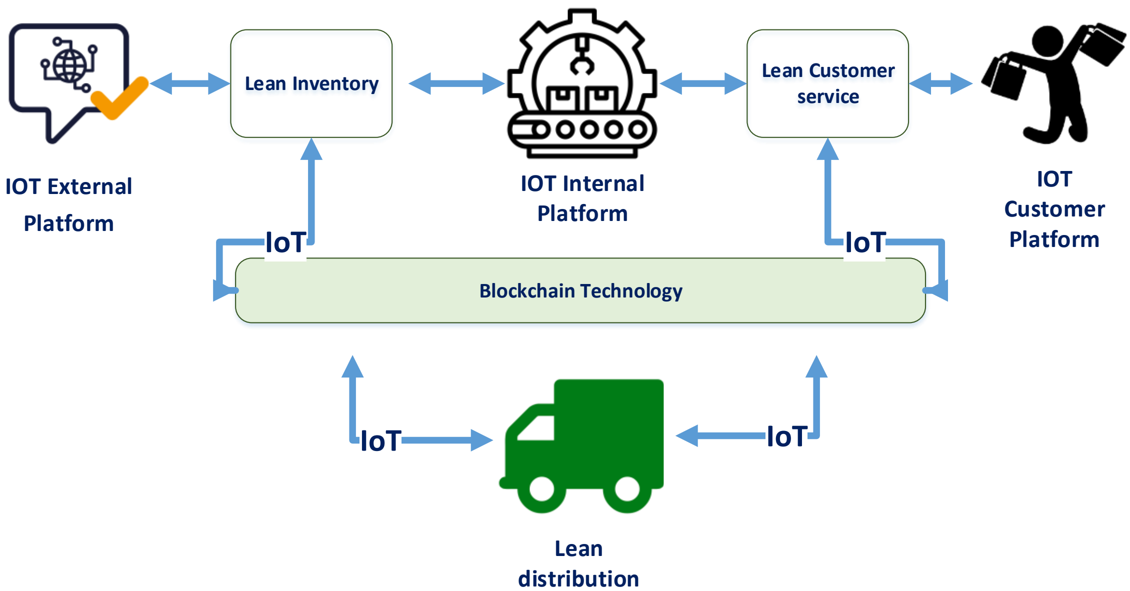

Fig 2. A framework for the lean supply chain based on the Internet of Things and blockchain

3-2- Critical success factors for lean supply chains based on IoT and blockchain

Critical success factor was first introduced in 1961 by Daniel as a business guide. The purpose of determining and defining these factors was to identify the types of information needed to support the organization's senior management activities. Critical success factors include a limited number of areas that, if satisfactory results are achieved in these areas, satisfactory competitive performance is predictable for the individual, department or organization (Leidecker & Bruno, 1987).

Critical success factors are characteristics, situations, or variables that, if properly maintained, supported, and managed, can play an undeniable role in a company's success in a competitive market. In every field of activity, there are countless factors that fundamentally affect the expected results. Therefore, strategy can be associated with success if these factors are controlled and used skillfully. These factors are called critical success factors. Applying critical success factors and accurately identifying them can be the basis for determining and developing core competencies and supporting the organization's competitive advantages. These factors clearly present what the organization needs to succeed and allow managers to measure the success of their organization (Perboli et al., 2018).

Various scientists have studied the critical factors of success in implementing lean supply chain in organizations and have presented various criteria and models. Most of these criteria refer to conditions and actions that the organization is somewhat able to control. In the present study, the indicators of critical success factors in the implementation of lean supply chain based on the use of IoT and blockchain technologies were extracted. In order to extract these factors, the critical factors of supply chain success were extracted from the beginning using the literature review. Then, using the opinions of experts active in Jose supply chain, the factors that emphasized the lean supply chain were identified, and finally, using the opinions of active industrial and academic experts with experience in the field of studying critical success factors for lean supply chain and Emphasis was placed on these transformative technologies. Finally, using the 5-level Likert scale questionnaire, the importance of critical success factors for implementing a lean supply chain based on the Internet of Things and blockchain was identified and presented in three main categories. In order to study the industrial experts with more than three years of experience in the field of supply chain and familiar with the concepts of modern technologies, as well as academic experts with a good research background in the field under study were used. The number of specialists with a background in industry over 4 years was 18 and the number of university specialists was 12. Refined indicators of critical success factors in implementing a sustainable smart supply chain are presented in table 2.

Table 2. Critical factors for the success of the lean supply chain based on the IoT and blockchain

The main criterion	Code	CSF	Code	References
Internal processes	C_1	Accurate Asset Tracking	C_{11}	(Zhang et al., 2014) (McAllister et al., 2017)
		Speedy Information Retrieval	C_{12}	(Zhang et al., 2020) (Ali et al., 2022) (Shen et al., 2019)
		Enhanced visibility along the supply chain	C_{13}	(Pradhan & Routroy, 2018) (De Vass, et al., 2021)
		Data access control	C_{14}	(Patil, et al., 2021) (Abdi et al., 2020)
		Adaptation to new technology	C_{15}	(Wang & Sarkis, 2013)
Customer management	C_2	Information sharing and quality	C_{21}	(Du & Jiang, 2019) (Saini et al., 2022) (Kazancoglu et al., 2022)
		Quick response to customer needs	C_{22}	(Tan & Sidhu, 2022) (Oliveira-Dias et al., 2022)
		Customer support	C_{23}	(Guo et al., 2022) (Shahzad et al., 2022) (Aryal et al., 2018)
Supplier management	C_3	Remove intermediaries	C_{31}	(Srivastava & Dashora, 2022) (Saurabh & Dey, 2021)
		Transparency in communication and reliability	C_{32}	(Iqbal & Butt, 2020) (Baralla et al., 2018)
		Improve relationships and partnerships with suppliers	C_{33}	(De Vass, et al., 2021) (Saini et al., 2022)

