Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 October 2018 doi:10.20944/preprints201810.0443.v1

Peer-reviewed version available at *Symmetry* **2018**, *10*, 603; doi:10.3390/sym10110603

Article

Fuzzy multicriteria analysis for performance evaluation of Internet of Things based supply chains

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Abstract: The performance evaluation of the Internet of Things (IoT) based supply chain is challenging due to the involvement of multiple decision makers, the multi-dimensional nature of the evaluation process, and the existence of uncertainty and imprecision in the decision making process. To ensure effective decisions are made, this paper presents a fuzzy multicriteria analysis model for evaluating the performance of IoT based supply chain. The inherent uncertainty and imprecision of the performance evaluation process is adequately handled by using intuitionistic fuzzy numbers. A new algorithm is developed for determining the overall performance index for each alternative across all criteria. The development of the fuzzy multicriteria group decision making model provides organizations with the ability to effectively evaluate the performance of their IoT based supply chains for improving their competitiveness. An example is presented for demonstrating the applicability of the model for dealing with real world IoT-based performance evaluation problems.

Keywords: Group decision makers; Multicriteria analysis; Performance evaluation; Internet of Things; Intuitionistic environment

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1. Introduction

Internet of Things (IoT) is a global network of machines and devices capable of interacting with each other [1]. It is increasingly being used in various supply chains for improving the competitiveness of individual organizations. This is because IoT can be used in supply chains to connect various devices to communicate with each other and integrate vendor-managed inventory systems, customer support systems, business intelligence applications, and business analytics all together in organizations [2], therefore leading to the reduction in cycle times and the improvement in customer services [2,3]. This shows that IoT based supply chains are critical for the continuous development of individual organizations. As a result, evaluating the performance of IoT based supply chains for development and implementation in an organization is significant.

Evaluating the performance of IoT based supply chains is complex and challenging. This is due to the presence of multiple decision makers, (b) the conflicting nature of multiple evaluation criteria, (c) existence of uncertainty, and (d) the use of subjective assessments in the evaluation process. To adequately solve this problem, it is desirable to have a structured model that is capable of comprehensively evaluating the overall performance of available IoT based supply chains with respect to the multiple, usually conflicting evaluation criteria under uncertainty.

Much research has been conducted in evaluating the performance of IoT based supply chains in different contexts. For example, Nallakaruppan and Kumaran [4] present the technique ordered preference by similarity to the ideal solution (TOPSIS) approach for evaluating the performance of IoT in an organization. Linguistic variables are used to assess the weights of all evaluation criteria and the performance of each alternative with respect to each criterion. The decision matrix is converted into a fuzzy decision matrix, and a weighted-normalized fuzzy decision matrix is constructed once the

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decision maker's fuzzy ratings have been pooled. Based on the concept of the TOPSIS approach, a closeness coefficient is defined for determining the ranking order of all alternatives by calculating the distances to both the fuzzy positive-ideal solution and the fuzzy negative-ideal solution simultaneously. Huang et al. [5] present the fuzzy analytical hierarchy process (AHP) approach for evaluating the performance of IoT. Triangular fuzzy numbers are used for representing the decision maker's judgments. The concept of fuzzy synthetic extent analysis is applied for deciding the final priority of different decision criteria. Dachyar and Risky [6] present the AHP for evaluating IoT in Indonesia's telecommunication company. This process comprises three main steps including problem decomposition, priority judgment and priority aggregation. The first phase constructs a hierarchy structure that models the relationship between the goals of the service selection, the quality of service criteria, and the service candidates. Pairwise comparisons are then conducted in the second phase to determine the relative importance of the criteria and the local ranking of the service candidates. Lastly, the global ranking of services is generated.

These approaches, however, are incapable of dealing with the IoT based supply chains performance evaluation in an effective manner as these methods can be very demanding cognitively on the decision maker in the performance evaluation process. Tedious mathematical computation may also be involved which is undesirable.

To overcome the limitations of the existing methods, this paper presents a fuzzy multicriteria group decision making model for evaluating the performance of IoT based supply chain. The multi-dimensional nature of the evaluation process is handled in the context of multicriteria decision analysis. The inherent uncertainty and imprecision of the evaluation process is modeled by using intuitionistic fuzzy numbers. A new algorithm is developed for calculating the overall performance index for each alternative across all criteria. An example is given for demonstrating the applicability of the proposed fuzzy multicriteria group decision making model for evaluating the performance of IoT based supply chain in an organization.

