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USING FUZZY CHOQUET INTEGRAL OPERATOR FOR SUPPLIER SELECTION WITH ENVIRONMENTAL CONSIDERATIONS

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Abstract. The increasing importance of considering environmental issues as a part of the corporate social responsibility, which has environmental and social impacts as well as affects the image and competitiveness of a firm, has encouraged companies to revise their major processes of supply chain management (SCM). Since the performance of a company heavily relies on its suppliers, it is of vital importance to incorporate environmental criteria into supplier selection problem to satisfy both conventional and environmental criteria, which have only been considered by a limited number of studies. Therefore, following a brief review of green supply chain management (GSCM) and sustainable supply chain management (SSCM) concepts and investigation of supplier selection approaches, this study after focuses on a modified Delphi method that has been applied to determine supplier selection criteria. Also, the intuitionistic fuzzy value (IFV) and interval value intuitionistic fuzzy (IVIF) have been utilised for supplier evaluation regarding the subjective nature and uncertainty of judgment. By using the Choquet Integral operator and fuzzy measures, the best supplier has been selected, and the comparison between IFV and IVIF has been made. This methodology has been applied to a manufacturing company to assess the applicability of the proposed methodology. The proposed methodology can be used for real world problems that contain fuzziness or interacting decision criteria. Moreover, due to a high level of expert involvement in the decision-making process, we claimed that the knowledge of experts has been utilised constructively.

Keywords: supplier selection, sustainable supply chain, green supply chain, Delphi method, intuitionistic fuzzy value, Choquet Integral operator.

JEL Classification: C61, D81, L62, Q01, Q50.

Introduction

In recent years, the characteristics of marketplaces have changed. Now, customers demand quicker delivery, higher quality, better price and greater service excellence. Moreover, environmental issues have guided organisations to take into account their environmental management (Sahu *et al.* 2012). The last ten years indicate an increase in consolidation of SCM and environmental management (Lee *et al.* 2012). SCM sets up and controls the flows of money, components, processes and information; however, due to changes in non-governmental organisations (NGOs) as well as the attitude and awareness of people and legislators towards the environmental impact of industrial activities, firms cannot neglect environmental challenges (Büyüközkan, Çifçi 2012). To cope with the issue, companies have employed different programmes and practices to guarantee that vendors supply high-quality services and materials that are in line with environmental standards (Kannan *et al.* 2013). Special attention is given to the convergence of green and SSCM (Büyüközkan, Çifçi 2011). The terms GSCM and SSCM are to link the concepts of SCM with sustainability or environmental consideration. Definitions of SSCM and GSCM noticeably overlap: "it is argued that SSCM is essentially an extension of GSCM" (Ahi, Searcy 2013). Within the supply chain (SC) practices, supplier selection as a key function consists of assessment, ranking, and selection of the best supplier among potential alternatives, especially when criteria are typically conflicting. Many studies have shown that the business performance and the customer satisfaction are noticeably affected by supplier selection (Shemshadi *et al.* 2011). The supplier selection studies encounter three main challenges: (i) the collection of criteria from various sources suited to the needs of the company, in which case comprehensive criteria are not met. This problem is partly caused by a lack of expert knowledge on the importance of new perspectives, such as sustainability or environmental consideration, or a limitation in methods to consider large numbers of criteria. (ii) The subjective nature of human judgment, which is a prerequisite for the evaluation processes. The expert opinions about the weights of criteria and the evaluation of each alternative inherently contain some uncertainties. And the last challenge is (iii) to capture the interactions or dependencies between the criteria. In order to cope with these challenges, the authors have utilised a research process to include a large number of criteria divided into main groups; and on the next level, they have used fuzzy values and fuzzy measures to evaluate these criteria. Also, the interactions of the criteria have been captured by the Choquet integral.

The rest of the paper is structured as follows: in Section 1, SSCM and GSCM concepts are introduced and supplier selection approaches are reviewed. The research process, various stages and methods are described in Section 2. Section 3 reviews an application of the proposed methodology in a manufacturing firm to validate the method. The results are put forward in last Section.

1. Literature review

1.1. Brief review of GSCM & SSCM

The SCM term appeared in the early 1980s, earned enough attention and evolved during past three decades. Nowadays, companies have accepted a high level of commitment to sustainability as a consequence of great pressures from different stakeholders, NGOs and global competition (Hassini *et al.* 2012). The triple bottom line (TBL) approach defines sustainability by the dimensions of the natural environment, society, and economic performance. The TBL approach suggests that the positive economic performance alone is not enough; therefore, organisations must take action so as to have a positive effect on the society and the environment. It means that a firm's long-term survival and profitability could be outstandingly achieved by readjusting these goals with social and environmental goals (Dao *et al.* 2011). It is an accepted fact that SSCM is a theoretical and practical broadening of SCM (Beske, Seuring 2014). Seuring and Muller (2008) described SSCM as "the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements. In sustainable supply chains, environmental and social criteria need to be fulfilled by the members to remain within the supply chain, while it is expected that competitiveness would be maintained through meeting customer needs and related economic criteria". Gupta and Palsule-Desai (2011) have explained the concept of SSCM in three steps: firms must consider (1) the environmental impact of their activities as an essential element of their performance, not as imposed constraints as well as (2) the environmental impact of all members of the value chain; besides, (3) the perspective of firms on sustainability must go beyond a narrow functional perspective and embrace issues, problems and solutions across functional boundaries. Ahi and Searcy (2013) represented a definition of SSCM as "Creating coordinated SC by the voluntary integration of economic, environmental, and social considerations with key inter-organisational business systems designed to effectively and efficiently manage the material, information, and capital flows associated with the procurement, production and distribution of services or products in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organisation over the short and long-term". Esfahbodi *et al.* (2016) in their definition of SSCM have emphasised the product life-cycle stages in order to minimise the negative environmental impact.