As shown in table 2, the key indicators of success are identified in three general categories: internal processes, customer management, and supplier management. These key indicators can enhance the ability of the smart swing supply chain, so evaluating them can be very important. Blockchain can increase the power of the Internet of Things across the supply chain to track assets, improve workers' rights, and take a more sustainable approach to the environment, carbon management, and the circular economy (Zhang et al., 2014). Blockchain helps speed up data recovery through data encryption algorithms and then decrypts to be used with greater confidence while maintaining privacy (Zhang et al., 2020). With IoT technology and blockchain, collaboration between different stakeholders in the chain is much smoother and safer. You can make faster decisions and you can even create transactions by eliminating third parties and excessive costs (smart contracts). Therefore, the difference is in addition to transparency and security in the details of the information that can be obtained during the process (Pradhan & Routroy, 2018). Information sharing is considered as a common business strategy to improve the performance of supply chain operations, which has been used successfully in many industries. It is widely accepted that information sharing can be beneficial for the entire supply chain and each member at the same time (Du & Jiang, 2019). Rapid Response (QR) is both a management paradigm and a way of allowing supply systems to respond quickly to change while improving their performance. The purpose of QR is to help organize a business in the face of problems related to the wide range of goods and services now found in consumer markets. The Internet of Things and blockchain help to respond quickly (Mak et al., 2022). How to build IoT partnerships is a vital strategic skill that can differentiate between staying connected and getting out of business. The Internet of Things and blockchain help reduce market entry time by using existing resources and relationships with partners (Aslam et al., 2021).

4-Research methods

This research is applied in terms of purpose and descriptive-case in terms of data collection. Two methods of library and survey have been used to collect research data. The library method has been used to collect the subject literature and identify the default tutor guides, and the survey method has been used to collect the data needed for the communication matrix. The statistical population of the interviewees included 18 activists working in the field of supply chain and familiar with transformational technologies with a history of more than 4 years and 12 academics with relevant research experience.

In order to investigate the internal relationships between the key indicators of success in the lean supply chain based on the Internet of Things and blockchain, the fuzzy DEMATEL method has been used. In order to rank these critical success factors, a fuzzy nonlinear method based on Koch's hierarchical analysis called the Mikhailov method has been used. The framework of this research is shown in figure 3.