In what follows, a literature review on evaluating the performance of IoT based supply chains is first presented. A fuzzy multicriteria group decision making model is then presented for solving the problem of evaluating the performance of IoT based supply chains in organizations. An example is presented for demonstrating the applicability of the fuzzy multicriteria group decision making model in solving the real world IoT based supply chain performance evaluation problem.

2. Evaluating the Performance of IoT based Supply Chains

The application of IoT in developing specific supply chains is critical for improving the competitiveness of individual organizations. This is because the adoption of IoT can improve the effectiveness and efficiency of supply chain management through obtaining accurate information from a wide range of operating areas including transportation, inventory, purchasing, customer services, production scheduling, order processing, and vendor operations [7]. Such a seamless integration of information along the supply chain allows the organization to react quickly to market changes and to adjust inventory, production, and transportation systems, leading to the reduction of costs and the improved utilization of organizational assets [8].

Much research has been conducted on identifying the criteria for determining the performance of IoT based supply chains in different organizations [9-12]. A review of the related literature leads to the classification of these important criteria into (a) Financial Cost, (b) Service Quality, (c) Interoperability, (d) Technological Infrastructure, (e) Reliability, and (f) Security.

Financial Cost refers to the total cost of ownership of the IoT system. This cost includes the initial license fee of the software, cost of the required server hardware and software [13]. On top of that, Martinho and Domingos [14] believe that the cost also covers the implementation and supporting costs of the IoT system. Meanwhile, Lee [15] points out that IoT development and implementation are often associated with the high costs and high risks, and therefore it is critical for organizations to conduct a comprehensive and systematic assessment before making such a critical decision. At the same time, Brody and Pureswaran [13] identify cost factor as the most important criteria used in the evaluation of IoT system for development and implementation.

Service quality is an important differentiator in a competitive business environment, and a driver of service-based businesses [16]. By enhancing service quality, businesses can influence customers' value, trust [17], and commitment [18]. IoT service quality is determined by the value that the IT service brings to both the organization and its customers. Service Quality (C2) refers to the level of achievement of the IoT based supply chain alternative to meet or exceed customer's expectations [19]. Thaichon et al. [20] indicate that judgment of overall service quality in the telecommunications industry comes from organizations' perceptions of a stable and strong network and service qualities.

In a fully interoperable environment, any IoT device would be able to connect to any other device or system and exchange information as desired. Macaulay [21] states that interoperability among IoT devices and systems happens in varying degrees at different layers within the communications protocol stack between the devices. Kryvinska and Strauss [22] believe that, beyond the technical aspects, interoperability has significant influence on the potential economic impact of IoT. Meanwhile, Dehury and Sahoo [23] state that well-a functioning and well-defined device interoperability can encourage innovation and provide efficiencies for IoT device manufacturers, increasing the overall economic value of the market. Macaulay [21] states that interoperability is necessary to create 40 percent of the potential value that can be generated by the IoT in various settings. The author also stated that interoperability is required to unlock more than $4 trillion per year in potential economic impact for IoT use in 2025, out of a total impact of $11.1 trillion. While some organizations perceive competitive advantages and economic incentives in building proprietary systems, overall economic opportunities may be constrained in a marketplace of silos.

Technological Infrastructure is concerned with the integration level of IoT system with the technological infrastructure of the organization. If the integration is low, this may lead to many malfunctions and additional database and server costs. Miorandi et al. [8] point out that the IoT will only be able to operate effectively through a good infrastructure. Chin et al. [24] state that since IoT system can be used by different users from different departments in a specific organization, the integration of authorization and authentication system is a critical component. Olivier et al. [25] state that organizations need to ensure that IoT infrastructure is selected as the infrastructure must ensure reliable security and privacy by supporting individual authentication of billions of heterogeneous devices using heterogeneous communication technologies across different administrative domains. Zanella et al. [12] believe that the challenge in the future is for an IoT application infrastructure to run quickly and consistently, especially where real-time delivery is required for determining availability and status.

Building a reliable IoT system has always been an important requirement for the business to operate successfully [26]. Reliability is the capability of a measuring specification to maintain a specific level of performance each IoT applications and sensor devices which are different conditions. An IoT system deploys a massive number of network aware devices in a dynamic, error-prone, and unpredictable environment, and is expected to run for a long time without failure. To commission such a system and to keep it operational, it is essential that the IoT system is designed to be reliable. Sarkar [27] points out that an IoT platform must be tested for reliability under the most traffic-intensive work environments, with fault tolerance and network disaster recovery protocols mapped out.