As a way of reducing environmental impacts and improving ecological efficiency, GSCM means that companies should add environmental and social criteria to their SCM and to adjust their SC accordingly (Büyüközkan, Çifçi 2012). Two main approaches of greening supply chains are mentioned in literature as monitoring and collaboration (Tachizawa *et al.* 2015). The concept of GSCM commonly indicates that environmental performance of suppliers must be checked, and the collaboration can only continue if the suppliers have enough capability to satisfy environmental standards (Kannan *et al.* 2013). In other words, GSCM aims to remove negative environmental impacts or reduce resource depletion across the SC encompassing first stages to the final stages in order to reduce different incurred costs and to improve the competitive advantage (Govindan *et al*. 2013). Sarkis *et al.* (2011) have reported nine theories used to study various aspects of GSCM including ecological modernisation, complexity, institutional, information, resource dependence, resource-based view, stakeholder, social network, and transaction cost economics theories. Srivastava (2007) described GSCM as "adding environmental thought into SCM activities from product design to used products end-of-life management". Ahi and Searcy (2013) analysed 22 distinct definitions of GSCM in 124 academic articles and concluded that a distinguished definition of GSCM is not absolutely required because definitions of GSCM and SSCM are alike, but SSCM would incorporate the social and economic dimensions.

1.2. Supplier selection approaches

Supplier selection is a research topic that has been studied extensively during the last decade by different approaches and criteria. To the best of our knowledge based on an investigation of the following papers, there are at least five worthwhile research papers comprehensively investigating the literature on supplier selection (Jain *et al.* 2009; Chai *et al.* 2013; Ho *et al.* 2010; Wu, Barnes 2011; Govindan *et al.* 2015). Studies are available on the subject that the researchers have tried to give a comprehensive glimpse of the past and current research agenda. The various techniques and approaches, which are used to select green suppliers, are listed and reviewed in Table 1.

2. Methodology

This study proposes an approach based on a modified Delphi method and the fuzzy Choquet integral for supplier selection with environmental consideration.

2.1. Modified Delphi method

Achieving the most definite and reliable consensus of anonymous experts is the objective of the Delphi method. The Delphi method is composed of five rounds: (1) choosing the anonymous experts to make the expert panel; (2) handling the first round of a survey; (3) handling the second round of a questionnaire survey; (4) handling the third round of a questionnaire survey; (5) merging the expert opinions to achieve a consensus. Rounds (3) and (4) must be repeated until a consensus is reached. The number of experts could be between 5 and 50, and other researchers have expressed this number could be between 10 and 30 (Okoli, Pawlowski 2004; Gumus 2009).

2.2. Choquet integral and the applications

The usefulness of Choquet integral in measuring the expected utility of an uncertain event and its capability to illustrate the dependencies or interactions among criteria is expressed by Xu (2010) from Grabisch's notable example "evaluation in high school". Grabisch (1995) explained that "we want to assess a group of students in terms of three subjects: {mathematics, physics, literature}, the science-related subjects are more important than literature, but simultaneously, the students who are good in both literature and each of science-related subjects have an advantage against other students".

Table 1. Literature review

Authors	Method adopted	Criteria selected	Scope of the study
Gumus (2009)	Fuzzy-AHP and TOPSIS	Hygiene and safety; Quality of service; Complementary service; Economic factors; Service time; Taking care of the human health and environmental protection standards; Problem solving ability; The owned vehicle fleet.	The researcher intends to evaluate the hazardous waste of transportation firms.
Lee *et al.* (2009)	Delphi method-Fuzzy extended AHP (FEAHP)	Quality, Technology capability, Pollution control, Environment management, Green product, Green competency.	The researchers have proposed a model for evaluating green suppliers.
Tuzkaya *et al.* (2009)	Fuzzy ANP and Fuzzy PROMETHEE	Green process management, Environmental costs, Green image, Pollution control, Green product, Environmental and legislative management.	The researchers have presented a methodology for the evaluation of environmental performances of suppliers.
Awasthi *et al.* (2010)	Linguistic assessments, Fuzzy TOPSIS	Use of environment-friendly technology, Use of environment-friendly materials, Green-market share, Partnership with green organisations, Management commitment, Adherence to environmental policies, Green R&D projects, Staff training, Lean process planning, Design for the environment, Environmental certification, Pollution control initiatives.	The researchers have proposed a model to evaluate the environmental performance of suppliers.
Bai *et al.* (2010)	A review of the literature on Rough set or neighbourhood rough set methodologies for SCM	A three-staged ecological green supplier management process including Supplier selection, Environmental and economic supplier performance measurement, and Green supplier development.	The researchers have proposed the rough set methodology as a useful tool for management of the decision-making process.
Bai and Sarkis (2010)	A multistage rough set methodology	Green knowledge transfer and communication (17 attributes), Investment and resource transfer (8 attributes), Management and organisational practices (15 attributes). A subset of attributes was utilised.	The researchers have proposed a formal model using rough set theory to investigate the relationships between organisational attributes, supplier development program involvement attributes, and performance outcomes.
Genovese *et al.* (2010)	Literature review	Availability of a waste management system, Environmental staff training, Availability of a green supplier selection system, Use of green materials in the production process, Energy efficiency, Green design capability, Percentage of waste that goes to a landfill, Percentage of recycled waste, Availability of an environmental management system, Availability of an hazardous substance management system, Air emission level, Availability and use of clean technologies.	The researchers have reviewed the papers publicised in international scientific journals in the recent years on Green Supplier Selection Problem.
Ho *et al.* (2010)	Literature review	Quality, Delivery, Price/Cost, Manufacturing capability, Service, Management, Technology, Research and Development, Finance, Flexibility, Reputation, Relationship, Risk, Safety and environment.	The researchers reviewed articles in international journals from 2000 to 2008.