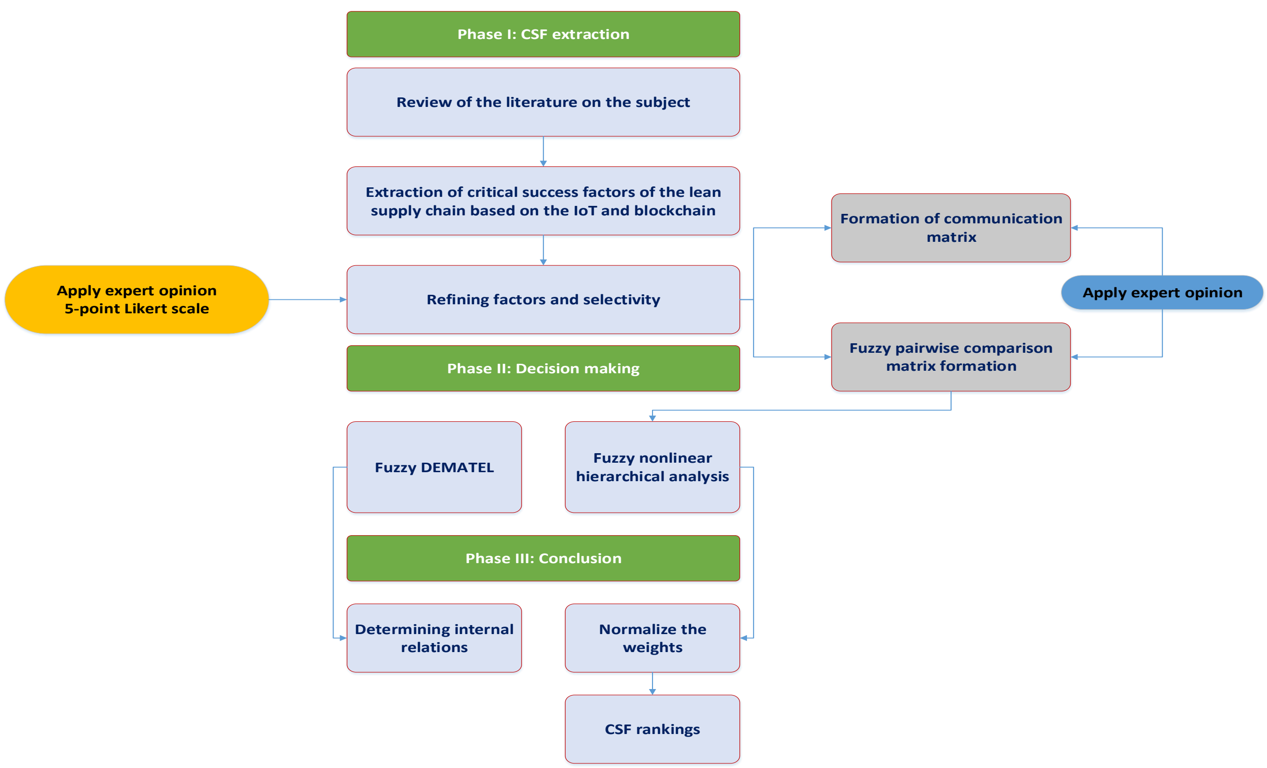

Fig 3. Research framework

4-1- Fuzzy DEMATEL

In this research, in order to determine the critical success factors of effective and efficient success in the lean intelligent supply chain based on the Internet of Things and blockchain, the fuzzy DEMATEL technique has been used. To perform the Dimtel method calculations with the fuzzy approach, first a suitable linguistic spectrum must be used for data collection. A variety of ranges are suggested based on the conventional Demetel scoring scale. A common range is given in table 3.

Table 3. Fuzzy linguistic scale

Linguistic Terms	Triangular Fuzzy Number
Very low (VL)	**(0, 0, 0.25)**
Low (L)	**(0, 0.25, 0.5)**
Medium (M)	**(0.25, 0.5, 0.75)**
High (H)	**(0.5, 0.75, 1)**
Very high (VH)	**(0.75, 1, 1)**

Several models have been proposed to perform fuzzy DEMATEL calculations. A commonly used pattern has been strongly influenced by defuzzication methods. The fuzzy DEMATEL execution algorithm is as follows (Nozari et al., 2019):

Step 1: Calculate the direct relationship matrix

To measure the relationships between criteria, we need to put them in a square matrix and ask experts to compare them in pairs based on how much they affect each other. In this survey, experts will express their views based on table 3. Assuming we have n experts; And each object of the direct fuzzy matrix is represented by $\tilde{x}_{ij}$, then $\tilde{x}_{ij}$ is calculated as follows:

$$\tilde{x}_{ij} = \left(\frac{\sum l_{ij}}{n}, \frac{\sum m_{ij}}{n}, \frac{\sum u_{ij}}{n}\right) \tag{1}$$

Step 2: Normalize the direct relationship matrix

For this purpose, linear scale conversion is used as the normalization formula for converting benchmark scales to comparable criteria. To normalize the values, $\sum u_{ij}$ per row must be calculated.

$$k = \max\left(\sum_{j=1}^{n} u_{ij}\right)$$
$$\tilde{N} = \frac{1}{k} \times \tilde{X} \tag{2}$$

Step 3: Calculate the complete relationship matrix

Calculate the total fuzzy correlation matrix. In this step, we first calculate the inverse of the normal matrix and then subtract it from the matrix I, and finally multiply the normal matrix by the resulting matrix.

$$N_u = \begin{bmatrix} 0 & u_{12} & \cdots & u_{1n} \\ u_{21} & 0 & \cdots & u_{2n} \\ \vdots & \vdots & \ddots & \\ u_{n1} & u_{n2} & \cdots & 0 \end{bmatrix}, \quad N_m = \begin{bmatrix} 0 & m_{12} & \cdots & m_{1n} \\ m_{21} & 0 & \cdots & m_{2n} \\ \vdots & \vdots & \ddots & \\ m_{n1} & m_{n2} & \cdots & 0 \end{bmatrix},$$

$$N_l = \begin{bmatrix} 0 & l_{12} & \cdots & l_{1n} \\ l_{21} & 0 & \cdots & l_{2n} \\ \vdots & \vdots & \ddots & \\ l_{n1} & l_{n2} & \cdots & 0 \end{bmatrix} \tag{3}$$

Then the identity matrix $I_{n\times n}$ is formed and the following operations are performed:

$$T_l = N_l \times (I - N_l)^{-1} \ , T_m = N_m \times (I - N_m)^{-1} \ , \quad T_u = N_u \times (I - N_u)^{-1} \tag{4}$$

$$\tilde{t}_{ij} = (t_{ij}^l, t_{ij}^m, t_{ij}^u) \tag{5}$$

In this step, the matrices r and c are defined as two matrices $n \times 1$, which show the sum of the rows and columns of the matrix as a complete relation.

$$r = [r_i]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij} \right)_{n\times 1}$$

$$c = [c_j]'_{1\times n} = \left(\sum_{i=1}^{n} t_{ij} \right)'_{1\times n} \tag{6}$$

r_i is equal to the sum of the ith row of the total relation matrix T. Thus r_i represents the effect of the total factor i on other factors. This effect includes direct and indirect effects. c_j is equal to the sum of jth columns of the matrix of the total relation T. Thus c_j represents the overall effect that factor j has received from other factors. This effect includes direct and indirect effects. Therefore, when $j = i$, then $(r_i + c_i)$ is equal to the total effect applied and received by factor i. In other words, $(r_i + c_i)$ indicates the degree of importance of factor i in the system. $(r_i - c_i)$ also represents the net effect that factor i exerts on the entire system. When $(r_i - c_i)$ is a positive value, it means that factor i is an influential factor in the system as a whole, and when $(r_i - c_i)$ is a negative value, it means that factor i is an influential factor in the whole system (Nozari et al., 2022).