Security is the biggest concern in adopting IoT technology and security considerations must be an integral part of the evaluation criteria before any IoT system is adopted by an organization, and additional security measures will likely be needed to ensure the integrity of both the network, and the data it houses and transmits. Not only will organizations that gather data from billions of devices need to be able to protect those data from unauthorized access, but they will also need to deal with new categories of risk that the IoT can introduce. Hersent et al. [28] point out that security is paramount for the safe and reliable operation of IoT connected devices. At the same time, Gubbi et al. [26] state that security is the foundational enabler of IoT and therefore, it is important the right IoT system should be selected in order to provide an appropriate security level and ensure a reliable system performance.

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Farooq et al. [29] state that organizations need to enhance privacy and built secure IoT devices by adopting a security-focused approach, reducing the amount of data collected by IoT devices, and increasing transparency and providing consumers with a choice to opt-out of data collection. Weber [30] believes that organizations also need to build security into software applications and network connections that link to those devices. Without adequate security, intruders can break into IoT systems and networks, accessing potentially sensitive personal information about users, and using vulnerable devices to attack local networks and devices, thereby breaching their privacy.

Evaluating the performance of the IoT based supply chain alternatives with respect to a set of specific criteria is however complex and challenging. This is due to the presence of multiple decision makers, the multi-dimensional nature of the decision making process, the conflicting nature of the multiple evaluation criteria, and the presence of uncertainty and imprecision in the decision making process [31]. To help address this complex and challenging issue in evaluating the performance of the IoT based supply chain alternatives, it is therefore desirable to have a structured decision making process for effectively solving the IoT based supply chain performance evaluation problem.

3. The Fuzzy Multicriteria Group Decision Making Algorithm

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

The multicriteria group decision making process starts with the determination of the performance of each IoT based supply chain alternative A_i ($i = 1, 2, \ldots, n$) with respect to each criterion C_j ($j = 1, 2, \ldots, m$) by individual decision makers D_k ($k = 1, 2, \ldots, s$). Here, the decision maker D_k provides his/her intuitionistic assessments for each alternative in a form of an intuitionistic preference relation $y_{ij}^k = (\mu_{ij}^k, v_{ij}^k)$, and $0 \le \mu_{ij}^k + v_{ij}^k \le 1, \mu_{ij}^k = v_{ij}^k, v_{ij}^k = \mu_{ij}^k = 0.5$. μ_{ij}^k indicates the degree that the alternative A_i satisfies the criterion C_j whereas v_{ij}^k indicates the degree that the alternative A_i does not satisfy the criterion C_j. As a result, the decision matrix for each decision maker can be expressed as

$$y_{ij}^k = \begin{bmatrix} \mu_{11}^k, v_{11}^k & \mu_{12}^k, v_{12}^k & \cdots & \mu_{1m}^k, v_{1m}^k \\ \mu_{21}^k, v_{21}^k & \mu_{22}^k, v_{22}^k & \cdots & \mu_{2m}^k, v_{2m}^k \\ \cdots & \cdots & \cdots & \cdots \\ \mu_{n1}^k, v_{n1}^k & \mu_{n2}^k, v_{n2}^k & \cdots & \mu_{nm}^k, v_{nm}^k \end{bmatrix} \quad (1)$$

The relative importance of the evaluation criteria C_j for each decision maker can be represented as

$$w_j^k = (w_1^k,\ w_2^k, \ldots,\ w_m^k) \quad (2)$$

where $w_j^k = (\mu_j^k, v_j^k)$ is the intuitionistic fuzzy number obtained from the decision makers for assessing the relative importance of the evaluation criteria. μ_j^k indicates the degree where the decision maker considers the evaluation criterion C_j to be important whereas v_j^k indicates the degree where the decision maker considers the evaluation criterion C_j to be unimportant.

By averaging the fuzzy assessments made by individual decision makers as given in (1) and (2), the overall intuitionistic fuzzy decision matrix and the overall intuitionistic fuzzy weight vector can be obtained respectively as

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$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \quad (3)$$

$$W = (w_1, w_2, \ldots, w_j, \ldots, w_m) \quad (4)$$

Based on (3) and (4), the collective weighted interval-valued based intuitionistic fuzzy performance matrix for the problem can be obtained as in (5).

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \quad (5)$$

The concept of the ideal solution is first introduced as the best decision outcome in a given decision situation [34]. This concept is then extended to include the negative ideal solution in order to avoid the worst decision outcome in the decision making process. This concept has since been widely used for solving practical decision problems [32] due to (a) its simplicity and comprehensibility in concept, (b) its computation efficiency, and (c) its ability to measure the relative performance of the decision alternatives in a simple mathematical form [31].