Continue of Table 1

Authors	Method adopted	Criteria selected	Scope of the study
Hu and Hsu (2010)	Factor analysis	Supplier management (Environmental auditing for suppliers, Supplier environmental questionnaire, Compliance statement, Product testing report, BOM, Establishing environmental requirements for purchasing items, Green purchasing), Product recycling (Joining a local recycling organisation, Collaboration on products recycling with the same industry sector, Produce disassembly manual), Organisation involvement (Green design, Top management support, Environmental policy for GSCM, Cross-function integration, Manpower involvement, Effective communication platform within companies and with suppliers, Establish an environmental risk management system for GSCM, Supplier evaluation and selection), Life-cycle management (Applying LCA to carry out eco-report, Establish an environmental database of products).	The researchers extracted critical factors for implementing GSCM practice.
Kuo *et al.* (2010)	ANN-MADA methods (DEA and ANP)	Quality, Cost, Delivery, Service, Environment and Corporate social responsibility.	The researchers developed a green supplier selection model.
Thongchattu and Siripokapirom (2010)	IS014000 framework with AHP technique and artificial neural network	Company reliability (Capacity and Lead time), Material quality (Defect), Material price (Defect), Environmental (Green Project), ISO 14000 (Environmental performance evaluation, Environmental labelling, Auditing, Life Cycle Assessment ISO 14000 Certificate).	The researchers have proposed a Green Supplier Selection Consensus model.
Büyüközkan and Çifçi (2011)	Fuzzy ANP under Incomplete preference relations	Organisation, Financial performance, Service quality, Technology, Social responsibility, Environmental competencies.	The researchers identified a model based on sustainability principles for supplier selection operations in supply chains.
Chen (2011)	DEA, TOPSIS and a MADM	Quality, Cost, Delivery Time, Service, Technical and production capability, Relation combination, Organisational management.	The researchers structured a methodology for supplier selection and evaluation.
Sarkis *et al.* (2011)	Literature review	–	The researchers provided a background discussion on GSCM, categorised and reviewed recent GSCM literature under nine broad organisational theories, with a special emphasis on investigation of adoption, diffusion and outcomes of GSCM practices.
Shemshadi *et al.* (2011)	Fuzzy VIKOR and Shannon entropy	Product quality, Effort to establish cooperation, Technical level of a supplier, Supplier's delay on delivery, Price/Cost.	The researchers proposed that supplier selection is a group multiple criteria decision-making (GMCDM) problem.

Continue of Table 1

Authors	Method adopted	Criteria selected	Scope of the study
Wu and Barnes (2011)	Literature review	–	The researchers reviewed the literature on supply partner decision-making published between 2001 and 2011.
Yeh and Chuang (2011)	Multi-objective Genetic Algorithms	Green principles, Production cost, Production time, Transportation cost, Transportation time, Average product quality.	The researchers proposed an optimum mathematical planning model.
Amindoust *et al.* (2012)	Fuzzy inference system (FIS)	Economic (Profit, Quality, Delivery, Service), Environmental (Environmental management system, Environmental competencies), Social (The rights of stakeholders Work safety and labour health).	The sustainable supplier selection criteria and sub-criteria are determined, and suppliers were evaluated accordingly.
Ashayeri *et al.* (2012)	Intuitionistic fuzzy Choquet integral operator	Capacity, Capability, Reliability, Flexibility, Information infrastructure, Global marketing.	The researchers proposed an approach for partners and configuration selection based on intuitionistic fuzzy Choquet integral operator.
Azadnia *et al.* (2012)	FAHP-SOM neural network-TOPSIS	Economic (Cost, Quality, Delivery), Social (Occupational health and safety management systems, Rights of stakeholders), Environmental (Pollution, Environment-friendly product design, Environmental management system).	The researchers modelled an integrated approach to solve sustainable supplier selection problem.
Büyüközkan and Çifçi (2012)	Fuzzy DEMATEL, ANP and TOPSIS	Green logistics (Procurement, Production, Distribution, Reverse logistics and packaging), Green organisational activities (Reduce, Reuse, Remanufacture, Recycle and disposal), Organisational performance (Cost, Quality, Delivery and Flexibility), Green supplier evaluation (Organisation, Financial performance, Service quality, Technology, and Green competencies).	The researchers examined GSCM and its capability dimensions to propose an evaluation framework for green suppliers.
Hassini *et al.* (2012)	Literature review	Percent of suppliers with an up-to-date sustainable development policy, Percent of contracts with Provincial suppliers, Percent of purchase orders placed with original companies, Level of stakeholder trust by category.	The researchers (i) reviewed SSCM research, (ii) proposed a unified conceptual framework, (iii) highlighted the importance of reliable supply chain performance measures, (iv) presented a case study of sustainable supply chain performance indicators, and (v) highlighted the gaps in the literature that need further investigation.
Peng (2012)	AHP, GRA (Grey Relational Analysis)	Production flexibility, Production scale, Level of information, Price rate, Delivery time, Delivery-check qualified rate, On-time delivery, Average order completion rate, Cooperation degree, Hazardous substances content, Energy consumption, Harmlessness.	The researchers proposed a model to optimise green suppliers.