4-2- Mikhailov nonlinear fuzzy ranking

In this research, a fuzzy nonlinear hierarchical analysis method, which is represented by Mikhailov method, is used to prioritize the critical success factors in a lean supply chain based on digital technologies. The steps for using this method are as follows:

1- Drawing the hierarchical structure: which is shown in table 2.

2- Formation of fuzzy pairwise comparison matrix: Fuzzy judgment agreement matrices are formed based on the opinions of experts. For this reason, fuzzy numbers have been used to express the preferences of experts in this study. Linguistic variables and their fuzzy scale are presented in table 4.

Table 4. Linguistic scale for the pairwise comparison matrix

Linguistic values for pairwise comparisons	**Triangular fuzzy scales**
Very low(VL)	(1,2,3)
Low(L)	(2,3,4)
Medium(M)	(3,4,5)
High(H)	(4,5,6)
Very high(VH)	(5,6,7)

As shown in table 4, fuzzy triangular numbers are used for linguistic scales.

3- Modeling and Problem Solving: In this method, fuzzy even comparisons are assumed to be triangular fuzzy numbers. The definite weight vectors $w = (w_1, w_2, \dots, w_n)$ are extracted in such a way that the priority rate is approximately within the range of the initial fuzzy judgments. In other words, the weights are determined so that the following relation is established.

$$l_{ij} \le \frac{w_i}{w_j} \le u_{ij} \tag{7}$$

Each definite weight vector (w) holds with a degree in the above fuzzy inequalities which can be measured by the linear membership function of the following relation:

$$\mu_{ij}\left(\frac{w_i}{w_j}\right) = \begin{cases} \dfrac{(w_i / w_j) - l_{ij}}{m_{ij} - l_{ij}} & \dfrac{w_i}{w_j} \le m_{ij} \\ \dfrac{u_{ij} - (w_i / w_j)}{u_{ij} - m_{ij}} & \dfrac{w_i}{w_j} \le m_{ij} \end{cases} \tag{8}$$

Given the specific form of membership functions, the fuzzy prioritization problem becomes a nonlinear optimization problem as follows.

$$\begin{aligned} & \max \ \lambda \\ & \textit{Subject to}: \\ & (m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \le 0 \\ & (u_{ij} - m_{ij})\lambda w_j + w_i - u_{ij} w_j \le 0 \\ & i = 1,2,\dots,n-1\,, \quad j = 2,3,\dots,n\,, \quad j > i, \\ & \sum_{k=1}^{n} w_k = 1 \qquad w_k > 0, \qquad k = 1,2,\dots,n \end{aligned} \tag{9}$$

Positive optimal values for the λ index (objective function) indicate that all weight ratios are completely true in the initial judgment, but if this index is negative, it can be seen that the fuzzy judgments are strongly inconsistent and the weight ratios are almost true in these judgments

5-Research findings

5-1- Internal relations for critical success factors in the smart lean supply chain

In this research, the fuzzy DEMATEL decision method has been used to investigate the internal relationships of critical success factors. For this purpose, for accurate analysis, fuzzy questionnaires were sent to 30 experts. Experts with industrial and academic backgrounds in the field were studied and selected. Experts were asked to express their views on the internal effects of these factors based on linguistic variables. From these questionnaires, 30 questionnaires were completed and received. The fuzzy direct relation matrix for the performance indicators is presented in table 5.

Table 5. Fuzzy direct relationship matrix between smart lean supply chain based on IoT and Blockchain (summarized)

	C_{11}			C_{12}			***C*** ...	C_{32}			C_{33}		
	L	*M*	*U*	*L*	*M*	*U*	...	*L*	*M*	*U*	*L*	*M*	*U*
C_{11}	0	0	0	0.25	0.35	0.85	…	0.41	0.55	0.74	0.33	0.47	0.81
C_{12}	0.28	0.56	0.74	0	0	0	…	0.24	0.35	0.67	0.32	0.47	0.68
…	…	…	…	…	…	…	…	…	…	…	…	…	…
C_{32}	0.21	0.35	0.74	0.28	0.65	0.84	…	0	0	0	0.45	0.84	0.91
C_{33}	0.35	0.47	0.81	0.42	0.65	0.77	…	0.45	0.84	0.95	0	0	0

Table 6 shows the general fuzzy relation matrix for the intelligent lean supply chain.

Table 6. Total fuzzy relation matrix for smart lean supply chain based on IoT and Blockchain (summarized)

	C_{11}			C_{12}			***C*** ...	C_{32}			C_{33}		
	L	*M*	*U*	*L*	*M*	*U*	...	*L*	*M*	*U*	*L*	*M*	*U*
C_{11}	0.05	0.12	0.18	0.06	0.21	0.35	…	0.085	0.12	0.21	0.018	0.09	0.11
C_{12}	0.11	0.15	0.35	0.038	0.09	0.21	…	0.09	0.14	0.2	0.21	0.35	0.45
…	…	…	…	…	…	…	…	…	…	…	…	…	…
C_{32}	0.21	0.13	0.1	0.24	0.14	0.11	…	0.1	0.13	0.14	0.19	0.22	0.31
C_{33}	0.1	0.15	0.21	0.21	0.12	0.1	…	0.08	0.18	0.21	0.11	0.17	0.27

The sum of the elements in the columns and rows of the whole matrix was calculated for the critical success factors in the intelligent lean supply chain to provide a relational map. These values are called effective vectors (R) and effective vectors (D). The results are shown in table 7.

