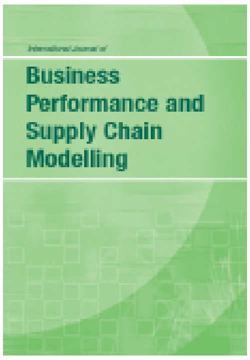

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Selection of ideal supplier in e-procurement for manufacturing industry using intuitionistic fuzzy AHP

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Abstract: Purchasing plays a momentous role in establishing relationships with a plethora of business partners in supply chain and is pivotal concerning overall firm operations and supply chain performance. Majority of firms militate against the cost-competitive world in reducing the overall component cost by scrutinising cost-effective suppliers. E-procurement is one of the pre-eminent features in supply chain management (SCM) and has garnered considerable attention among manufacturing industries in the Middle East. Due to its distinct nature, a glut of novice criteria and sub-criteria has been augmented with the traditional classifications for selecting a consummate supplier. Initially, the selected criteria were analysed and compared by deriving priority weights using AHP, FAHP and IF-AHP, respectively. Subsequently, we focused on utilising IF-AHP for the first time in e-procurement for efficient supplier selection. Of particular note, this study assists the firm in optimising the evaluation of impeccable supplier selection in e-procurement based on key criteria.

Keywords: e-procurement; supplier selection; multi-criteria decision making; MCDM; fuzzy analytic hierarchy process; FAHP; intuitionistic preference relation; IPR; intuitionistic fuzzy set; IFS; consistency.

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1 Introduction

Purchasing comprises a sequence of activities to target acquiring the right product or service at the best quality and at the lowest price. The global marketplace today is thriving hard to motivate companies to transform their supply chain, specifically involved in reducing overall costs and eliminating inefficiencies. Information technology can bolster the organisation in making abrupt, precise and impeccable purchasing decisions in order to manage their supplier relationships more efficiently. As part of this assistance, companies employ electronic procurement software along with supplier selection systems. E-procurement also referred to as online procurement can be defined in short as, electronic purchase of materials for a firm's overall operation. Major benefits of e-procurement include: reducing the paperwork and cycle time, faster ordering, reducing the inventory, transaction costs, etc. Moreover, the majority of governments universally intend to improve transparency in their procurement procedures with the use of e-procurement software (Neupane et al., 2012).

In any supply chain management (SCM) model, selecting the right supplier is the cornerstone, and it is essentially a multi-criteria decision making (MCDM) process. Although supplier selection in an e-procurement environment has been discussed using analytic hierarchy process (AHP) and fuzzy analytic hierarchy process (FAHP) methodologies in early literature, only a few efforts have been made to implement intuitionistic fuzzy analytic hierarchy process (IF-AHP)-based e-procurement system. Therefore, a study was conducted in the Middle East manufacturing sector to evaluate a supplier selection strategy when conducting an electronic procurement using IF-AHP. In this paper, a robust and more powerful IF-AHP methodology has been proposed for selecting an ideal supplier through meticulous assessment of all the potential criteria considered in an e-procurement system. A questionnaire on these common criteria was provided to over 20 leading firms in the Middle East. Based on the responses, an impeccable pairwise comparison was built. After generating the preference relation, this paper provides a comparison analysis of criteria to enhance the efficiency of the IF-AHP approach. In this paper, Section 2 focuses on literature survey that places a seismic role in data collection regarding e-procurement, criteria opting for ideal supplier, FAHP and IF-AHP, Section 3 depicted the research highlights, Section 4 illustrates the problem description, Section 5 manifests the procedure for IF-AHP and Section 6 presents a questionnaire development, Section 7 clearly elucidates an illustrative example and also discusses ranking outcomes to predict the ideal supplier respectively. Finally, Section 8 ends the paper with proper conclusions.

2 Literature survey

Many researchers have explored the implementation of AHP and FAHP-based e-procurement strategies as well as various qualitative and quantitative key criteria for selecting right suppliers. In this paper, however, we will investigate robust IF-AHP-based procurement software and will augment new criteria based on expert recommendations to improve its efficiency. The literature review is structured into four distinctive sections. The top and foremost section depicts the utilisation of e-procurement systems in various applications. The second section explores a list of criteria for the evaluation of highly qualified suppliers in an e-procurement system. The third and final section reveals the usage of FAHP and IF-AHP methodologies.

2.1 E-procurement system

Myriad of erudite scholars and research practitioners in the Middle East focused on the concept of implementing online procurement in SCM. Below is the literature review of implementing an online procurement system and also depicts the framework model, benefits, critical success factors (CSFs), drivers, barriers, etc.

Kheng and Al-Hawamdeh (2002) discussed B2B e-commerce, with an emphasis on e-procurement systems among companies in Singapore. Chang et al. (2004) provided a coherent explanation about the design principle of an online procurement system and also included their implementation issues. Furthermore, the paper provides a lucid demonstration of their technical architecture, functional diagram, data entities and generic procurement processes. Angeles and Nath (2007) aimed at providing cogent information about recent business-to-business (B2B) e-procurement strategies by illustrating their success factors and implementation issues in the corporate world. Choi and Kim (2008) presented an online procurement decision model by merging MCDM methodology and a rule-based reasoning for the selection of skilled suppliers. Gunasekaran and Ngai (2008) devised a conceptual structure for the implementation of procurement through online among firms in Hong Kong by organising a survey in the form of a questionnaire type and also provided manifestations about the drivers and barriers for e-procurement system implementation.

Al-Aama (2012) explored the e-procurement system in Jeddah municipality which empowers citizens of Saudi Arabia to monitor and govern all the e-procurement services online in order to enhance transparency. Changsen (2012) outlined a framework model for e-procurement system implementation in China that also explored its functional benefits. Gupta and Narain (2014) proposed the fuzzy analytic network process (FANP) methodology primarily aimed at selecting an ultimate electronic business scheme. According to the outcome of a proposed model, electronic procurement systems outperform various alternatives because it improves firms' efficacy, accelerates sales performance and establishes enhanced dealing with partners and vendors. Jonathan et al. (2017) illustrated the implementation of an electronic procurement system based on success factors in the Indonesian government. Nanang et al. (2017) provided a demonstration of success factor measurement during the implementation of an e-procurement system in Indonesia. Jadhav et al. (2020) proposed a comprehensive framework model regarding e-procurement system for the police department and also depicts the motivational factors and benefits of e-procurement in various government and private organisations.

2.2 Criteria of e-procurement

Supplier selection has played a monumental role among various academicians and research scholars since the 1960s. Researchers of that era posited that quality and delivery of a product are preferred as the pivotal criteria for picking potential suppliers. But, an excess of other essential and pertinent criteria are augmented for the evaluation process to enhance the peculiarity of e-procurement for picking a consummate supplier.

The review below shows the investigation of various factors and criteria for the selection of ideal supplier in an e-procurement system.

Bottani and Rizzi (2005) depicts an evaluation and assessment of relevant criteria for opting for highly qualified suppliers in online procurement among the food industry in Italy, and in turn applied the procurement of MRO materials using FAHP. Puschmann and Alt (2005) provided exploration on electronic procurement system implementation and mentioned all their essential benefits, success factors, criteria and characteristics for describing online procurement systems in SCM. Pani and Kar (2011) provided coherent explanations about various criteria considerations for the selection of potential Indian manufacturing industry suppliers through an online procurement system using FAHP. Basheka et al. (2012) investigated most of the CSFs for applying procurement technologies online in the public sector in Uganda. Kamarulzaman and Mohamed (2013) meticulously explored relevant factors for implementing e-procurement technologies in the selection of Malaysian agro-based SME suppliers. Taherdoost and Brard (2019) illustrates a deep exploration of the supplier selection process based on various criteria and evaluation methodologies. Samut and Aktan (2019) focused on the evaluation and an extensive demonstration on supplier selection based on assessing various factors.