Continue of Table 1

Authors	Method adopted	Criteria selected	Scope of the study
Lee *et al*. (2012)	FAHP	Supplier (Financial strength, Management approach and capability, Technical ability, Quality systems, Risk, History performance, Cultural and communication barriers), Product performance (Product quality, Maintainability, Packaging and storage requirements, Environmentally friendly features, Ease of disassembly or recovery, Product appearance), Service performance (Customer support, Customer satisfaction, Professionalism, Delivery performance, Supply capacity, Warranty period, Reverse logistic program), Cost (Purchase price Freight , Tax and custom duties, Operational expenses, Cost of component disposal, Recycling cost), Environment management (Pollution control, Green image, Environment-related certificates, Environmental purchasing managing systems, Employment practices).	The researchers studied the factors that are considered to be the most important when choosing Green partners/suppliers.
Sahu (2012)	Grey TOPSIS and COPRAS-G	Enterprise ability (Volume flexibility, Scale of production, Information level, Service level (Price rate, Delivery time, Delivery-check qualified rate), Cooperation degree (On-time delivery rate, Average order completion ratio), Environmental factors (Content of hazardous substances, Energy consumption, Harmless rate).	The researchers developed a measurement index evaluation system towards assessing suppliers' green performance practices.
Shen *et al*. (2013)	Fuzzy set theory, Fuzzy TOPSIS	Pollution production, Resource consumption, Eco-design, Green image, Environmental management system, Commitment of GSCM from managers, Use of environmentally friendly technology, Use of environmentally friendly materials, Staff environmental training.	The researchers examined GSCM to propose a fuzzy multi criteria approach for green suppliers' evaluation.
Chai *et al*. (2013)	Literature review	–	The researchers proposed a systematic literature review on articles published from 2008 to 2012 on the application of decision-making techniques for supplier selection.
Govindan *et al*. (2013)	Fuzzy TOPSIS	Economic (Cost, Delivery reliability, Quality, Technology capability), Environmental (Pollution production, Resource consumption, Eco-design, Environmental management system), Social (Employment practices, Health and safety, Local communities influence, Contractual stakeholders influence).	The researchers explored sustainable supply chain initiatives and examined the problem of identifying an effective model based on the TBL approach.
Kannan *et al*. (2013)	Fuzzy AHP, Fuzzy TOPSIS, Multi-Objective Linear Programming	Cost (Product cost, Logistics cost, Quantity discount), Quality (Quality assurance, Rejection ratio), Delivery (Lead time, Order fulfilment rate), Technology Capability (Technology level, Capability of R&D, Capability of design), Environmental competency (Pollution production, Resource consumption, Environmental management system, Eco-design).	The researchers proposed an integrated approach to rate and select the best green suppliers and to allocate optimum order quantities.

Continue of Table 1

Authors	Method adopted	Criteria selected	Scope of the study
Hsu *et al.* (2013)	DEMATEL	Planning (Carbon governance, Carbon policy, Carbon reduction targets, Carbon risk assessment, Training related carbon management, Lifecycle cost management), Implementation (Measures of carbon management, Involvement in initiatives for carbon management, Management systems of carbon information, Supplier collaboration), Management (Carbon accounting and Inventory, Carbon verification, Carbon disclosure and report).	The researchers assessed the influential criteria of carbon management in the overall performance of suppliers.
Tuzkaya (2013)	Intuitionistic fuzzy Choquet integral operator	Environmental (Green process management, Environmental costs, Pollution control, Green Image, Environmental and legislative management, Green product), Agility (Upside supply chain flexibility, Upside supply chain adaptability, Downside supply chain adaptability), Reliability (Perfect order fulfilment), Assets (Cash-to-cash cycle time, Return to supply chain fixed assets, Return on working capital), Cost (SCM cost, Cost of goods sold), Responsiveness (Order fulfilment cycle time).	The researchers proposed a decision-making methodology for environmental criteria integrated supplier evaluation processes.
Rostamzadeh (2014)	FAHP & TOPSIS	Managerial capabilities (organizing, directing, staffing, coordinating, planning, commitment), Money (current assets, product technology, fix assets, reputation), Method (technoware, hardware, infoware, orgware), Machine (capacity, usability, technology, efficiency, precise), Material (price, quality, supply, delivery time), Marketing (plan, price, promotion, place, packaging) and Manpower (education, age, experience, motivation and skill).	A new framework proposed to evaluate suppliers of a manufacturing company.
Dobos and Vörösmarty (2014)	DEA with the common weights analysis	Management criteria (Lead time, Quality, Price) Environmental criteria (Reusability, CO2 emission).	The researchers proposed a mixed DEA and composite indicator method for Green supplier selection.
Ghorabaee *et al.* (2014)	COPRAS method with interval type-2 fuzzy sets	Responsiveness, Cost, Defect rate, Delivery reliability, Flexibility.	The researchers presented a new fuzzy multiple criteria group decision-making.
Rostamzadeh *et al.* (2015)	Fuzzy VIKOR	Green Design, Green Purchasing, Green Production, Green Warehousing, Green Transportation, Green Recycling.	The researchers developed a quantitative evaluation model to measure the uncertainty of GSCM activities.
Gurel *et al.* (2015)	Literature review	Eight main criteria (Cost, Delivery, Quality, Service, Strategic Alliance, Pollution Control, Green Product, Environmental Management) with 31 sub-criteria.	The researchers presented the determinants of the green supplier for long term collaboration.

End of Table 1

Authors	Method adopted	Criteria selected	Scope of the study
Freeman and Chen (2015)	Semi-structured interviews, AHP, Entropy and TOPSIS	Cost (Average market price rate of commodities, The lowest market price rate of commodities), Green Competency (Green material selection, Green image, Cleaner production technologies, Reduced green packaging), Quality (Rejected and returned material ratio, Quality management capacity, Product percentage of pass), Delivery schedule (Service performance, On-time delivery rate, On-time delivery quantity rate), Environmental management performance (Use of toxic/restricted substances, Waste management, Remanufacturing/reuse activity, ISO-14001 certification).	The researchers proposed a green supplier selection model.
Hashemi *et al.* (2015)	ANP & improved GRA	Cost, Quality, Technology, Pollution Production, Resource Consumption, Management Commitment	The researchers presented a green supplier selection model.
Govindan *et al.* (2015)	Literature review	–	Questions addressed: (i) Which selection approaches are commonly applied? (ii) What environmental and other selection criteria for green supplier management are popular? (iii) What limitations exist?
Kannan *et al.* (2015)	Fuzzy axiomatic design	Quality, price, Capability of Supplier/Delivery, Service, Environment protection/ Management, Corporate social responsibility (CSR), Pollution control, Green Product, Green Image, Green Innovation, Hazardous Substance Management.	Proposing fuzzy axiomatic design (FAD) to select the best green supplier for Singapore-based plastic manufacturing company.
Yu and Hou (2016)	The modified multiplicative AHP	Product performance (Quality, Price, Cost), Supplier criteria (Financial status, Quality certification, Social status, Geographical position), Cooperation and development potential (Business implementation capacity, Development and innovation, Technical ability, Service level), Green performance (Green degree level, Resources recycling ability, Energy utilisation ability).	Proposed a supplier selection framework and compared the result with conventional AHP method.
Darabi and Heydari (2016)	Interval-Valued Hesitant Fuzzy ranking method	Cost, Quality, Delivery, Technology capability, Environmental competency.	Proposed a Green supplier selection method under Interval-Valued Hesitant Fuzzy environment.
Banaeian *et al.* (2016)	Fuzzy TOPSIS, Fuzzy VIKOR and Fuzzy GRA	Service level, Quality, Price, EMS (Environmental Management Systems),	The researchers compared the performance of Fuzzy TOPSIS, Fuzzy VIKOR and Fuzzy GRA in green supplier selection.
Awasthi and Govindan (2016)	Fuzzy NGT & Fuzzy VIKOR	Input (Time, Cost, Labour, Resources, Energy Usage, Water) Output (Emissions, Noise, Waste), Process (Green: Packaging, Manufacturing, Product Design, Transportation, Warehousing, Procurement and Reverse Logistics).	Proposed an integrated approach for green supplier selection.