Table 7. Results of calculating the internal effects

CSF	D	R	$D+R$	$D-R$
Accurate Asset Tracking	0.741	0.314	1.055	0.427
Speedy Information Retrieval	0.351	0.6241	0.9751	-0.2731
Enhanced visibility along the supply chain	0.678	0.214	0.892	0.464
Data access control	0.354	0.847	1.201	-0.493
Adaptation to new technology	0.799	0.124	0.923	0.675
Information sharing and quality	0.417	0.854	1.271	-0.437
Quick response to customer needs	0.687	0.412	1.099	0.275
Customer support	0.841	0.354	1.195	0.487
Remove intermediaries	0.654	0.124	0.778	0.53
Transparency in communication and reliability	0.325	0.698	1.023	-0.373
Improve relationships and partnerships with suppliers	0.874	0.247	1.121	0.627

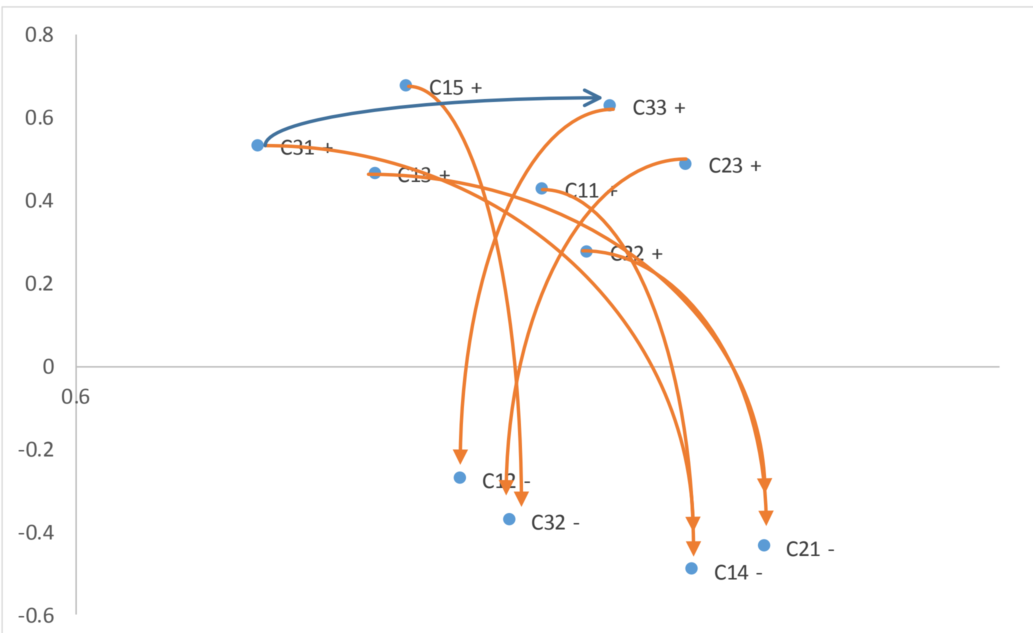

Fig 4. Internal impacts of Smart lean supply chain based on IoT and blockchain

5-2- Ranking of naval success factors in lean supply chain based on IoT and blockchain

The steps involved in evaluating and ranking critical success factors in the Internet of Things-based lean supply chain and transformational technologies in this study are divided into two main parts:

1- Determining the matrix of pairwise comparisons based on the integration of experts' opinions

2- Using mathematical modeling in order to rank and obtain the weight of factors

In order to evaluate and prioritize the critical success factors, fuzzy questionnaires using language variables were sent to 30 experts in industry and academia. 30 questionnaires were completed and received. These pairwise comparison tables are shown in tables 8 to 11.

Table 8. Matrix of pairwise comparisons for the main criteria

	C_1			C_2			C_3		
C_1	-	-	-	-	-	-	-	-	-
C_2	1.1	2.5	3.7	-	-	-	-	-	-
C_3	1.6	1.95	2.7	3.2	4.95	5.11	-	-	-

Table 9. Paired comparison matrix for factors related to internal processes

	C_{11}			C_{12}			C_{13}			C_{14}			C_{15}		
C_{11}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C_{12}	3.1	3.5	4.5	-	-	-	-	-	-	-	-	-	-	-	-
C_{13}	2.1	2.5	3.25	2.1	2.45	3.21	-	-	-	-	-	-	-	-	-
C_{14}	2.1	2.8	4.7	1.84	2.84	3.68	2.74	2.98	3.1	-	-	-	-	-	-
C_{15}	1.1	2.21	5.1	2.1	2.35	4.21	2.7	3.24	4.1	1.87	2.45	3.68	-	-	-

Table 10. Pair comparison matrix for factors related to customer management

	C_{21}			C_{22}			C_{23}		
C_{21}	-	-	-	-	-	-	-	-	-
C_{22}	2.7	3.1	4.5	-	-	-	-	-	-
C_{23}	2.9	3.2	3.9	2.45	3.48	5.1	-	-	-

Table 11. Matrix of pairwise comparisons for factors related to supplier management

	C_{31}			C_{32}			C_{33}		
C_{31}	-	-	-	-	-	-	-	-	-
C_{32}	1.85	2.15	3.75	-	-	-	-	-	-
C_{33}	3.9	4.5	5.1	2.5	3.55	4.25	-	-	-

By placing the data from tables 8 to 11 in the nonlinear model (9) as a model providing weights and rankings based on hierarchical analysis, the weight and rank of each factor can be obtained. The computational results related to solving the non-speech model for general categories and individual challenges are shown in tables 12 to 15.