Table 1 Problem analysis using FAHP

S. no.	*Authors*	*Problem description*
1	Bottani and Rizzi (2005)	Evaluation of criteria and selection of impeccable suppliers in the Italian food industry in an e-procurement environment using FAHP.
2	Chan and Kumar (2007)	Scrutinising critical decision criteria and risk factors for opting suppliers using FEAHP methodology.
3	Chan et al. (2008)	Global supplier selection in the manufacturing industry using the fuzzy analytic hierarchy process.
4	Chen et al. (2010)	Evaluation of B2C electronic commerce companies' customer value using fuzzy analytic hierarchy process
5	Fu et al. (2010)	Evaluation of automobile R&D project features and selection of project management software respectively using fuzzy analytic hierarchy process and MCDM methodologies.
6	Sun (2010)	Evaluation model based on performance by integrating fuzzy analytic hierarchy process and fuzzy TOPSIS.
7	Kilincci and Onal (2011)	Picking potential suppliers for a Turkey-based washing machine firm using the fuzzy analytic hierarchy process methodology.
8	Sofyalıoglu and Kartal (2012)	Determination of risks in supply chain and management tactics in the iron and steel industry are implemented using FAHP.
9	Junior et al. (2014)	Integration of fuzzy analytic hierarchy process and TOPSIS for decision making process.
10	Pornsing et al. (2019)	Evaluation of problems related to supplier selection using fuzzy analytic hierarchy process for an e-manufacturer.
11	Feng (2021)	Evaluation of safety risk management in high rise building construction using fuzzy analytic hierarchy process.

2.3 Fuzzy analytic hierarchy process

FAHP is a MCDM tool. Utilisation of fuzzy set theory in making decisions related to criteria in various application domains. Table 1 clearly depicts the applications of the FAHP in a range of scenarios in the recent years and their problems analysed with the help of FAHP.

2.4 Intuitionistic fuzzy analytic hierarchy process

IF-AHP shows distinct advantages over the archaic AHP and FAHP methodologies. The following shows literature review regarding the applications of IF-AHP in multiple scenarios in the past years.

Qian and Feng (2008) developed a consistency checking methodology for intuitionistic preference relations (IPRs). Furthermore, programming models were implemented in order to estimate an intuitionistic priority vector from IPR. Boran (2011) focused on devising a novel and powerful method by integrating IFPR and IF-TOPSIS for facility location selection. Of particular note, the derivation of priority weights and ranking the alternatives are done by means of IFPR and IF-TOPSIS approaches respectively. Liao and Xu (2014) aimed to propose a novice methodology for priority weight generation from an IFPR.

Xu and Liao (2014) devised a novel approach for consistency check of an IPR. As a result, an automatic repairing procedure (Xu and Liao, 2014) was implemented in order to save time in repairing inconsistent IPR without consulting a decision maker. Interestingly, this novice repairing procedure does not appear in traditional AHP and FAHP. Additionally, this paper devised a normalising rank summation method (Xu and Liao, 2014) for generating priority weights of an IPR. Finally, a detailed demonstration of IF-AHP was presented with an illustrative example regarding global supplier development (Xu and Liao, 2014). Table 2 clearly depicts the applications of IF-AHP implemented in recent years and also presents issues relevant to IF-AHP methodology.

On the basis of an examination of early literature, we conclude that IF-AHP has been used for various decision-making problems. In addition to that, some researchers examine the most basic criteria in common and they do not address the importance of augmenting novel criteria and sub-criteria in order to outline the potential ones. As a result, it is evident that fewer efforts have been made in the early literature to implement electronic procurement using IF-AHP for the impeccable supplier selection problem. In order to address this research gap, this paper seeks to fill the gap through the following processes: The first step was to thoroughly examine all basic and essential criteria and sub-criteria. The second step was to add a few novel criteria and sub-criteria that are based on expert recommendations or replace any less desirable criteria and sub-criteria to improve efficiency. Following that, the priority weights will be generated using AHP, FAHP and IF-AHP separately for each selected criterion to facilitate the extensive analysis necessary to boost the efficiency of the IF-AHP methodology. Finally, supplier selection in an e-procurement system using the IF-AHP approach was performed.

Table 2 Problem analysis using IF-AHP

S. no.	*Authors*	*Problem description*
1	Sadiq and Tesfamariam (2008)	Undergone a robust methodology to handle vagueness and uncertainty in environmental decision making using IF-AHP.
2	Tavana et al. (2016)	Evaluation of strategic factors and sub-factors for outsourcing reverse logistics (ORL) using IF-AHP and SWOT methodologies.
3	Rodriguez et al. (2017)	Demonstration of the risk management selection strategy in information technology (IT) projects using IF-AHP.
4	Zhang and Pedrycz (2017)	Intuitionistic multiplicative group analytic hierarchy process (Zhang and Pedrycz, 2017) (IMGAHP) was proposed to solve multi-criteria group decision making issues. Proposed methodologies for consistency check and repairing process. Finally, devised an approach for generating an intuitionistic multiplicative priority weight vector.
5	Buyukozkan and Gocer (2017)	Supplier selection in Turkey by a novice integration of IF-AHP for deriving weights and intuitionistic fuzzy axiomatic design (IFAD) for the assessment of potential suppliers respectively.
6	Buyukozkan et al. (2019a)	Evaluating hazardous waste carrier (HWC) selection process using a novice and innovative integration of IF-AHP and IF-VIKOR methodologies for the first time in Turkey.
7	Buyukozkan et al. (2019b)	Evaluation and analysis of service quality for the hospitality industry using intuitionistic fuzzy analytic hierarchy process methodology.
8	Wang (2019)	Demonstration of an excellent PhD student selection based on the integration of uninorm-based fusion method and IF-AHP.
9	Liang et al. (2020)	Construction of an evaluation index for assessing a transmission network planning scheme using IF-AHP.
10	Su (2020)	Proposed a framework for selecting viable building material suppliers using intuitionistic fuzzy analytic hierarchy process approach.
11	Verma and Chandra (2021)	Security attributes evaluation for fog-IOT environment by means of prioritising and ranking using interval-valued IF-AHP.

3 Research highlights

1. Common potential criteria for the selection of the consummate supplier in the e-procurement model are meticulously collected through literature review and experts' recommendations.
2. A comparison assessment of every selected key criterion was performed by estimating the priority weights using AHP, FAHP and IF-AHP respectively.
3. A comprehensive framework model has been proposed by using the IF-AHP methodology.

4 From the outset, it is prerequisite to perform the following steps according to the framework model such as: construction of IPR, consistency check, automatic repairing procedure and derivation of priority weights among the alternatives are computed.

5 The outcomes are validated through feedback and replies from industrial experts.

4 Problem description

Majority of companies militate against the cost-competitive market by cutting their overall component and material cost. A firm must take into account the benefits of e-procurement as a solution to meet the demands of environmental concerns. In this study, criteria evaluation for opting ideal supplier for the manufacturing industry in an e-procurement system is preferred as the main objective. In general, deep exploration and investigation of various decision making criteria and supplier selection methodologies tend to determine companies' progress. Thus, criteria play a crucial role in determining highly potential suppliers in an e-procurement model. Prior to making a decision, it is imperative to meticulously review the following steps: exploring pre-defined criteria, identifying qualitative and quantitative criteria, augmenting essential criteria with an existing one and discarding any less important criteria, and generating weights using popular methods such as AHP, FAHP and IF-AHP to enhance the effectiveness of our proposed approach. All these steps are done through proper evaluation of existing literature review and an analysis survey given by the leading firm experts in the Middle East. According to the existing literature survey, it is evidenced that most of the researchers are utilising the previously defined common criteria like cost, quality, delivery and service (Taherdoost and Brard, 2019) for selection of supplier problems using any MCDM tool. In addition to that, some researchers investigated and discussed various qualitative and quantitative criteria for supplier selection but they did not prioritise all the available criteria to pick the top essential criteria group for consideration. This paper attempts to add few new criteria and sub-criteria to the previously defined ones based on the analysis of existing literature survey and experts' recommendation.

The questionnaire includes a list of essential criteria for supplier selection. It was provided to production managers in leading Middle Eastern firms. Consequently, the construction of pairwise comparison is generated by managers using intuitionistic values from 0.1 to 0.9 scales. In addition to that, the corresponding pairwise matrix provided by managers in the Middle Eastern manufacturing industries were analysed and compared using our popular AHP and FAHP methods. Finally, the outcomes are evaluated using IF-AHP methodology along with experts' opinion and industrial managers' views. Table 3 depicts an overview of pre-defined and newly added criteria along with sub-criteria for the supplier selection problem, explanations of each criterion and their corresponding sub-criterion along with relevant sources from an existing literature review. Of particular note, the evaluation assessment was based on five criteria and 17 sub-criteria. This will definitely bolster the company to analyse essential criteria for better adoption of supplier selection to increase the company's success rate.