In this respect, the dependency between criteria can be captured through the Choquet integral (Grabisch 1995; Xu 2010; Ashayeri *et al.* 2012). So far, Choquet integral and its derivatives have been applied for the various decision-making problems as shown in Table 2.

Table 2. Application of Choquet operator in decision-making problems

Source	Used problem
Srivastava *et al.* (2008)	Nonlinear system modelling
Shieh *et al.* (2009)	Student performance evaluation
Ashayeri *et al.* (2012)	Supply chain partner selection
Qin, Liu (2013)	IIF-MAGDM based on Choquet integral
Tuzkaya (2013)	Supplier evaluation with environmental criteria
Wu *et al.* (2014)	Solar thermal power plant site selection

Recently, some fuzzy aggregation operators based on Choquet integral have been presented by Tan and Chen (2010), Xu (2010) and Yu *et al.* (2015), which have considered both elements of importance and the correlations or dependencies of the elements. Based on TOPSIS, Tan (2011) developed an IVIF technique with the Choquet integral related Hamming distance for group decision making. Park *et al.* (2011) also extended the TOPSIS, Zavadskas *et al.* (2014, 2015) developed MULTIMOORA and WASPAS methods for decision making under the IVIF environment.

2.3. Intuitionistic fuzzy sets (IFS)

Before the presentation of these methodologies, some basic definitions of IFSs and IVIFs have to be presented. Since Zadeh (1965) introduced his famous theory of a fuzzy set, many extensions of his fuzzy set theory have been developed and been utilised for solving decision-making problems under vagueness or uncertainty. In 1986, Atanassov presented a new extension of Zadeh's fuzzy sets and called it "the intuitionistic fuzzy sets". Each element in an IFS is shown by an ordered pair, and each ordered pair is defined by a membership degree and a non-membership degree. The sum of the two degrees of each ordered pair must be less than or equal to one (Tan, Chen 2010; Xu 2010).

Suppose a fixed set $X = \{x_1, x_2, ..., x_n\}$, an IFS is defined as (Xu 2010):

$$A = \left\{ \left\langle x_i, t_A(x_i), f_A(x_i) \right\rangle \mid x_i \in X \right\}, \tag{1}$$

which assigns to each element x_i a membership degree $t_A(x_i)$ and a non-membership degree $f_A(x_i)$ under the condition

$$0 \le t_A(x_i) + f_A(x_i) \le 1, \text{for all } x_i \in X. \tag{2}$$

An ordered pair $\alpha(x_i) = \langle t_\alpha(x_i), f_\alpha(x_i) \rangle$ is called an intuitionistic fuzzy value (IFV) if it could satisfy the condition below:

$$t_\alpha(x_i) \in [0,1], \;\; f_\alpha(x_i) \in [0,1], \; t_\alpha(x_i) + f_\alpha(x_i) \le 1. \tag{3}$$

Xu (2010) gave some useful operations on IFVs, as follows:

Let $\alpha(x_i)=(t_\alpha(x_i),f_\alpha(x_i))$ and $\alpha(x_j)=(t_\alpha(x_j),f_\alpha(x_j))$ be two IVFs; then

$$\alpha(x_i)\oplus\alpha(x_j)=\left(t_\alpha(x_i)+t_\alpha(x_j)-t_\alpha(x_i)t_\alpha(x_j),f_\alpha(x_i)f_\alpha(x_j)\right); \quad (4)$$

$$\alpha(x_i)\otimes\alpha(x_j)=\left(t_\alpha(x_i)t_\alpha(x_j),f_\alpha(x_i)+f_\alpha(x_j)-f_\alpha(x_i)f_\alpha(x_j)\right); \quad (5)$$

$$\lambda\alpha(x_i)=\left(1-(1-t_\alpha(x_i))^\lambda,\ (f_\alpha(x_i))^\lambda\right),\ \lambda>0; \quad (6)$$

$$(\alpha(x_i))^\lambda=\left((t_\alpha(x_i))^\lambda,1-(1-f_\alpha(x_i))^\lambda\right),\ \lambda>0. \quad (7)$$

For comparing any two IFVs, the concepts of the score function and accuracy function will be used (Tan and Chen 2010). Xu (2010) clarified this comparison method as follows:

Let $\alpha(x_i)=(t_\alpha(x_i),f_\alpha(x_i))$ and $\alpha(x_j)=(t_\alpha(x_j),f_\alpha(x_j))$ be two IVFs, then $s(\alpha(x_i))=t_\alpha(x_i)-f_\alpha(x_i)$ and $s(\alpha(x_j))=t_\alpha(x_j)-f_\alpha(x_j)$ be the score of $\alpha(x_i)$ and $\alpha(x_j)$, respectively, and let $h(\alpha(x_i))=t_\alpha(x_i)+f_\alpha(x_i)$ and $h(\alpha(x_j))=t_\alpha(x_j)+f_\alpha(x_j)$ be the accuracy degrees of $\alpha(x_i)$ and $\alpha(x_j)$ respectively; then

if $s(\alpha(x_i))<s(\alpha(x_j))$, then $\alpha(x_i)$ is smaller than $\alpha(x_j)$, denoted by $\alpha(x_i)<\alpha(x_j)$,

if $s(\alpha(x_i))=s(\alpha(x_j))$, then

if $h(\alpha(x_i))=h(\alpha(x_j))$, then $\alpha(x_i)$ and $\alpha(x_j)$ represent the same information,

i.e., $t_\alpha(x_i)=t_\alpha(x_j)$ and $f_\alpha(x_i)=f_\alpha(x_j)$, denoted by $\alpha(x_i)=\alpha(x_j)$,

if $h(\alpha(x_i))<h(\alpha(x_j))$, then $\alpha(x_i)$ is smaller than $\alpha(x_j)$, denoted by $\alpha(x_i)<\alpha(x_j)$.

The relation between the score function S and the accuracy function h is similar to the relation between the mean and variance in statistics (Xu 2010).

2.4. Interval-valued intuitionistic fuzzy sets (IVIFS)

In 1989, Atanassov and Gargov presented a new extension of IFS, which membership function and non-membership function were intervals instead of exact numbers and could not be specified accurately (Tan 2011; Xu 2010) because of expressing membership function and non-membership function as intervals the IVIFS are more suitable to overcome the fuzziness of an uncertain environment.

Suppose a fixed set $X=\{x_1,x_2,...,x_n\}$, then an IVIFS $\tilde{A}$ over X is an object of the form:

$$\tilde{A}=\left\{\left\langle x_i,\tilde{t}_{\tilde{A}}(x_i),\tilde{f}_{\tilde{A}}(x_i)\right\rangle \mid x_i\in X\right\}, \quad (8)$$

where $\tilde{t}_{\tilde{A}}(x_i)\subset[0,1]$ and $\tilde{f}_{\tilde{A}}(x_i)\subset[0,1]$ are intervals, and for every $x_i\in X$ $0\le \sup\ t_A(x_i)+\sup\ f_A(x_i)\le 1$.

The ordered pair $\tilde{\alpha}(x_i)=(\tilde{t}_{\tilde{\alpha}}(x_i),\tilde{f}_{\tilde{\alpha}}(x_i))$ is called an interval-valued intuitionistic fuzzy value (IVIFV), and an IVIFV is denoted by $\tilde{\alpha}(x_i)=([a(x_i),b(x_i)],[c(x_i),d(x_i)])$ if

$$[a(x_i), b(x_i)] \subset [0,1], [c(x_i), d(x_i)] \subset [0,1], b(x_i) + d(x_i) \le 1. \quad (9)$$

For any two IVIFVs $\tilde{\alpha}(x_i) = ([a(x_i), b(x_i)], [c(x_i), d(x_i)])$ and $\tilde{\alpha}(x_j) = ([a(x_j), b(x_j)], [c(x_j), d(x_j)])$ we have some operation as follows:

$$\tilde{\alpha}(x_i) \oplus \tilde{\alpha}(x_j) = ([a(x_i) + a(x_j) - a(x_i)a(x_j), b(x_i) + b(x_j) - b(x_i)b(x_j)], [c(x_i)c(x_j), d(x_i)d(x_j)]); \quad (10)$$

$$\tilde{\alpha}(x_i) \otimes \tilde{\alpha}(x_j) = ([a(x_i)a(x_j), b(x_i)b(x_j)], [c(x_i) + c(x_j) - c(x_i)c(x_j), d(x_i) + d(x_j) - d(x_i)d(x_j)]); \quad (11)$$

$$\lambda\tilde{\alpha}(x_i) = ([1-(1-a(x_i))^{\lambda}, 1-(1-b(x_i))^{\lambda}], [(c(x_i))^{\lambda}, d(x_i))^{\lambda}]), \lambda > 0; \quad (12)$$

$$(a(x_i))^{\lambda} = ([(a(x_i))^{\lambda}, b(x_i))^{\lambda}], [1-(1-c(x_i))^{\lambda}, 1-(1-d(x_i))^{\lambda}]), \lambda > 0. \quad (13)$$

For comparing any two IVIFVs, the following method will be used:
Let $\tilde{\alpha}(x_i) = ([a(x_i), b(x_i)], [c(x_i), d(x_i)])$ and $\tilde{\alpha}(x_j) = ([a(x_j), b(x_j)], [c(x_j), d(x_j)])$ be two IVIFVs: $s(\tilde{\alpha}(x_i)) = \frac{1}{2}(a(x_i) - c(x_i) + b(x_i) - d(x_i))$ and $s(\tilde{\alpha}(x_j)) = \frac{1}{2}(a(x_j) - c(x_j) + b(x_j) - d(x_j))$ be the scores of $\tilde{\alpha}(x_i)$ and $\tilde{\alpha}(x_j)$, and let $h(\tilde{\alpha}(x_i)) = \frac{1}{2}(a(x_i) + b(x_i) + b(x_i) + d(x_i))$ and $h(\tilde{\alpha}(x_j)) = \frac{1}{2}(a(x_j) + b(x_j) + b(x_j) + d(x_j))$ be the accuracy degrees of $\tilde{\alpha}(x_i)$ and $\tilde{\alpha}(x_j)$, respectively; then:

- if $s(\tilde{\alpha}(x_i)) \le s(\tilde{\alpha}(x_j))$ then $\tilde{\alpha}(x_i)$ is smaller than $\tilde{\alpha}(x_j)$, denoted by $\tilde{\alpha}(x_i) < \tilde{\alpha}(x_j)$.
- If $s(\tilde{\alpha}(x_i)) = s(\tilde{\alpha}(x_j))$, then
- (1) if $h(\tilde{\alpha}(x_i)) = h(\tilde{\alpha}(x_j))$, then $\tilde{\alpha}(x_i)$ and $\tilde{\alpha}(x_j)$ represent the indifference information, denoted by $\tilde{\alpha}(x_i) = \tilde{\alpha}(x_j)$,
- (2) if $h(\tilde{\alpha}(x_i)) < h(\tilde{\alpha}(x_j))$, then $\tilde{\alpha}(x_i)$ is smaller than $\tilde{\alpha}(x_j)$, denoted by $\tilde{\alpha}(x_i) < \tilde{\alpha}(x_j)$.