Table 12. Weight and ranking of main criteria

Category	**Code**	**Weight**	**Rank**	λ
Internal processes	C_1	0.371124	1	0.52147
Customer management	C_2	0.335412	2	
Supplier management	C_3	0.297111	3	

Table 13. Weight and ranking of factors related to internal processes

CSF	Code	Weight	Rank	λ
Accurate Asset Tracking	C_{11}	0.123521	5	0.45214
Speedy Information Retrieval	C_{12}	0.242142	2	
Enhanced visibility along the supply chain	C_{13}	0.291245	1	
Data access control	C_{14}	0.201425	3	
Adaptation to new technology	C_{15}	0.153251	4	

Table 14. Weight and ranking of factors related to customer management

CSF	Code	Weight	Rank	λ
Information sharing and quality	C_{21}	0.298452	3	0.38412
Quick response to customer needs	C_{22}	0.354126	1	
Customer support	C_{23}	0.342547	2	

Table 15. Weight and ranking of factors related to supplier management

CSF	Code	Weight	Rank	λ
Remove intermediaries	C_{31}	0.261245	3	0.44412
Transparency in communication and reliability	C_{32}	0.392125	1	
Improve relationships and partnerships with suppliers	C_{33}	0.352547	2	

As can be seen in tables 12 to 15, a positive value for the compatibility index indicates the acceptable compatibility of the matrices. By normalizing the weights, we can obtain the total weight of all factors as well as their overall rank. The normalized computational results are shown in table 16.

Table 16. Normal Weight and Rank of Critical Success Factors for Lean IoT-Based Supply Chain and Blockchain

Main criteria	Weight	CSF	Weight	Normalized weight	Rank
Internal processes	0.371124	Accurate Asset Tracking	0.123521	0.045842	11
		Speedy Information Retrieval	0.242142	0.089865	7
		Enhanced visibility along the supply chain	0.291245	0.108088	4
		Data access control	0.201425	0.074754	9
		Adaptation to new technology	0.153251	0.056875	10
Customer management	0.335412	Information sharing and quality	0.298452	0.100104	6
		Quick response to customer needs	0.354126	0.118778	1
		Customer support	0.342547	0.114894	3
Supplier management	0.297111	Remove intermediaries	0.261245	0.077619	8
		Transparency in communication and reliability	0.392125	0.116505	2
		Improve relationships and partnerships with suppliers	0.352547	0.104746	5

As can be seen in table 16, increasing customer response speed as well as increasing transparency and reliability are the most critical critical success factors in a lean supply chain based on IoT and blockchain technologies.

6-Discussion and conclusion

The competitive environments of today's world have brought about many changes in production organizations and systems, and many concepts, tools, and techniques have been developed to enhance productivity. Pure production / thinking is one of the most important. Lean thinking from a supply chain point of view means creating a value stream that eliminates all waste of time and makes a step-by-step planning possible. This strategy can include reducing inventories, reducing production volume, reducing the supplier base delivery volume, and evaluating suppliers based on quality and delivery performance, establishing long-term relationships with suppliers, and eliminating paperwork. In the digital transformation, Internet and communication technologies that empower them play a key role in establishing this pure approach in the business environment. Since with the presence of the Internet of Things, a lot of high quality data can be obtained, so you can trust that the information is valid. Reliable information is the key to unlocking the benefits of the Internet of Things (IoT), and the simultaneous presence of these intelligent technologies can improve the accuracy, speed and quality of all supply chain processes and provide a cleaner yet clearer path for supply chain users.

Today, organizations are trying to take steps towards a clean supply chain and adapt to complex and changing environments by emphasizing the use of transformational technologies such as the Internet of Things and blockchain. In recent years, financial conflicts, regulatory and competitive pressures, increasing customer demand, and complex regulations have increased attention to lean supply chains. Therefore, in order to identify the critical success factors for the implementation of lean supply chain management based on the Internet of Things and blockchain, the literature and research background have been reviewed and the critical success factors have been extracted. Then using decision techniques Fuzzy capture was attempted to determine the internal relationships and rank of these critical success factors. For this purpose, fuzzy DEMATEL method was used to determine internal flows. To evaluate and rank these factors, a nonlinear ranking method based on hierarchical analysis called Mikhailov method was used. The results showed that increasing the speed of customer response and transparency and reliability are the most critical critical factors for the success of the smart lean supply chain.

It can be understood that in markets where demand is very variable and the customer needs for high diversity, a higher level of agility is needed. Responding to customer needs is based on demand characteristics and the basis of responding to customer needs in an agile and pure approach. Is different. In addition, many studies suggest that lean and agile approaches can be integrated in a variety of ways to create what is called lean agile supply chain strategy.

References

Abd Rahman, M. S. B., Mohamad, E., & Abdul Rahman, A. A. B. (2021). Development of IoT—enabled data analytics enhance decision support system for lean manufacturing process improvement. *Concurrent Engineering*, *29*(3), 208-220.