Table 3 Criteria for supplier selection

Criteria 1: cost and delivery (pre-defined criteria)		
Monetary valuation of producing a product that involves value for material/utilities consumed, time, effort, risks incurred and delivery of goods or services (Su, 2020; Taherdoost and Brard, 2019; Xu and Liao, 2014)		
SC_1	Material cost	Cost of raw materials used to produce a product (Su, 2020; Taherdoost and Brard, 2019; Xu and Liao, 2014).
SC_2	Freight cost	Amount paid for the transportation of goods from one place to another by means of air, sea or land (Su, 2020; Xu and Liao, 2014).
SC_3	Production lead time	Total time taken to fabricate a product and deliver it to a consumer (Su, 2020; Taherdoost and Brard, 2019; Xu and Liao, 2014).
SC_4	Freight lead time	Total time taken for the transportation of goods from one place to another by means of air, sea or land (Su, 2020; Taherdoost and Brard, 2019).
Criteria 2: quality (pre-defined criteria)		
Ability of a supplier to meet consistent quality specifications (Su, 2020; Taherdoost and Brard, 2019; Xu and Liao, 2014)		
SC_5	Material standard	Focused on quality features of material, design, dimension, durability, etc. (Su, 2020; Taherdoost and Brard, 2019; Xu and Liao, 2014).
SC_6	Process standard	Focused on production quality and their continuous improvement (Taherdoost and Brard, 2019).
Criteria 3: payment terms (new criteria and sub-criteria augmented by the expert)		
Expected payment on a product and specifies how much amount of time a buyer has to make a payment on every purchase		
SC_7	Document against payment (D/P)	Initially, the buyer transfers funds to the bank. Once received, the bank forwards the original documents and the cash to the buyer and seller respectively (expert recommendation).
SC_8	Letter of credit (LC)	Payment was officially guaranteed by a bank (expert recommendation).
SC_9	Days after delivery	Number of days in which a buyer has to make a payment, i.e., 30 days, 60 days, 90 days, etc. (expert recommendation).
Criteria 4: supplier profile (new criteria and sub-criteria augmented by the expert)		
Displays supplier's status, certificates, history, etc. (Su, 2020; Taherdoost and Brard, 2019; Xu and Liao, 2014)		
SC_{10}	Supplier history	It shows suppliers' past performance history including financial, social and organisational area (Su, 2020; Taherdoost and Brard, 2019; Xu and Liao, 2014).
SC_{11}	Supplier infrastructure	Supplier's ability to procure new resources and equipment for development and research-oriented processes (Su, 2020; Taherdoost and Brard, 2019; Xu and Liao, 2014).
SC_{12}	Certification of quality and standard	Supplier's ability to consistently meet customer requirements in providing products and services and also focused on continuous improvement (Taherdoost and Brard, 2019; expert recommendation).
SC_{13}	Production volume	Volume of products manufactured by a supplier (Su, 2020; Taherdoost and Brard, 2019; Xu and Liao, 2014).

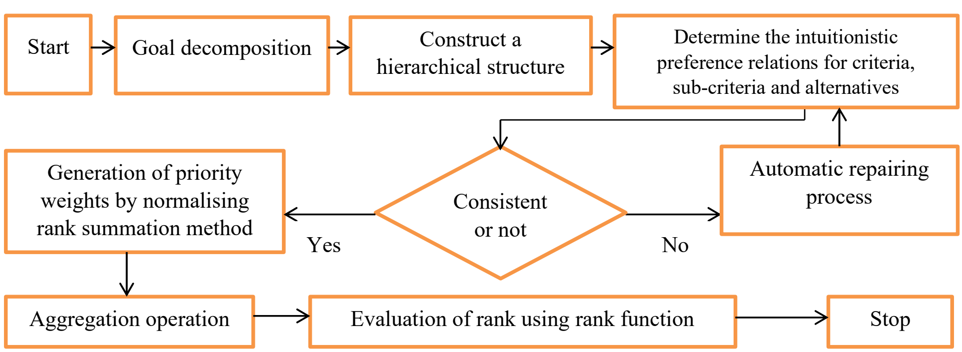
Table 3 Criteria for supplier selection (continued)

Criteria 5: reliability (new criteria and sub-criteria augmented by the expert)		
Quality of a supplier being trustworthiness and reliable based on consumers' feedback, business partners and their financial stability during the e-procurement process (Taherdoost and Brard, 2019)		
SC_{14}	Transparency	Ensures creating contract authorities more reliable to beneficiaries and all stakeholders to monitor and govern the process (Jonathan et al., 2017; Al-Aama, 2012; expert recommendation).
SC_{15}	Precise information	Supplier's quality of providing precise and accurate information in an e-procurement system to empower fidelity (Masudin et al., 2021; Taherdoost and Brard, 2019; expert recommendation).
SC_{16}	Just-in-time updation	Provide timely access or notifications to the buyers during the business process (Jadhav et al., 2020; Taherdoost and Brard, 2019; expert recommendation).
SC_{17}	Customer feedback	Quality of a supplier being reliable based on buyers' feedback (Taherdoost and Brard, 2019; expert recommendation).

5 Procedure for IF-AHP

The step-by-step procedure for IF-AHP was provided in a lucid manner to make the process easier to comprehend.

Figure 1 Schematic diagram of IF-AHP (see online version for colours)



5.1 Comparison between AHP, FAHP and IF-AHP

Table 4 Effectiveness of IF-AHP over other methods

Characteristics	*AHP*	*FAHP*	*IF-AHP*
Rating scale	1–9 crisp number scale	Fuzzy number scale	0.1–0.9 fuzzy number scale
Handling vagueness and uncertainty	No	Yes	Yes

Table 4 Effectiveness of IF-AHP over other methods (continued)

Characteristics	*AHP*	*FAHP*	*IF-AHP*
Disparities in processing pairwise comparison matrix	The pairwise matrices are evaluated separately, and then their weight vectors are summed up by using the geometric mean (Lee, 2016)	First combines all the pairwise matrices using a predetermined weight aggregation, and then computes a single weight vector (Lee, 2016)	The priority weights for each IPR are determined, combined using an aggregation operation, and then the rank function value is determined
Generation of priority weights	Yes	Yes	Yes
Ranking	Based on priority weights	Based on relative weights	Based on rank function values
Consistency check	It is performed by calculating CI and CR	It is performed by calculating CI and CR	Not necessary
Distance method	Not necessary	Not necessary	To calculate the distance between the inconsistent IPR and a newly derived consistent IPR for the consistency check process
Consistency threshold (τ)	Not necessary	Not necessary	It plays a vital role during consistency check process and it set to 0.1
Consistency ratio	It plays a crucial role during consistency check process and it should be less than 0.1	It plays a crucial role during consistency check process and it should be less than 0.1	Not necessary
Automatic repairing procedure	Absent in AHP	Absent in FAHP	Introduced newly in IF-AHP
Efficiency	Making decisions is a time-consuming process	Making decisions is a time-consuming process	A decision maker does not have to be involved, which can save time and improve efficiency
Controlling parameters (σ)	No	No	Parameter value (σ) is determined by the decision maker