2.5. IFC integral operator-based method for decision-making

Here, we articulately describe the steps of the decision-making methodology based on the Choquet integral operator as follows (Tan, Chen 2010):

Step 1. In connection with criteria $c_j = (j = 1, 2, ..., n)$, the partial evaluation of the alternative $a_i = (i = 1, 2, ..., m)$ is made by an intuitionistic fuzzy value $\tilde{a}_{ij} = (t_{ij}, f_{ij})(i = 1, 2, ..., m; j = 1, 2, ..., n)$ and a decision-making matrix must be constructed as follows:

$$R = \begin{pmatrix} \tilde{a}_{11}, & \tilde{a}_{12}, & ..., & \tilde{a}_{1n} \\ \tilde{a}_{21}, & \tilde{a}_{22}, & ..., & \tilde{a}_{2n} \\ ... & ... & ... & \\ \tilde{a}_{m1}, & \tilde{a}_{m2}, & ..., & \tilde{a}_{mn} \end{pmatrix}.$$

Step 2. Calculate $S(\tilde{a}_{ij})$ of the partial evaluation $\tilde{a}_{ij}$ of the alternative $a_i = (i = 1, 2, ..., m)$, and utilise $S(\tilde{a}_{ij})$ to rank the partial evaluation $\tilde{a}_{ij}$. If there is no difference between two score functions $S(\tilde{a}_{ij})$ and $S(\tilde{a}_{ik})$, then by accuracy function *H*, calculate $H(\tilde{a}_{ij})$ and $H(\tilde{a}_{ik})$ of the partial evaluation $\tilde{a}_{ij}$ and $\tilde{a}_{ik}$, respectively, and rank the partial evaluations $\tilde{a}_{ij}$ and $\tilde{a}_{ik}$ in accordance with accuracy degrees $H(\tilde{a}_{ij})$ and $H(\tilde{a}_{ik})$. So, the partial evaluation $\tilde{a}_{ij}$ of the alternative a_i is recorded so that $\tilde{a}_{i(j)} \le \tilde{a}_{i(j+1)}$.

Step 3. After the evaluation of criteria by experts, calculate the fuzzy measures. (In 1974, the fuzzy measure concept was developed by Sugeno as a subjective scale to specify the degrees of fuzziness. It is applicable for analysing subjective processes of humans (Chen, Wang 2001)). To determine fuzzy measures for given *n* criteria, $2^n - 2$ values must be calculated (Larbani *et al.* 2011). So, the identification of fuzzy measures is a complex process because the number of subsets is exponential. Now, there are numerous methods in literature to identify fuzzy measures that have been proposed by different researchers (Murillo *et al.* 2013; Larbani *et al.* 2011; Wang *et al.* 2011; Takahagi 2008; Grabisch *et al.* 2008; Chen *et al.* 2000; Grabisch 1995).

Step 4. Use the following intuitionistic fuzzy Choquet (IFC) integral operator:

$$IFC_\mu(\tilde{a}_{i1}, ..., \tilde{a}_{in}) = \left(1 - \prod_{j=1}^{n} (1 - t_{\tilde{a}_{i(j)}})^{\mu(A_{(j)}) - \mu(A_{(j+1)})}, \prod_{j=1}^{n} (f_{\tilde{a}_{i(j)}})^{\mu(A_{(j)}) - \mu(A_{(j+1)})} \right). \quad (14)$$

Aggregate all $\tilde{a}_{ij} = (t_{ij}, f_{ij})(j = 1, 2, ..., n)$ in the *i*th line of the intuitionistic fuzzy decision matrix into overall values $\tilde{a}_i = (t_{\tilde{a}_i}, f_{\tilde{a}_i}) = IFC_\mu(\tilde{a}_{i1}, ..., \tilde{a}_{in})(i = 1, 2, ..., m)$ of the alternatives $\tilde{a}_i$, where $A_{(j)} = (j = 1, 2, ..., n), A_{(n+1)} = \varphi$.

Step 5. According to the overall values $\tilde{a}_{ij} = (t_{ij}, f_{ij})$ of the alternative $a_i (i = 1, 2, ..., m)$, calculate the score function $S(\tilde{a}_i)$ or the accuracy degree $H(\tilde{a}_i)$ to rank the alternative $a_i (i = 1, 2, ..., m)$, which is similar to Step 2, then, select the best one.

Step 6. End.

2.6. IVIFC integral operator-based method for decision-making

The basic steps of the decision-making methodology with IVIF, which is extracted from Xu (2010) is similar to MCDM with the IFC integral operator proposed by Tan and Chen (2010) but their difference is on the Choquet integral operator is used in Step 4 which is shown below:

$$IVIFCA(\tilde{\alpha}(x_1), \tilde{\alpha}(x_2), ..., \tilde{\alpha}(x_n)) =$$
$$\left(\begin{array}{l} \left[1 - \prod_{i=1}^{n} (1 - a(x_{s(i)}))^{\mu(B_{s(i)}) - \mu(B_{s(i+1)})}, 1 - \prod_{i=1}^{n} (1 - b(x_{s(i)}))^{\mu(B_{s(i)}) - \mu(B_{s(i+1)})} \right], \\ \left[\prod_{i=1}^{n} (c(x_{s(i)}))^{\mu(B_{s(i)}) - \mu(B_{s(i+1)})}, \prod_{i=1}^{n} (d(x_{s(i)}))^{\mu(B_{s(i)}) - \mu(B_{s(i+1)})} \right] \end{array} \right). \quad (15)$$

3. Case study

Automobile manufacturing is one of the key industries in Iran besides petrochemical and food industries. Based on car production statistics presented by the International Organisation of Motor Vehicle Manufacturers, Iranian manufacturers increased their production number from 119419 to 1090846 between 1999 and 2014 (Anon 2016a, 2016b). Due to the growth in the number of both car produced per year and car manufacturing companies in Iran, the environmental issues have received considerable attention in recent years. This study has been implemented in a factory which is the main supplier for a well-known Iranian car manufacturer. We try to consider both green supplier criteria and sustainable supplier criteria beside the usual criteria to evaluate and rank four candidate suppliers based on the proposed methodology to find out, which one is the most appropriate with regard to environmental criteria.