The positive (or negative) ideal solution consists of the best (or worst) criterion values attainable from all the alternatives (Hwang et al., 1993; Yeh et al., 2010). The fuzzy positive ideal solution α^+ and the fuzzy negative ideal solution α^- can be determined respectively as

$$\alpha^+ = (\alpha_1^+, \alpha_2^+, \ldots, \alpha_m^+) = \{\langle ([(\max_i \mu_{ij}) | j \in J_1, (\min_i v_{ij}) | j \in J_2)], \\ [(\min_i \mu_{ij}) | j \in J_1, (\max_i v_{ij}) | j \in J_2]) \rangle i = 1, 2, \ldots, n\} \quad (6)$$

where $\alpha_j^+ = [\mu_j^+, v_j^+]$ and (j = 1, 2, …, m).

$$\alpha^- = (\alpha_1^-, \alpha_2^-, \ldots, \alpha_m^-) = \{\langle ([(\min_i \mu_{ij}) | j \in J_1, (\max_i v_{ij}) | j \in J_2)], \\ [(\max_i \mu_{ij}) | j \in J_1, (\min_i v_{ij}) | j \in J_2]) \rangle i = 1, 2, \ldots, n\} \quad (7)$$

where $\alpha_j^- = [\mu_j^-, v_j^-]$

This is followed by calculating the degree of indeterminacy π_j^+ of the relative positive ideal value $\alpha_j^+ = [\mu_j^+, v_j^+]$ and the degree of indeterminacy π_j^- of the relative negative ideal value $\alpha_j^- = [\mu_j^-, v_j^-]$ for each criterion C_j respectively by

$$\pi_j^+ = 1 - \mu_j^+ - v_j^+ \quad (8)$$

$$\pi_j^- = 1 - \mu_j^- - v_j^- \quad (9)$$

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Based on (8) - (9), the degree of similarity (Chen et al., 2016) between alternative A_i and the positive ideal solution and the negative solution can be calculated respectively as follows

$$G_i^+ = 1 - \frac{\left|2(\mu_j^+ - \mu_{ij})(\nu_j^+ - \nu_{ij})\right|}{3} \times (1 - \frac{\pi_j^+ + \pi_{ij}}{2}) - \frac{\left|2(\nu_j^+ - \nu_{ij})(\mu_j^+ - \mu_{ij})\right|}{3} \times (\frac{\pi_j^+ + \pi_{ij}}{2}) \quad (10)$$

$$G_i^- = 1 - \frac{\left|2(\mu_j^- - \mu_{ij})(\nu_j^- - \nu_{ij})\right|}{3} \times (1 - \frac{\pi_j^- + \pi_{ij}}{2}) - \frac{\left|2(\nu_j^- - \nu_{ij})(\mu_j^- - \mu_{ij})\right|}{3} \times (\frac{\pi_j^- + \pi_{ij}}{2}) \quad (11)$$

The most preferred alternative should not only have the shortest distance from the positive ideal solution, but also the longest distance from the negative ideal solution (Hwang et al., 1993; Wibowo and Deng, 2013). Thus, an overall performance index for each alternative A_i across all the criteria can be determined by

$$P_i = \frac{S_i^-}{S_i^- + S_i^+} \qquad i = 1, 2, \quad , n \quad (12)$$

The procedure for the fuzzy multicriteria group decision making algorithm is summarized as:

Step 1. Obtain the decision matrix for each decision maker as expressed in (1).
Step 2. Determine the relative importance of the evaluation criteria Cj for each decision maker as expressed in (2).
Step 3. Obtain the overall intuitionistic fuzzy decision matrix of each alternative as given in (3).
Step 4. Obtain the overall intuitionistic fuzzy weight vector of each alternative as shown in (4).
Step 5. Calculate the collective weighted interval-valued based intuitionistic fuzzy performance matrix as in (5).
Step 6. Determine the fuzzy positive ideal solution and the fuzzy negative ideal solution using (6) and (7) respectively.
Step 7. Calculate the degree of indeterminacy of the relative positive ideal value and the relative negative ideal value by (8) and (9) respectively.
Step 8. Calculate the degree of similarity between alternative Ai and the positive ideal solution and the negative solution by (10) and (11) respectively.
Step 9. Compute the overall degree of closeness for each alternative across all the criteria by (12).
Step 10. Rank the alternatives in descending order of their index values.

4. An Example

To demonstrate the applicability of the proposed fuzzy multicriteria group decision making model above, an IoT based supply chain performance evaluation problem at a high-technology manufacturing company is presented.