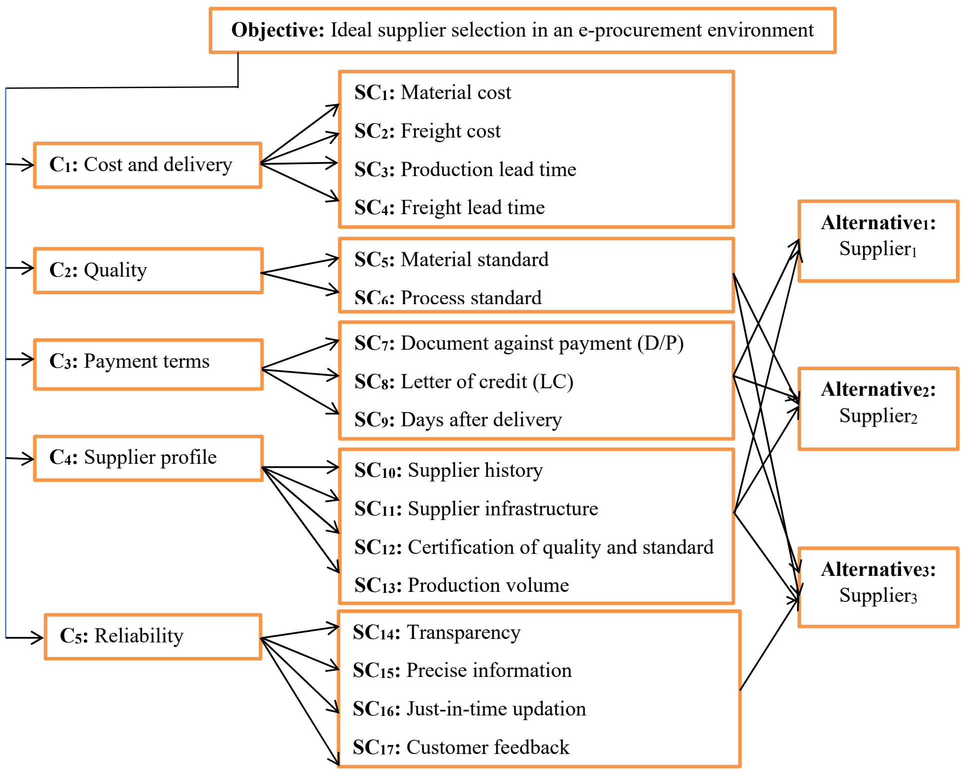
5.2 Solution methodology

IF-AHP is an extension approach of archaic methodologies like AHP and FAHP to handle uncertainty. The step-by-step elucidation of an IF-AHP approach (Xu and Liao, 2014; Deepika and Kannan, 2016) is explained below in a lucid manner.

Step 1 Construction of a hierarchical structure

In order to construct a multi-level hierarchical structure, it is imperative to investigate and identify the goal/objective, criteria, sub-criteria and alternatives of a decision making problem as shown in Figure 2. Of particular note, supplier selection plays a key role in this paper. The criteria (*C*) and sub-criteria (*SC*) classifications were demonstrated in Figure 2 in a coherent manner. For better understanding, we will evaluate and compare only three suppliers as alternatives to this decision making issue.

Figure 2 Hierarchy for ideal supplier selection (see online version for colours)



Step 2 Construction of multiplicative consistent IPR

Each preference value in the IPR was represented by the fusion of membership (μ) and non-membership function (v). By general rule, μ and v holds value between 0 to 1 and their overall sum should be less than or equal to 1. According to Szmidt and Kacprzyk (2000), hesitancy (π) plays a seismic role in IF-AHP when computing the distance between two intuitionistic fuzzy sets (IFSs). Furthermore, Xu (2007) stated that, the intuitionistic fuzzy value is a mixture of μ, v and π and it is shown in equation (2).

$$\text{Intuitionistic preference relation, } R = (r_{ik})_{n\times n}; \quad \text{where preference value, } r_{ik} = (\mu_{ik}, v_{ik}) \tag{1}$$

Hesitancy function, $\pi(x_i, x_k) = 1 - \mu(x_i, x_k) - v(x_i, x_k)$; for all $i, k = 1, 2, \ldots, n$. (2)

In IF-AHP methodology, the values in a preference relation must follow a 0.1 to 0.9 rating scale. This is shown in Table 5 along with their corresponding linguistic terms. Additionally, a 1–9 rating scale and a triangular fuzzy scale were also provided in Table 5 for better understanding of AHP, FAHP rating scale. The following steps from 2.1 to 2.3 are mandatory to check before constructing a perfectly multiplicative consistent IPR. With regard to, the construction of IPR is derived based on Xia and Xu's (2011) proven theorem (Xu et al., 2011).

$$b_{ik} = \frac{\sqrt[n]{\prod_{s=1}^{n} b_{is} b_{sk}}}{\sqrt[n]{\prod_{s=1}^{n} b_{is} b_{sk}} + \sqrt[n]{\prod_{s=1}^{n} (1 - b_{is})(1 - b_{sk})}}, \text{ where } i, k = 1, 2, \ldots, n$$

Table 5 Rating scale corresponding to AHP, FAHP and IF-AHP

AHP	*FAHP*	*IF-AHP*	*Rating scale meaning in linguistic terms*
(1–9 crisp number scale)	*Triangular fuzzy scale (i.e., l, m, u)*	*(0.1–0.9 fuzzy number scale)*	
1/9	(1/10,1/9,1/8)	0.1	Extremely not preferred
1/7	(1/8,1/7,1/6)	0.2	Very strongly not preferred
1/5	(1/6,1/5,1/4)	0.3	Strongly not preferred
1/3	(1/4,1/3,1/2)	0.4	Moderately not preferred
1	(1,1,1)	0.5	Equally preferred
3	(2,3,4)	0.6	Moderately preferred
5	(4,5,6)	0.7	Strongly preferred
7	(6,7,8)	0.8	Very strongly preferred
9	(8,9,10)	0.9	Extremely preferred
Other values between 1/9 to 9	Intermediate values	Other values between 0 and 1	Intermediate values used to present compromise

Source: Xu and Liao (2014)

Step 2.1

For $k > i + 1$, let $\bar{r}_{ik} = (\bar{\mu}_{ik}, \bar{v}_{ik})$ where $((\bar{\mu}_{ik}, \bar{v}_{ik}) \in [0, 1])$, $\bar{\mu}_{ik} + \bar{v}_{ik} \leq 1$ and $\mu_{ii} = v_{ii} = 0.5$.

$$\bar{\mu}_{ik} = \frac{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1} \mu_{it} \mu_{tk}}}{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1} \mu_{it} \mu_{tk}} + \sqrt[k-i-1]{\prod_{t=i+1}^{k-1} (1 - \mu_{it})(1 - \mu_{tk})}}, \text{ where } k > i + 1 \quad (3)$$

$$\bar{v}_{ik} = \frac{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1} v_{it} v_{tk}}}{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1} v_{it} v_{tk}} + \sqrt[k-i-1]{\prod_{t=i+1}^{k-1} (1 - v_{it})(1 - v_{tk})}}, \text{ where } k > i + 1 \quad (4)$$

Using equations (3) and (4), we can derive the upper triangular values of a perfectly consistent IPR and they are represented as (μ, v) pair.

Step 2.2

For $k = i + 1$, let $\overline{r}_{ik} = r_{ik}$. If Step 2.2 is satisfied, then assign the older values taken from an inconsistent preference relation to a perfect consistent matrix.

Step 2.3

For $k < i$, let $\overline{r}_{ik} = (\overline{v}_{ki}, \overline{\mu}_{ki})$. If Step 2.3 is satisfied, then we can acquire lower triangular values using equations (3) and (4) and they are represented as (v, μ) pair.

Step 3 Consistency check

Consistency check plays a crucial role after the construction of an IPR. It is imperative to ensure whether the constructed preference relation is consistent or not. If the pairwise comparison matrix is found to be inconsistent, then it needs some repairing process in order to build a perfectly consistent preference relation. Otherwise, it will result in ambiguous conclusions during the evaluation process. As a result, it is regarded as a central measure in the preference relation. From the outset, consistency check in AHP and FAHP were performed by calculating consistency index (CI) and consistency ratio (CR) are shown below (Xu and Liao, 2014; Deepika and Kannan, 2016).

$$CI = (\lambda_{\max} - n)/(n-1), \text{ where } \lambda_{\max} \text{ is the largest eigenvalue} \tag{5}$$

$$CR = CI/RI(n), \text{ where } RI \text{ is the random index and } n \text{ is the size of the matrix} \tag{6}$$

On the contrary, it is not required to calculate CI and CR for checking consistency in IF-AHP methodology. Instead, it is mandatory to compute the distance between the inconsistent IPR (R) and a newly derived consistent IPR ($\overline{R}$). This can be mathematically described as follows:

$$d(\overline{R}, R^{(p)}) = \frac{1}{2(n-1)(n-2)} \sum_{i=1}^{n} \sum_{k=1}^{n} \left(\left|\overline{\mu}_{ik} - \mu_{ik}^{(p)}\right| + \left|\overline{v}_{ik} - v_{ik}^{(p)}\right| + \left|\overline{\pi}_{ik} - \pi_{ik}^{(p)}\right| \right), \tag{7}$$

$$d(R, \overline{R}^{(p)}) < \tau, \tag{8}$$

where τ is the consistency threshold and p is the number of iterations.