Alemsan, N., Tortorella, G., Rodriguez, C. M. T., Jamkhaneh, H. B., & Lima, R. M. (2022). Lean and resilience in the healthcare supply chain–a scoping review. *International Journal of Lean Six Sigma*.

Ali, A., Pasha, M. F., Fang, O. H., Khan, R., Almaiah, M. A., & K Al Hwaitat, A. (2022). Big Data Based Smart Blockchain for Information Retrieval in Privacy-Preserving Healthcare System. In *Big Data Intelligence for Smart Applications* (pp. 279-296). Springer, Cham.

Alvim, S. L., & Oliveira, O. G. (2020). Lean Supply Chain Management: a lean approach applied to distribution–a literature review of the concepts, challenges and trends. *Journal of Lean Systems*, *5*(1), 85-103.

Anand, G., & Kodali, R. (2008). A conceptual framework for lean supply chain and its implementation. *International Journal of Value Chain Management*, *2*(3), 313-357.

Arif-Uz-Zaman, K., & Ahsan, A. N. (2014). Lean supply chain performance measurement. *International Journal of Productivity and Performance Management*.

Aryal, A., Liao, Y., Nattuthurai, P., & Li, B. (2018). The emerging big data analytics and IoT in supply chain management: a systematic review. *Supply Chain Management: An International Journal*.

Bamakan, S. M. H., Faregh, N., & ZareRavasan, A. (2021). Di-ANFIS: an integrated blockchain–IoT–big data-enabled framework for evaluating service supply chain performance. *Journal of Computational Design and Engineering*, *8*(2), 676-690.

Baralla, G., Ibba, S., Marchesi, M., Tonelli, R., & Missineo, S. (2018, August). A blockchain based system to ensure transparency and reliability in food supply chain. In *European conference on parallel processing* (pp. 379-391). Springer, Cham.

Buer, S. V., Strandhagen, J. O., & Chan, F. T. (2018). The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda. *International journal of production research*, *56*(8), 2924-2940.

Chang, C., & Huang, P. (2022). Design Lean Supply Chain for Post COVID-19. *Journal of Lean Systems*, *7*(1), 1-14.

De Vass, T., Shee, H., & Miah, S. J. (2021). Iot in supply chain management: a narrative on retail sector sustainability. *International Journal of Logistics Research and Applications*, *24*(6), 605-624.

Du, H., & Jiang, Y. (2019). Strategic information sharing in a dynamic supply chain with a carrier under complex uncertainty. *Discrete Dynamics in Nature and Society*, *2019*.

Guo, L., Chen, J., Li, S., Li, Y., & Lu, J. (2022). A blockchain and IoT based lightweight framework for enabling information transparency in supply chain finance. *Digital Communications and Networks*.

Iqbal, R., & Butt, T. A. (2020). Safe farming as a service of blockchain-based supply chain management for improved transparency. *Cluster Computing*, *23*(3), 2139-2150.

Jasti, N. V. K., & Kodali, R. (2015). A critical review of lean supply chain management frameworks: proposed framework. *Production Planning & Control*, *26*(13), 1051-1068.

Jha, N., & Prashar, D. (2022). Adoption of Industry 4.0 in Lean Manufacturing. In *Industrial Internet of Things* (pp. 107-127). CRC Press.

Kazancoglu, Y., Ozbiltekin-Pala, M., Sezer, M. D., Kumar, A., & Luthra, S. (2022). Circular dairy supply chain management through Internet of Things-enabled technologies. *Environmental Science and Pollution Research*, 1-13.

Leidecker, J. K., & Bruno, A. V. (1987). CSF analysis and the strategy development process. *Strategic planning and management handbook*, 333-351.

Lian-yue, W. (2012, June). Think of construction lean SCM based on IOT. In *2012 IEEE Symposium on Robotics and Applications (ISRA)* (pp. 436-438). IEEE.

Lian-yue, W. (2012, June). Think of construction lean SCM based on IOT. In *2012 IEEE Symposium on Robotics and Applications (ISRA)* (pp. 436-438). IEEE.

Mahdavisharif, M., Cagliano, A. C., & Rafele, C. (2022). Investigating the Integration of Industry 4.0 and Lean Principles on Supply Chain: A Multi-Perspective Systematic Literature Review. *Applied Sciences*, *12*(2), 586.

Mahdavisharif, M., Cagliano, A. C., & Rafele, C. (2022). Investigating the Integration of Industry 4.0 and Lean Principles on Supply Chain: A Multi-Perspective Systematic Literature Review. *Applied Sciences*, *12*(2), 586.

Mahdavisharif, M., Cagliano, A. C., & Rafele, C. (2022). Investigating the Integration of Industry 4.0 and Lean Principles on Supply Chain: A Multi-Perspective Systematic Literature Review. *Applied Sciences*, *12*(2), 586.

Mak, H. Y., & Max Shen, Z. J. (2021). When Triple-A Supply Chains Meet Digitalization: The Case of JD. com's C2M Model. *Production and Operations Management*, *30*(3), 656-665.

Nozari, H., Najafi, E., Fallah, M., & Hosseinzadeh Lotfi, F. (2019). Quantitative analysis of key performance indicators of green supply chain in FMCG industries using non-linear fuzzy method. *Mathematics*, *7*(11), 1020.

Nozari, H., Szmelter-Jarosz, A., & Ghahremani-Nahr, J. (2022). Analysis of the Challenges of Artificial Intelligence of Things (AIoT) for the Smart Supply Chain (Case Study: FMCG Industries). *Sensors*, *22*(8), 2931.