Owing to the competition involved in joining the World Trade Organization, Taiwan has faced challenges in the electronics manufacturing sector [36]. For Taiwan to retain its competitive advantage, the manufacturing companies must reduce their production costs and increase sales of electronics products.

Against this background, a manufacturing company in Taiwan decides to take this opportunity to develop and implement an IoT based supply chain for meeting the challenges in the electronics manufacturing sector. This company is a top provider of innovative products in Taiwan and is ranked among top three in the global market for all its product lines. This company entered Taiwanese light emitting diodes (LED) industry, where it enjoyed the number one status for over thirty years, because of its innovative products for both local and global markets. Its product line includes imaging products, enclosures, power supplies and LEDs.

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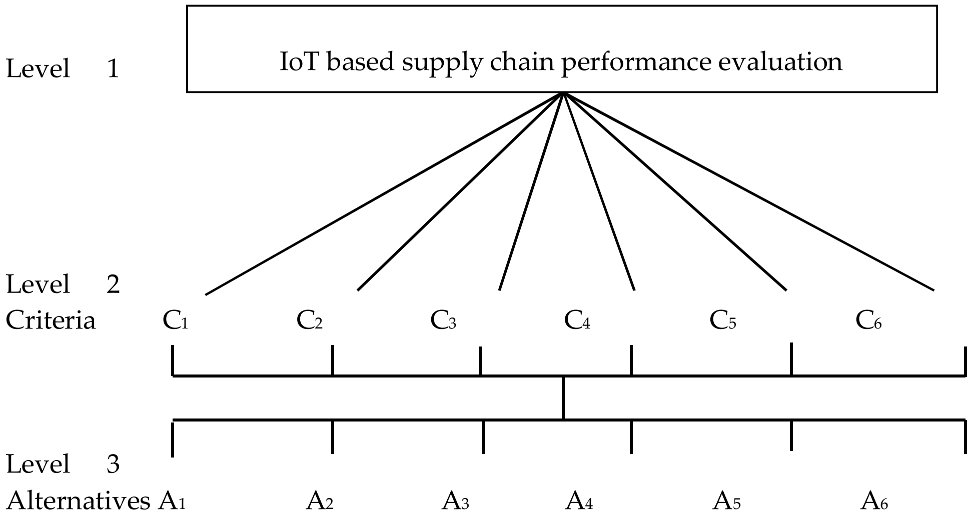
Through the adoption of the IoT based supply chain initiative, the company believes that it will continue to be one of the leaders in the electronics manufacturing sector and at the same time, improve its customers' overall satisfaction. Hence, the establishment of an IoT based supply chain is essential for the success of the company.

In order to select the most suitable IoT based supply chain for the company, a committee consisting of three departmental managers is formed. This committee has identified several IoT based supply chain alternatives, and the evaluation criteria through a comprehensive investigation. Six IoT based supply chain alternatives and six evaluation criteria are identified for evaluating the most suitable IoT based supply chain for development and implementation.

These evaluation criteria include Financial Cost (C_1), Service Quality (C_2), Functionality (C_3), Technological Infrastructure (C_4), Reliability (C_5) and Security (C_6). The hierarchical structure of IoT based supply chain performance evaluation is shown in Figure 1.



Legend:

C_1:	Financial Cost	C_2:	Service Quality
C_3:	Interoperability	C_4:	Technological Infrastructure
C_5:	Reliability	C_6:	Security

A_i ($i = 1, 2, \ldots, n$): IoT based supply chain alternatives.

Figure 1. The Hierarchical Structure of IoT based Supply Chain Performance Evaluation

Financial Cost (C_1) is concerned with the economical and financial feasibility of the organization to support the development and implementation of an IoT based supply chain alternative. This is measured by hardware costs, software costs, implementation costs, and maintenance costs [37].

Service Quality (C_2) refers to the level of achievement of the IoT based supply chain alternative to meet or exceed customer's expectations [19]. This is often measured by the information system quality, the process performance, the level of customer satisfaction, and the distribution network quality [20].

Interoperability (C_3) is the ability of an IoT system to provide services to and accept services from other systems, and to use the services exchanged to enable them to operate effectively together [26]. This is assessed by technical compliance measures, systems interoperability measures, and operational interoperability measures.

Technological Infrastructure (C_4) refers to the ability of electronic devices interconnected through the IoT, to provide prompt and effective service to end-users. This is measured by the efficiency of the system, the collaboration capabilities with other systems, and the portability of the system.