If the above equation (8) holds true, there is no need for a repairing process. It signifies that the given preference relation is of agreeable consistency. Thus, output becomes $R^{(p)}$. Otherwise, repair the inconsistent relation using the automatic repairing process.

Step 4 Automatic repairing procedure

The repairing process of an inconsistent multiplicative preference relation in the classic AHP and FAHP requires the participation of decision makers and it takes much time. In stark contrast, an automatic repairing procedure (Xu and Liao, 2014) was recently developed in IF-AHP for repairing the inconsistent preference relation. Thus, it does not require the involvement of decision makers. Automatic repairing procedure of a perfectly multiplicative consistent IPR was performed by constructing a fused IPR, $R^{(p)} = (\tilde{r}_{ik}^{(p)})_{n\times n}$, where $\tilde{r}_{ik}^{(p)} = (\tilde{\mu}_{ik}^{(p)}, \tilde{v}_{ik}^{(p)})$ by using the below derived equations (9) and (10).

$$\overline{\mu}_{ik}^{(p)} = \frac{\left(\mu_{ik}^{(p)}\right)^{1-\sigma} (\overline{\mu}_{ik})^{\sigma}}{\left(\mu_{ik}^{(p)}\right)^{1-\sigma} (\overline{\mu}_{ik})^{\sigma} + \left(1-\mu_{ik}^{(p)}\right)^{1-\sigma} (1-\overline{\mu}_{ik})^{\sigma}} \text{ where } i, k = 1, 2, \ldots, n \tag{9}$$

$$\overline{v}_{ik}^{(p)} = \frac{\left(v_{ik}^{(p)}\right)^{1-\sigma} (\overline{v}_{ik})^{\sigma}}{\left(v_{ik}^{(p)}\right)^{1-\sigma} (\overline{v}_{ik})^{\sigma} + \left(1-v_{ik}^{(p)}\right)^{1-\sigma} (1-\overline{v}_{ik})^{\sigma}} \text{ where } i, k = 1, 2, \ldots, n \tag{10}$$

The controlling parameter (σ) value is determined by the decision maker. To determine the degree of closeness between $\tilde{R}$ and R, it is advisable to set a smaller value for the controlling parameter to determine how closely $\tilde{R}$ is related to R. The major benefits of an automatic repairing procedure include: accelerates decision-making, improves consistency without missing any original information and eliminates decision makers from the process.

Step 5 Priority weight generation

After the repairing process, it is necessary to derive priority weights of each IPR. It is challenging to derive true weights in the case of classic FAHP. However, the priority method plays an important role in IF-AHP in describing the relative dominance or strength of preferences of the alternatives. Derivation of priority weights can be achieved by a novel normalising rank summation method (Xu and Liao, 2014; Deepika and Kannan, 2016) is described below.

$$\text{Priority weight, } w_i = \left(\frac{\sum_{k=1}^{n} \mu_{ik}}{\sum_{i=1}^{n} \sum_{k=1}^{n} (1-v_{ik})}, 1 - \frac{\sum_{k=1}^{n} (1-v_{ik})}{\sum_{i=1}^{n} \sum_{k=1}^{n} \mu_{ik}} \right) \tag{11}$$

where $i = 1, 2, \ldots, n$

Step 6 Aggregation operation

Combining all the priority weights from the lowermost level to the topmost level using an aggregation operation as shown below:

$$r_{ik} \oplus r_{tl} = \left(\mu_{ik} + \mu_{tl} - \mu_{ik}\mu_{tl}, v_{ik}v_{tl}\right), \text{ where } r_{ik} = \left(\mu_{ik}, v_{ik}\right) \text{ and } r_{tl} = \left(\mu_{tl}, v_{tl}\right) \tag{12}$$

$$r_{ik} \otimes r_{tl} = \left(\mu_{ik}\mu_{tl}, v_{ik} + v_{tl} - v_{ik}v_{tl}\right), \text{ where } r_{ik} = \left(\mu_{ik}, v_{ik}\right) \text{ and } r_{tl} = \left(\mu_{tl}, v_{tl}\right) \tag{13}$$

Step 7 Rank function

After aggregating all the priority weights using the aggregation operation shown in the equations (12) and (13), it is mandatory to rank the alternatives using the rank function proposed by Szmidt and Kacprzyk (2009) is shown below:

$$\rho(\alpha) = 0.5(1+\pi_\alpha)(1-\mu_\alpha) \tag{14}$$

In the equation (14), the rank function (ρ) and an intuitionistic fuzzy value (α) are indirectly proportional to each other. The smaller the value of the rank function, the greater the intuitionistic fuzzy value regarding the reliability of the information. Therefore, the rank function can effectively prioritise the alternatives in supplier selection in an e-procurement system.

6 Questionnaire development and data collection

Meticulous identification of relevant criteria and sub-criteria classifications for the selection of the ideal supplier in an e-procurement system was done initially based on literature review. A questionnaire on this common pre-defined criteria list was provided to various procurement managers, supply chain researchers and IT professionals working in SCM field. Based on the combination of literature review, industrial manager's views, and experts' analysis and recommendations from Middle East industries, the most relevant and essential five criteria and 17 sub-criteria for ideal supplier selection problem in an e-procurement system were identified finally. The pairwise comparison was based on this response from among criteria of ideal supplier selection in e-procurement using intuitionistic fuzzy values.

7 Illustrative examples

Global supplier development in an e-procurement system was concerned as a MCDM problem, which stands out the best to illustrate our step-by-step process of IF-AHP. Overall, Figure 1 depicts the hierarchy of objective, criteria, sub-criteria and alternatives of supplier selection and Figure 2 explores the demonstration of step-by-step procedure of IF-AHP to solve this decision making problem. After building the hierarchical structure, it is imperative to build pairwise comparison of one criterion, sub-criterion or alternative against another with the support of questionnaire. In this paper, we do not focus on the comparison of a sub-criterion against another, but we take them as a whole. The construction of an IPR for our whole decision making problem is shown in Tables 6–11. Table 6 shows the preference relation for overall criteria of the supplier selection problem and Tables 7, 8, 9, 10 and 11 depicts the pairwise comparison for alternatives with regard to each criterion using IF-AHP.

Table 6 IPR for criteria with regard to overall objective

R	C_1	C_2	C_3	C_4	C_5
C_1	(0.5, 0.5)	(0.7, 0.2)	(0.7, 0.2)	(0.6, 0.3)	(0.6, 0.3)
C_2	(0.2, 0.7)	(0.5, 0.5)	(0.7, 0.2)	(0.6, 0.3)	(0.6, 0.3)
C_3	(0.2, 0.7)	(0.2, 0.7)	(0.5, 0.5)	(0.7, 0.2)	(0.7, 0.2)
C_4	(0.3, 0.6)	(0.3, 0.6)	(0.2, 0.7)	(0.5, 0.5)	(0.7, 0.2)
C_5	(0.3, 0.6)	(0.3, 0.6)	(0.2, 0.7)	(0.2, 0.7)	(0.5, 0.5)

Source: Xu and Liao (2014)

Table 7 Alternatives with regard to C_1

R	A_1	A_2	A_3
A_1	(0.5, 0.5)	(0.6, 0.2)	(0.4, 0.45)
A_2	(0.2, 0.6)	(0.5, 0.5)	(0.45, 0.5)
A_3	(0.45, 0.4)	(0.5, 0.45)	(0.5, 0.5)

Table 8 Alternatives with regard to C_2

R	A_1	A_2	A_3
A_1	(0.5, 0.5)	(0.8, 0.1)	(0.45, 0.4)
A_2	(0.1, 0.8)	(0.5, 0.5)	(0.3, 0.4)
A_3	(0.4, 0.45)	(0.4, 0.3)	(0.5, 0.5)

Table 9 Alternatives with regard to C_3

R	A_1	A_2	A_3
A_1	(0.5, 0.5)	(0.55, 0.25)	(0.3, 0.45)
A_2	(0.25, 0.55)	(0.5, 0.5)	(0.6, 0.2)
A_3	(0.45, 0.3)	(0.2, 0.6)	(0.5, 0.5)

Table 10 Alternatives with regard to C_4

R	A_1	A_2	A_3
A_1	(0.5, 0.5)	(0.7, 0.1)	(0.65, 0.2)
A_2	(0.1, 0.7)	(0.5, 0.5)	(0.4, 0.25)
A_3	(0.2, 0.65)	(0.25, 0.4)	(0.5, 0.5)

Table 11 Alternatives with regard to C_5

R	A_1	A_2	A_3
A_1	(0.5, 0.5)	(0.8, 0.1)	(0.7, 0.25)
A_2	(0.1, 0.8)	(0.5, 0.5)	(0.45, 0.5)
A_3	(0.25, 0.7)	(0.5, 0.45)	(0.5, 0.5)

In order to improve the efficiency and appropriateness of our IF-AHP approach, it is imperative to do extensive analyses and comparisons for selected criteria using other methodologies such as AHP and FAHP respectively.