Núñez-Merino, M., Maqueira-Marín, J. M., Moyano-Fuentes, J., & Martínez-Jurado, P. J. (2020). Information and digital technologies of Industry 4.0 and Lean supply chain management: a systematic literature review. *International Journal of Production Research*, *58*(16), 5034-5061.

Oliveira-Dias, D., Maqueira, J. M., & Moyano-Fuentes, J. (2022). The link between information and digital technologies of industry 4.0 and agile supply chain: Mapping current research and establishing new research avenues. *Computers & Industrial Engineering*, 108000.

Perboli, G., Musso, S., & Rosano, M. (2018). Blockchain in logistics and supply chain: A lean approach for designing real-world use cases. *Ieee Access*, *6*, 62018-62028.

Perboli, G., Musso, S., & Rosano, M. (2018). Blockchain in logistics and supply chain: A lean approach for designing real-world use cases. *Ieee Access*, *6*, 62018-62028.

Perboli, G., Musso, S., & Rosano, M. (2018). Blockchain in logistics and supply chain: A lean approach for designing real-world use cases. *Ieee Access*, *6*, 62018-62028.

Pradhan, S. K., & Routroy, S. (2018). Improving supply chain performance by Supplier Development program through enhanced visibility. *Materials Today: Proceedings*, *5*(2), 3629-3638.

Raji, I. O., Shevtshenko, E., Rossi, T., & Strozzi, F. (2021). Industry 4.0 technologies as enablers of lean and agile supply chain strategies: an exploratory investigation. *The International Journal of Logistics Management*.

Raji, I. O., Shevtshenko, E., Rossi, T., & Strozzi, F. (2021). Industry 4.0 technologies as enablers of lean and agile supply chain strategies: an exploratory investigation. *The International Journal of Logistics Management*.

Reyes, J., Mula, J., & Díaz-Madroñero, M. (2021). Development of a conceptual model for lean supply chain planning in industry 4.0: multidimensional analysis for operations management. *Production Planning & Control*, 1-16.

Reyes, J., Mula, J., & Díaz-Madroñero, M. (2021). Development of a conceptual model for lean supply chain planning in industry 4.0: multidimensional analysis for operations management. *Production Planning & Control*, 1-16.

Saini, K., Kalra, S., & Sood, S. K. (2022). An Integrated Framework for Smart Earthquake Prediction: IoT, Fog, and Cloud Computing. *Journal of Grid Computing*, *20*(2), 1-20.

Saurabh, S., & Dey, K. (2021). Blockchain technology adoption, architecture, and sustainable agri-food supply chains. *Journal of Cleaner Production*, *284*, 124731.

Shahzad, K., Ahmed, H., Ahsan, F., Hussain, K., & Talib, M. N. (2022). Blockchain-Based Supply Chain System Using Intelligent Chatbot with IoT-RFID. In *Information Security Handbook* (pp. 233-245). CRC Press.

Shen, M., Deng, Y., Zhu, L., Du, X., & Guizani, N. (2019). Privacy-preserving image retrieval for medical IoT systems: A blockchain-based approach. *IEEE Network*, *33*(5), 27-33.

Sony, M. (2019). Lean Supply Chain Management and Sustainability: A Proposed Implementation Model. In *Ethical and Sustainable Supply Chain Management in a Global Context* (pp. 57-76). IGI Global.

Srivastava, A., & Dashora, K. (2022). Application of blockchain technology for agrifood supply chain management: a systematic literature review on benefits and challenges. *Benchmarking: An International Journal*.

Takeda-Berger, S. L., Tortorella, G. L., Rodriguez, C. M. T., Frazzon, E. M., Yokoyama, T. T., & de Oliveira, M. A. (2021). Analysis of the relationship between barriers and practices in the lean supply chain management. *International Journal of Lean Six Sigma*.

Tan, W. C., & Sidhu, M. S. (2022). Review of RFID and IoT integration in supply chain management. *Operations Research Perspectives*, 100229.

Tu, J., Zhang, J., Chen, S., Weise, T., & Zou, L. (2020). An improved retrieval method for multi-transaction mode consortium blockchain. *Electronics*, *9*(2), 296.

Vlachos, I. P., Pascazzi, R. M., Zobolas, G., Repoussis, P., & Giannakis, M. (2021). Lean manufacturing systems in the area of industry 4.0: a lean automation plan of agvs/iot integration. *Production Planning & Control*, 1-14.

Wang, L. (2015). Research on Construction Lean SCM in IOT Environment.

Zarrar, A., Rasool, M. H., Raza, S. M. M., & Rasheed, A. (2021, September). IoT-Enabled Lean Manufacturing: Use of IoT as a Support Tool for Lean Manufacturing. In *2021 International Conference on Artificial Intelligence of Things (ICAIoT)* (pp. 15-20). IEEE.

Zekhnini, K., Cherrafi, A., Bouhaddou, I., Chaouni Benabdellah, A., & Bag, S. (2021). A model integrating lean and green practices for viable, sustainable, and digital supply chain performance. *International Journal of Production Research*, 1-27.

Zhang, D., Yang, L. T., Chen, M., Zhao, S., Guo, M., & Zhang, Y. (2014). Real-time locating systems using active RFID for Internet of Things. *IEEE Systems journal*, *10*(3), 1226-1235.