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Reliability (C_5) is a concerned with the assurance that IoT system is free from hardware failures, software faults, and other defects that could make them break down [38]. For example, sensors, too, need to be calibrated to ensure proper measurements. This is measured by the fault tolerance, the connectivity of the system, the recoverability of the system, and the robustness of the system.

Security is often cited as one of the most significant issues in IoT deployment. Security at both the device and network levels is critical to the operation of IoT. Security (C_6) refers to area of endeavor concerned with safeguarding connected devices and networks in the IoT. This is measured by the level of access control, the level of device authentication, and the level of encryption and other robust security measures [30].

A comprehensive investigation has been carried out to collect the required data for the evaluation process. Subjective assessments are usually involved in evaluating the performance of alternative IoT based supply chain alternatives and the importance of the evaluation criteria. To adequately model the uncertainty and imprecision of the decision making process, intuitionistic fuzzy numbers are used for representing the subjective assessments of the decision makers.

It is observed that two common issues are involved in this IoT based supply chain performance evaluation process. The evaluation criteria are generally multi-dimensional in nature and a simultaneous consideration of those multiple criteria is required for making effective decisions. The evaluation process involves subjective assessments, resulting in qualitative and vague data being used.

To start with the IoT based supply chain performance evaluation process, the relative performance of all available IoT based supply chain alternatives in regard to three decision makers D_1, D_2, and D_3 can be determined by making their subjective assessments using the intuitionistic fuzzy numbers as shown in Table 1.

Table 1. Performance Assessments of IoT based Supply Chain Alternatives

		C_1	C_2	C_3	C_4	C_5	C_6
	D_1	(0.6,0.7)	(0.3,0.6)	(0.4,0.6)	(0.3,0.6)	(0.5,0.6)	(0.5,0.6)
A_1	D_2	(0.5,0.8)	(0.5,0.7)	(0.4,0.7)	(0.4,0.5)	(0.5,0.7)	(0.5,0.8)
	D_3	(0.5,0.6)	(0.3,0.4)	(0.7,0.8)	(0.5,0.7)	(0.4,0.6)	(0.7,0.8)
	D_1	(0.3,0.6)	(0.5,0.6)	(0.3,0.5)	(0.5,0.8)	(0.4,0.8)	(0.1,0.3)
A_2	D_2	(0.5,0.7)	(0.5,0.8)	(0.6,0.8)	(0.6,0.7)	(0.3,0.7)	(0.7,0.8)
	D_3	(0.2,0.6)	(0.7,0.8)	(0.5,0.9)	(0.3,0.6)	(0.5,0.9)	(0.4,0.6)
	D_1	(0.4,0.5)	(0.3,0.4)	(0.3,0.6)	(0.4,0.8)	(0.6,0.8)	(0.5,0.7)
A_3	D_2	(0.3,0.7)	(0.7,0.8)	(0.5,0.8)	(0.6,0.8)	(0.3,0.6)	(0.5,0.6)
	D_3	(0.5,0.6)	(0.1,0.3)	(0.7,0.8)	(0.5,0.6)	(0.3,0.8)	(0.6,0.8)
	D_1	(0.4,0.8)	(0.6,0.8)	(0.4,0.7)	(0.3,0.6)	(0.5,0.6)	(0.5,0.7)
A_4	D_2	(0.3,0.4)	(0.4,0.7)	(0.6,0.9)	(0.3,0.5)	(0.3,0.6)	(0.7,0.8)
	D_3	(0.7,0.8)	(0.5,0.6)	(0.5,0.8)	(0.5,0.7)	(0.5,0.7)	(0.5,0.6)
	D_1	(0.5,0.7)	(0.3,0.8)	(0.6,0.8)	(0.5,0.7)	(0.6,0.9)	(0.6,0.7)
A_5	D_2	(0.5,0.6)	(0.4,0.6)	(0.3,0.6)	(0.5,0.6)	(0.5,0.8)	(0.6,0.8)
	D_3	(0.7,0.8)	(0.5,0.8)	(0.5,0.8)	(0.6,0.8)	(0.4,0.6)	(0.3,0.6)
	D_1	(0.2,0.6)	(0.6,0.7)	(0.4,0.6)	(0.4,0.5)	(0.4,0.7)	(0.4,0.8)
A_6	D_2	(0.7,0.8)	(0.5,0.6)	(0.3,0.7)	(0.7,0.8)	(0.6,0.8)	(0.5,0.7)
	D_3	(0.5,0.6)	(0.4,0.7)	(0.5,0.6)	(0.3,0.4)	(0.4,0.6)	(0.5,0.6)

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Similarly, the criteria weights for evaluating the performance of IoT based supply chain alternatives can be obtained directly from the decision makers D_1, D_2 and D_3 as shown in Table 2.