The step-by-step procedure for deriving priority weights for each criterion using AHP and FAHP was clearly demonstrated in Tables 12, 13, 14 and 15. Our next step is to generate priority weights using the IF-AHP approach, and to prove the efficiency of our proposed method, we must compare our weights with the weights generated by other methods. Subsequently, it is imperative to estimate the consistency of each IPR by utilising equation (7) and ensuring that the distance measure is estimated to be less than the consistency threshold (i.e., $\tau = 0.1$) or not. If a distance measure between the inconsistent IPR and a newly derived consistent IPR is greater than the threshold, then the preference relation is not said to be multiplicative consistent. Therefore, it is advisable to utilise equations (9) and (10) to automatically repair the inconsistent IPR by automatic repairing procedure by setting the controlling parameter (σ) = 0.8. This controlling parameter is set by the decision maker. In Table 16, it is explicitly shown that the modified consistent IPR was constructed for each selected criterion after the consistency and repairing process had been completed. Moreover, Table 17 clearly presents the comparative analysis of each criterion based on the priority weights generated by AHP, FAHP and IF-AHP for ranking the significance of every potential criterion to select the most suitable supplier in an IF-AHP-based electronic procurement environment.

Table 12 Priority weights using AHP (see online version for colours)

R	C_1	C_2	C_3	C_4	C_5	R	C_1	C_2	C_3	C_4	C_5
C_1	1	5	5	3	3	C_1	1	5	5	3	3
C_2	1/5	1	5	3	3	C_2	0.2	1	5	3	3
C_3	1/5	1/5	1	5	5	C_3	0.2	0.2	1	5	5
C_4	1/3	1/3	1/5	1	5	C_4	0.333333	0.333333	0.2	1	5
C_5	1/3	1/3	1/5	1/5	1	C_5	0.333333	0.333333	0.2	0.2	1
						Sum	2.066666	6.866666	11.4	12.2	17

	After normalising each values					*Priority weights*
Cost and delivery	0.4838711	0.7281554	0.4385	0.2459	0.1764	0.4145653
Quality	0.096774	0.1456310	0.4385	0.2459	0.1764	0.220641
Payment terms	0.096774	0.0291262	0.0877	0.4098	0.2941	0.18350004
Supplier profile	0.1612902	0.0485436	0.01754	0.0819	0.2941	0.12067476
Reliability	0.1612902	0.0485436	0.01754	0.0163	0.0588	0.06049476
Sum						*1*

Table 13 Criteria – criteria comparison matrix in FAHP (see online version for colours)

R	C_1	C_2	C_3	C_4	C_5
C_1	(1, 1, 1)	(4, 5, 6)	(4, 5, 6)	(2, 3, 4)	(2, 3, 4)
C_2	(1/6, 1/5, 1/4)	(1, 1, 1)	(4, 5, 6)	(2, 3, 4)	(2, 3, 4)
C_3	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1, 1, 1)	(4, 5, 6)	(4, 5, 6)
C_4	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1/6, 1/5, 1/4)	(1, 1, 1)	(4, 5, 6)
C_5	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1, 1, 1)

R	C_1	C_2	C_3	C_4	C_5
C_1	(1, 1, 1)	(4, 5, 6)	(4, 5, 6)	(2, 3, 4)	(2, 3, 4)
C_2	(0.16667, 0.2, 0.25)	(1, 1, 1)	(4, 5, 6)	(2, 3, 4)	(2, 3, 4)
C_3	(0.16667, 0.2, 0.25)	(0.16667, 0.2, 0.25)	(1, 1, 1)	(4, 5, 6)	(4, 5, 6)
C_4	(0.25, 0.333333, 0.5)	(0.25, 0.333333, 0.5)	(0.16667, 0.2, 0.25)	(1, 1, 1)	(4, 5, 6)
C_5	(0.25, 0.333333, 0.5)	(0.25, 0.333333, 0.5)	(0.16667, 0.2, 0.25)	(0.16667, 0.2, 0.25)	(1, 1, 1)

Table 14 Deriving geometric mean in FAHP

	Geometric mean		
Cost and delivery	2.29739	2.95417	3.56520
Quality	1.21672	1.55184	1.88817
Payment terms	0.85028	1	1.17607
Supplier profile	0.52961	0.64439	0.82187
Reliability	0.28048	0.33850	0.43527
Sum	5.17448	6.4889	7.88658
After inverse	0.19325	0.154109	0.126797
Increasing order	0.126797	0.154109	0.19325

Table 15 Priority weights using FAHP

	Fuzzy weights			*Average*	*Priority weights (after normalisation)*
Cost and delivery	0.29130	0.21196	0.68899	0.39742	0.37489
Quality	0.15427	0.64575	0.36489	0.38830	0.36630
Payment terms	0.10781	0.07175	0.22728	0.13561	0.12792
Supplier profile	0.06715	0.04623	0.15883	0.09074	0.08559
Reliability	0.03556	0.02428	0.08411	0.04799	0.04527
Sum				*1.06008 ≠ 1*	*1*

Table 16 Multiplicative consistent IPR for criteria with regard to overall objective

R	C_1	C_2	C_3	C_4	C_5
C_1	(0.5, 0.5)	(0.7, 0.2)	(0.8212, 0.0761)	(0.7588, 0.1023)	(0.7754, 0.0547)
C_2	(0.2, 0.7)	(0.5, 0.5)	(0.7, 0.2)	(0.8212, 0.0761)	(0.6881, 0.1492)
C_3	(0.0761, 0.8212)	(0.2, 0.7)	(0.5, 0.5)	(0.7, 0.2)	(0.6748, 0.1788)
C_4	(0.1023, 0.7585)	(0.0761, 0.8212)	(0.2, 0.7)	(0.5, 0.5)	(0.7, 0.2)
C_5	(0.0547, 0.7754)	(0.1492, 0.6881)	(0.1788, 0.6748)	(0.2, 0.7)	(0.5, 0.5)

Table 17 Comparison analysis of criteria (see online version for colours)

Priority weights	*AHP*	*FAHP*	*IF-AHP*		*Ranking*
Cost and delivery	0.41456	0.37489	(0.2633, 0.8744)	0.2633	$C_1 > C_2 > C_3 > C_4 > C_5$
Quality	0.22064	0.36630	(0.2155, 0.8182)	0.2155	
Payment terms	0.18350	0.12792	(0.1593, 0.7523)	0.1593	
Supplier profile	0.12067	0.08559	(0.1169, 0.7025)	0.1169	
Reliability	0.06049	0.04527	(0.0802, 0.6594)	0.0802	

From Table 17, it is evident that it always holds $C_1 > C_2 > C_3 > C_4 > C_5$ for every method. Based on this explicit representation, it is apparent that suppliers are more sensitive to cost and delivery (i.e., C_1), and quality (i.e., C_2). Of particular note, this paper provides comparison analyses using AHP and FAHP for criteria alone and not for sub-criteria or alternatives. Therefore, the comparative evaluation of criteria was compared successfully and then we move to the next step of allowing the implementation of IF-AHP for different sub-criteria. Tables 18, 19, 20, 21 and 22 explicitly demonstrate that the modified consistent IPR for alternatives with respect to each criterion was constructed after completing the consistency and repairing processes.