Table 2. Criteria Weights of IoT based Supply Chain Alternatives

Criteria	Decision makers		
	D_1	D_2	D_3
C_1	(0.6, 0.3)	(0.5, 0.1)	(0.7, 0.3)
C_2	(0.5, 0.4)	(0.4, 0.3)	(0.5, 0.4)
C_3	(0.2, 0.5)	(0.3, 0.6)	(0.6, 0.4)
C_4	(0.6, 0.8)	(0.2, 0.5)	(0.8, 0.6)
C_5	(0.4, 0.2)	(0.7, 0.3)	(0.4, 0.3)
C_6	(0.7, 0.3)	(0.5, 0.4)	(0.5, 0.3)

Based on (3)-(5), the collective weighted intuitionistic fuzzy performance matrix for the IoT based supply chain performance evaluation problem can be obtained. Table 3 shows the results.

Table 3. The Collective Weighted Intuitionistic Fuzzy Performance Matrix

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	(0.52,0.64)	(0.58,0.63)	(0.67,0.75)	(0.51,0.62)	(0.43,0.48)	(0.42,0.51)
A_2	(0.37,0.46)	(0.46,0.57)	(0.41,0.49)	(0.35,0.46)	(0.44,0.52)	(0.52,0.59)
A_3	(0.73,0.87)	(0.56,0.71)	(0.68,0.76)	(0.63,0.68)	(0.55,0.64)	(0.37,0.64)
A_4	(0.68,0.73)	(0.52,0.58)	(0.54,0.61)	(0.55,0.63)	(0.35,0.46)	(0.56,0.71)
A_5	(0.44,0.58)	(0.36,0.62)	(0.48,0.54)	(0.52,0.59)	(0.63,0.68)	(0.47,0.63)
A_6	(0.48,0.53)	(0.48,0.55)	(0.54,0.62)	(0.43,0.52)	(0.55,0.63)	(0.38,0.53)

By using (6)-(12), the overall performance index for each IoT based supply chain alternative across all the criteria can be calculated in an effective and efficient manner. Table 4 shows the overall performance index values of the IoT based supply chain alternatives and their corresponding rankings. The results show the IoT based supply chain alternative A_3 has the best performance, relative to other alternatives as it has the highest overall intuitionistic fuzzy performance index value of 0.71.

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Table 4. The Performance Index of IoT based Supply Chain and their Rankings

Alternatives	Criteria													
	Financial Cost (C_1)		Service Quality (C_2)		Functionality (C_3)		Technological Infrastructure (C_4)		Reliability (C_5)		Security (C_6)		Overall	
	Index	Ranking	Index	Ranking	Index	Ranking	Index	Ranking	Index	Ranking	Index	Ranking	Index	Ranking
A_1	0.68	2	0.58	5	0.61	4	0.64	3	0.54	3	0.66	4	0.63	3
A_2	0.56	5	0.51	6	0.54	6	0.51	6	0.53	6	0.53	6	0.52	6
A_3	0.70	1	0.73	1	0.67	2	0.71	1	0.72	2	0.74	1	0.71	1
A_4	0.63	3	0.70	2	0.70	1	0.67	2	0.69	1	0.71	2	0.68	2
A_5	0.52	6	0.62	4	0.57	5	0.55	5	0.52	5	0.56	5	0.54	5
A_6	0.61	4	0.65	3	0.64	3	0.59	4	0.61	4	0.58	3	0.61	4

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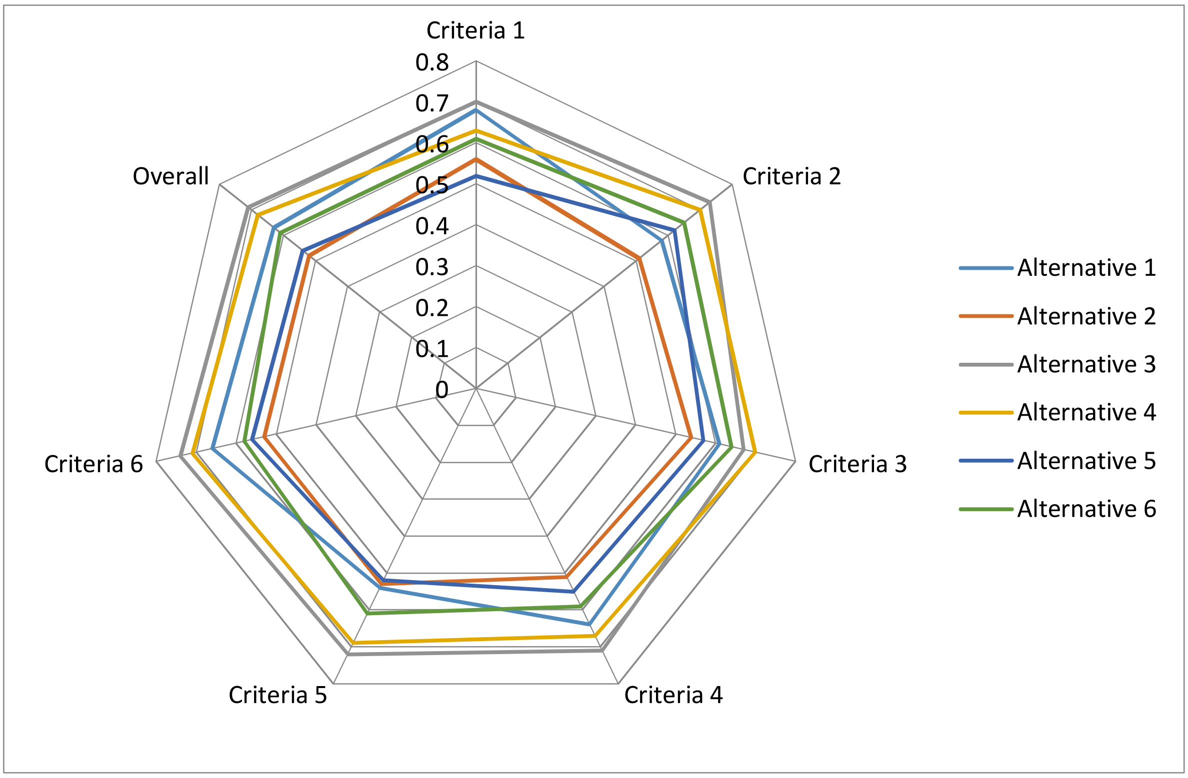

Figure 2. The Performance Index Values of Alternatives with respect to Each Criterion

Figure 2 presented above provides performance index values of the six alternatives with respect to each criteria highlighted in figure 1. The result in Table 4 also provides the company with relevant information about the performance level of individual IoT based supply chain alternatives in terms of both overall and individual performance criteria. Although alternative A_3 is the most suitable alternative, it does not have competitive advantages in all performance criteria. This comparative status also applies to other IoT based supply chain alternatives. For example, alternative A_1 requires improving its performance in all criteria, especially service quality and resource consumption. Despite being the best performer, alternative A_3 is not the best in terms of resource consumption. Meanwhile, alternative A_5 is not one of the most suitable alternatives and needs to improve its performance in all criteria, particularly in financial cost. The result can thus help the company to identify the relative weaknesses of the available alternatives for improving its competitiveness.

This demonstrates that the proposed fuzzy multicriteria group decision making algorithm is useful for solving real multicriteria group decision making problems. Furthermore, the underlying principle of the proposed algorithm which is based on the concept of ideal solutions is logical and comprehensible, and the computation involved is very simple and straightforward.

In addition, the proposed fuzzy multicriteria group decision algorithm can be easily incorporated into a decision support system which makes the overall performance evaluation process effective and efficient.

5. Conclusion

The IoT based supply chain performance evaluation is challenging due the involvement of multiple decision makers, the multi-dimensional nature of the evaluation process, and the existence of uncertainty and imprecision in the decision making process. As a result, how to handle the presence of multiple decision makers and the multi-dimensional nature of the evaluation process, and adequately model the uncertainty and imprecision becomes a critical issue for effectively dealing with the IoT based supply chain performance evaluation problem in a real world setting.

To effectively deal with this problem, this paper has presented a fuzzy multicriteria group decision making model for evaluating the performance of IoT based supply chain alternatives. The inherent uncertainty and imprecision of the evaluation process is adequately handled by using

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intuitionistic fuzzy numbers. The concept of ideal solutions is developed for producing a performance index for every IoT based supply chain alternative. The result shows that the developed fuzzy multicriteria group decision making model is capable of solving the IoT based supply chain performance evaluation problem effectively due to its simplicity in concept and its efficiency in computation. The limitation of this research is due to the dependency of the decision outcome on the inputs provided by the decision makers. The future studies on this research area can include the development of a decision support system for dealing with the performance evaluation problem in a more efficient manner.

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