Table 18 Modified consistent IPR for alternatives with respect to C_1

R	A_1	A_2	A_3
A_1	(0.5, 0.5)	(0.6, 0.2)	(0.6382, 0.0946)
A_2	(0.2, 0.6)	(0.5, 0.5)	(0.45, 0.5)
A_3	(0.0946, 0.6382)	(0.5, 0.45)	(0.5, 0.5)

Table 19 Modified consistent IPR for alternatives with respect to C_2

R	A_1	A_2	A_3
A_1	(0.5, 0.5)	(0.8, 0.1)	(0.8983, 0.0267)
A_2	(0.1, 0.8)	(0.5, 0.5)	(0.3, 0.4)
A_3	(0.0267, 0.8983)	(0.4, 0.3)	(0.5, 0.5)

Table 20 Modified consistent IPR for alternatives with respect to C_3

R	A_1	A_2	A_3
A_1	(0.5, 0.5)	(0.55, 0.25)	(0.5378, 0.1421)
A_2	(0.25, 0.55)	(0.5, 0.5)	(0.6, 0.2)
A_3	(0.1421, 0.5378)	(0.2, 0.6)	(0.5, 0.5)

Table 21 Modified consistent IPR for alternatives with respect to C_4

R	A_1	A_2	A_3
A_1	(0.5, 0.5)	(0.7, 0.1)	(0.8145, 0.022)
A_2	(0.1, 0.7)	(0.5, 0.5)	(0.4, 0.25)
A_3	(0.022, 0.8145)	(0.25, 0.4)	(0.5, 0.5)

Table 22 Modified consistent IPR for alternatives with respect to C_5

R	A_1	A_2	A_3
A_1	(0.5, 0.5)	(0.8, 0.1)	(0.916, 0.0233)
A_2	(0.1, 0.8)	(0.5, 0.5)	(0.45, 0.5)
A_3	(0.0233, 0.916)	(0.5, 0.45)	(0.5, 0.5)

After repairing each IPR R_i (i = 1, 2, 3, 4, 5), we need to derive priority weights of three alternatives (i.e., A_1, A_2 and A_3) over the 5 criteria (i.e., C_1, C_2, C_3, C_4 and C_5) using equation (11). Finally, by applying equation (14), we can compute the rank values for each alternative in order to find the most appropriate supplier in an e-procurement environment using the IF-AHP was also mentioned in Table 23.

From Table 23, it is evident that priority weights play a major role in computing rank values for each alternative. The relationship is thus: ρ (W_2) > ρ (W_3) > ρ (W_1). Then, the ranking order is as follows: A_2 > A_3 > A_1. As a result, it was explicitly proved that, alternative A_2 was the most suitable supplier to select. Thus, the criteria for ideal supplier selection in an e-procurement model are prioritised by an efficient IF-AHP methodology.

Table 23 Priority weights and rank of the alternatives with regard to criteria C_i (i = 1, 2, 3, 4, 5)

R	C_1 (0.2633, 0.8744)	C_2 (0.2155, 0.8182)	C_3 (0.1593, 0.7523)	C_4 (0.1169, 0.7025)	C_5 (0.0802, 0.6594)	*Priority weights* (W_j)	*Rank value* (ρ)	*Ranking*
A_1	(0.3547, 0.6922)	(0.4353, 0.797)	(0.3083, 0.6332)	(0.3874, 0.7407)	(0.4715, 0.8177)	(0.2804, 0.7248)	0.3579	*3*
A_2	(0.2347, 0.5488)	(0.1782, 0.4684)	(0.2621, 0.5714)	(0.1923, 0.4737)	(0.2234, 0.5465)	(0.1681, 0.5403)	0.5372	*1*
A_3	(0.2234, 0.5353)	(0.1835, 0.4751)	(0.1635, 0.4395)	(0.1485, 0.4137)	(0.2177, 0.5403)	(0.3485, 0.2179)	0.4669	*2*

8 Conclusions

Supplier selection plays a seismic aspect in the implementation of an e-procurement system in the Middle East countries. Furthermore, the adoption of B2B e-procurement models is also a major concern among the company authorities and production managers in the leading firms. As a result, it is necessary to explore their framework, criteria, strategies, technologies, drivers, barriers, CSFs, etc. This study provides an extensive exploration and investigation of an array of criteria, which plays a pivotal role in supplier selection in the implementation of e-procurement in the majority of leading firms in the Middle East. In this paper, we have identified five criteria and 17 sub-criteria for selecting potential suppliers in e-procurement by utilising IF-AHP. Based on the literature review, we have identified two pre-defined criteria such as cost and delivery and quality (Taherdoost and Brard, 2019). In addition to that, various novice criteria like payment terms, supplier profile and reliability were augmented with the pre-defined criteria for better investigation of suppliers in the e-procurement model. Furthermore, this paper presents extensive evaluation of criteria based on priority weights generated by classic methods like AHP and FAHP compared with our proposed IF-AHP approach for criteria only for improving efficiency. Consequently, this paper proposes an effective strategy for consistency check and automatic repairing procedure to repair the inconsistent preference relations. Specifically, this repairing procedure was newly developed in IF-AHP and was not in AHP and FAHP. Moreover, this paper also proposes a normalising rank summation method (Xu and Liao, 2014) for generating priority vectors of a preference relation. Finally, the ranking procedure is performed by using the rank function for ideal supplier selection for the manufacturing industry in an e-procurement system. However, this work fails to include a comparative analysis of sub-criteria and alternatives using a variety of existing methodologies. Furthermore, this work can be made more efficient in the future by incorporating the ability to optimise weights through teaching learning-based optimisation (TLBO) or genetic algorithm (GA). Additionally, our future work will investigate supplier selection using machine learning algorithms or technique for order preference similarity to ideal solution (TOPSIS) for various decision making applications.

References

Al-Aama, A.Y. (2012) 'E-procurement vs. online procurement: a means to increase transparency in a Saudi Government organisation: the case of the Jeddah municipality', *International Journal of Procurement Management*, Vol. 5, No. 6, pp.765–783.

Angeles, R. and Nath, R. (2007) 'Business-to-business e-procurement: success factors and challenges to implementation', *Supply Chain Management: An International Journal*, Vol. 12, No. 2, pp.104–115.

Basheka, C., Oluka, B., Pross, N. and Mugurusi, G. (2012) 'Adopting new approaches for public procurement efficiency: critical success factors (CSFs) for the implementation of e-procurement in Uganda's public sector', *International Journal of Procurement Management*, Vol. 5, No. 6, pp.712–732.

Boran, E. (2011) 'An integrated intuitionistic fuzzy multi criteria decision making method for facility location selection', *Mathematical and Computational Applications*, Vol. 16, No. 2, pp.487–496.

Bottani, E. and Rizzi, A. (2005) 'A fuzzy multi-attribute framework for supplier selection in an e-procurement environment', *International Journal of Logistics: Research and Applications*, Vol. 8, No. 3, pp.249–266.

Buyukozkan, G. and Gocer, F. (2017) 'Application of a new combined intuitionistic fuzzy MCDM approach based on axiomatic design methodology for the supplier selection problem', *Applied Soft Computing*, Vol. 52, No. C, pp.1222–1238.

Buyukozkan, G., Gocer, F. and Karabulut, Y. (2019a) 'A new group decision making approach with IF AHP and IF VIKOR for selecting hazardous waste carriers', *Measurement*, Vol. 134, pp.66–82.

Buyukozkan, G., Feyzioglu, O. and Havle, C.A. (2019b) 'Intuitionistic fuzzy AHP based strategic analysis of service quality in digital hospitality industry', *IFAC – PapersOnLine*, Vol. 52, No. 13, pp.1687–1692.

Chan, F.T.S., Kumar, N., Tiwari, M.K., Lau, H.C.W. and Choy, K.L. (2008) 'Global supplier selection: a fuzzy-AHP approach', *International Journal of Production Research*, Vol. 46, No. 14, pp.3825–3857.

Chang, Y., Markatsoris, H. and Richards, H. (2004) 'Design and implementation of an e-procurement system', *Production Planning and Control, The Management of Operations*, Vol. 15, No. 7, pp.634–646.

Changsen, Z. (2012) 'The study on the enterprises' e-procurement in China', *3rd International Conference on System Science, Engineering Design and Manufacturing Informatization (ICSEM)*.

Chen, S., Yang, H. and Jian, T. (2010) 'Evaluating customer value of B2C companies by using FAHP', *2nd International Conference on E-business and Information System Security*, pp.1–3.

Choi, J.H. and Kim, J.W. (2008) 'A hybrid decision support model for selecting highly qualified suppliers', *Journal of Computer Information Systems*, Vol. 49, No. 1, pp.90–100.

Deepika, M. and Kannan, A.S.K. (2016) 'Global supplier selection using intuitionistic fuzzy analytic hierarchy process', *International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT)*, pp.2390–2395.

Feng, Y. (2021) 'Risk level comprehensive evaluation model of high rise building construction based on FAHP', *International Conference of Social Computing and Digital Economy (ICSCDE)*.

Fu, L., Shi, L., Yang, Y. and Yu, B. (2010) 'The selection of project management software by FAHP and FMCDM in automobile R&D process', *International Conference on Networking and Digital Society, ICNDS*.

Gunasekaran, A. and Ngai, E.W.T. (2008) 'Adoption of e-procurement in Hong Kong: an empirical research', *International Journal of Production Economics*, Vol. 113, No. 1, pp.159–175.

Gupta, M. and Narain, R. (2014) 'A fuzzy ANP based approach in the selection of the best e-business strategy and to assess the impact of e-procurement on organizational performance', *Information Technology and Management*, Vol. 16, No. 4, pp.339–349.

Jadhav, P., Jadhav, P., Thombre, S., Papat, K. and Mhantati, S. (2020) 'Architecture of e-procurement system for police department', *International Conference on Information and Communication Technology Convergence (ICTC)*.

Jonathan, K., Napitupulu, T. and Sari, R. (2017) 'IT good governance: a case of the role of e-procurement in Indonesia', *International Conference on Information Management and Technology (ICIMTech)*.

Junior, F.R.L., Osiro, L. and Carpinetti, L.C.S. (2014) 'A comparison between fuzzy AHP and fuzzy TOPSIS methods to supplier selection', *Applied Soft Computing*, Vol. 21, pp.194–209.

Kamarulzaman, N.H. and Mohamed, Z.A. (2013) 'Application of e-procurement technologies for selecting suppliers of agro-based SMEs in Malaysia', *International Journal of Economics and Management*, Vol. 7, No. 1, pp.45–66.

Kheng, C.B. and Al-Hawamdeh, S. (2002) 'The adoption of electronic procurement in Singapore', *Electronic Commerce Research*, Vol. 2, Nos. 1–2, pp.61–73.

Kilincci, O. and Onal, S.A. (2011) 'Fuzzy AHP approach for supplier selection in a washing machine company', *Expert Systems with Applications*, Vol. 38, No. 8, pp.9656–9664.

Lee, S. (2016) 'Application of AHP and fuzzy AHP to decision making problems in construction', *52nd ASC Annual International Conference Proceedings*.

Liang, L., Hong, Z., ShaoRong, C., YiBen, L., Li, J. and YuHong, W. (2020) 'Comprehensive evaluation of transmission network planning schemes based on IFAHP', *4th International Conference on HVDC (HVDC)*, pp.375–381.

Liao, H. and Xu, Z. (2014) 'Priorities of intuitionistic fuzzy preference relation based on multiplicative consistency', *IEEE Transactions on Fuzzy Systems*, Vol. 22, No. 6, pp.1669–1681.

Masudin, I. et al. (2021) 'Impact of e-procurement adoption on company performance: evidence from Indonesian manufacturing industry', *Logistics*, Vol. 5, No. 16, pp.1–16.

Nanang, H., Misman, A.F. and Zulkifli, Z. (2017) 'Trust, risk and public key infrastructure model on e-procurement adoption', *5th International Conference on Cyber and IT Service Management (CITSM)*.

Neupane, A., Soar, J., Vaidya, K. and Yong, J. (2012) 'Role of public e-procurement technology to reduce corruption in government procurement', *5th International Public Procurement Conference*, Seattle, Washington.

Pani, A.K. and Kar, A.K. (2011) 'A study to compare relative importance of criteria for supplier evaluation in e-procurement', *44th Hawaii International Conference on System Sciences (HICSS)*, pp.1–8.

Pornsing, C. et al. (2019) 'Solving supplier selection problem using fuzzy-AHP for an electronic manufacturer', *IEEE 6th International Conference on Industrial Engineering and Applications (ICIEA)*.

Puschmann, T. and Alt, R. (2005) 'Successful use of e-procurement in supply chains', *Supply Chain Management: An International Journal*, Vol. 10, No. 2, pp.122–133.

Qian, G. and Feng, X-Q. (2008) 'Intuitionistic weight generation approach from intuitionistic preference relations', *International Conference on Machine Learning & Cybernetics (ICMLC)*.

Rodriguez, A., Ortega, F. and Concepcion, R. (2017) 'An intuitionistic method for the selection of a risk management approach to information technology projects', *Information Sciences*, Vol. 375, pp.202–218.

Sadiq, R. and Tesfamariam, S. (2008) 'Environmental decision-making under uncertainty using intuitionistic fuzzy analytic hierarchy process (IF-AHP)', *Stochastic Environmental Research and Risk Assessment*, Vol. 23, No. 1, pp.75–91.

Samut, P.K. and Aktan, H.E. (2019) 'Integrating qualitative and quantitative factors in supplier selection and performance evaluation', *South African Journal of Industrial Engineering*, Vol. 30, No. 2, pp.146–160.

Sofyalıoglu, C. and Kartal, B. (2012) 'The selection of global supply chain risk management strategies by using fuzzy analytic hierarchy process – a case from Turkey', *Procedia-Social and Behavioral Sciences*, Vol. 58, pp.1448–1457.

Su, Y. (2020) 'Selection and application of building material suppliers based on intuitionistic fuzzy analytic hierarchy process (IFAHP) model', *IEEE Access*, Vol. 8, pp.136966–136977.

Sun, C-C. (2010) 'A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods', *Expert Systems with Applications*, Vol. 37, No. 12, pp.7745–7754.

Szmidt, E. and Kacpryzk, J. (2000) 'Distances between intuitionistic fuzzy sets', *Fuzzy Sets and Systems*, Vol. 114, No. 3, pp.505–518.

Szmidt, E. and Kacprzyk, J. (2009) 'Amount of information and its reliability in the ranking of Atanassov's intuitionistic fuzzy alternatives', *Recent Advances in Decision Making (Studies in Computational Intelligence)*, pp.7–19, Springer, Berlin, Germany.

Taherdoost, H. and Brard, A. (2019) 'Analyzing the process of supplier selection criteria and methods', *Procedia Manufacturing*, Vol. 32, pp.1024–1034.

Tavana, M., Zareinejad, M., Caprio, D. and Kaviani, M. (2016) 'An integrated intuitionistic fuzzy AHP and SWOT method for outsourcing reverse logistics', *Applied Soft Computing*, Vol. 40, pp.544–557.

Verma, R. and Chandra, S. (2021) 'Interval-valued intuitionistic fuzzy-analytic hierarchy process for evaluating the impact of security attributes in fog based internet of things paradigm', *Computer Communications*, Vol. 175, pp.35–46.

Wang, Z. (2019) 'A representable uninorm-based intuitionistic fuzzy analytic hierarchy process', *IEEE Transactions on Fuzzy Systems*, Vol. 28, No. 10, pp.2555–2569.

Xia, M.M. and Xu, Z.S. (2011) 'On consensus in group decision making based on fuzzy preference relations', *Consensus Process: Studies in Fuzziness and Soft Computing*, Vol. 267, pp.263–287.

Xu, Z. (2007) 'Intuitionistic fuzzy aggregation operators', *IEEE Transactions on Fuzzy Systems*, Vol. 15, No. 6, pp.1179–1187.

Xu, Z. and Liao, H. (2014) 'Intuitionistic fuzzy analytic hierarchy process', *IEEE Transactions on Fuzzy Systems*, Vol. 22, No. 4, pp.749–761.

Xu, Z. et al. (2011) 'Algorithms for estimating missing elements of incomplete intuitionistic preference relations', *International Journal of Intelligent Systems*, Vol. 26, No. 9, pp.787–813.

Zhang, Z. and Pedrycz, W. (2017) 'Intuitionistic multiplicative group analytic hierarchy process and its use in multicriteria group decision-making', *IEEE Transactions on Cybernetics*, Vol. 48, No. 7, pp.1950–1962.