4. Results and discussion

4.1. Results

4.1.1. Modified Delphi method

The modified Delphi method was used to determine the criteria. A group of 5 managers comprised an expert panel to specify the criteria. The evaluation criteria for suppliers were collected through a literature review of GSCM and SSCM articles listed in Table 1. Then, the expert panel reached a consensus on the criteria related to the condition of the firm. The criteria were divided into 6 groups: Cost (C1), Time (C2), Delivery (C3), Quality (C4), Green principles (C5) and Social responsibility (C6). They also determined candidate suppliers as A1, A2, A3 and A4. We have arranged the criteria based on three dimensions of sustainability. Table 3 presents the details discussed.

Table 3. Criteria and sub-criteria for supplier selection

Sustainability dimensions	Criteria		Sub-criteria
Economic	Cost	C1	Production cost, Transportation cost, Recycling cost, Financial capability
	Time	C2	Production time, Transportation time
	Delivery	C3	Lead time, Order fulfilment rate
	Quality	C4	Quality-related certificates, Reject rate, Quality assurance
Environmental	Green principles	C5	Pollution control, Elimination of hazardous elements, Reverse logistic management, Green image, packaging, Environmental friendly technology, Environmental certificates
Social	Social responsibility	C6	Social responsibility, Management commitment, Rights of stakeholders, Information disclosure

4.1.2. Decision-making with the IFC integral operator

Step 1. In the first step, i.e. the partial evaluation of the alternative is made according to the six criteria. Ten experts were invited to evaluate the candidate suppliers. For example, the fuzzy evaluating value of criteria C2 of the candidate A1, can be expressed by the intuitionistic fuzzy value (0.6, 0.3) because six of the experts think that A1 is strong for the criteria C2, three of experts think that A1 is weak for the criteria C2, and one of them does not give a judgement on the criteria C2. The result of Step 1 is displayed in Table 4.

Table 4. IFVs decision matrix of alternative suppliers

	C1	C2	C3	C4	C5	C6
A1	(0.5, 0.4)	(0.6, 0.3)	(0.6, 0.2)	(0.5, 0.3)	(0.5, 0.5)	(0.4,0.5)
A2	(0.4, 0.5)	(0.5, 0.4)	(0.6, 0.1)	(0.7, 0.2)	(0.2, 0.6)	(0.4,0.4)
A3	(0.8, 0.1)	(0.6, 0.2)	(0.7, 0.3)	(0.7, 0.2)	(0.6, 0.3)	(0.5,0.2)
A4	(0.6, 0.2)	(0.5, 0.2)	(0.7, 0.1)	(0.5, 0.3)	(0.4, 0.5)	(0.5,0.3)

Step 2. In the second step, the IFVs were reordered based on the calculated score and accuracy degrees (Table 5).

Table 5. Reordered IFVs

	C1	C2	C3	C4	C5	C6
A1	(0.4,0.5)	(0.5, 0.5)	(0.5, 0.4)	(0.5, 0.3)	(0.6, 0.3)	(0.6, 0.2)
A2	(0.2, 0.6)	(0.4, 0.5)	(0.4,0.4)	(0.5, 0.4)	(0.6, 0.1)	(0.7, 0.2)
A3	(0.5,0.2)	(0.6, 0.3)	(0.6, 0.2)	(0.7, 0.3)	(0.7, 0.2)	(0.8, 0.1)
A4	(0.4, 0.5)	(0.5,0.3)	(0.5,0.3)	(0.5, 0.2)	(0.6, 0.2)	(0.7, 0.1)

Step 3. Fuzzy measures must be calculated after receiving the expert opinion about the share of each criterion on supplier competencies as illustrated in Table 6.

Step 4. In this step, the final IFVs of supplier evaluations are calculated by using the intuitionistic fuzzy Choquet integral operator (Eq. 14) and fuzzy measures (Table 6) which were used as weights of criteria. The produced IFVs are as follow: (0.55, 0.297), (0.56, 0.249), (0.72, 0.166), (0.595, 0.183) for A1, A2, A3 and A4.

Step 5. To select the best supplier, we compared the final result of step 4 based on their score and accuracy degrees. (0.72, 0.166) > (0.595, 0.183) > (0.56, 0.249) > (0.55, 0.297) it means that A3 > A4 > A2 > A1, so A3 is the best supplier.

Table 6. Fuzzy measures of criteria

$\mu(\varphi) = 0, \mu(\{C_1\}) = 0.4$, $\mu(\{C_2\}) = 0.3$, $\mu(\{C_3\}) = 0.3$, $\mu(\{C_4\}) = 0.3$, $\mu(\{C_5\}) = 0.2$, $\mu(\{C_6\}) = 0.2$,
$\mu(\{C_1,C_2\}) = 0.6$, $\mu(\{C_1,C_3\}) = 0.6$, $\mu(\{C_1,C_4\}) = 0.6$, $\mu(\{C_1,C_5\}) = 0.53$, $\mu(\{C_1,C_6\}) = 0.53$,
$\mu(\{C_2,C_3\}) = 0.53$, $\mu(\{C_2,C_4\}) = 0.53$, $\mu(\{C_2,C_5\}) = 0.45$, $\mu(\{C_2,C_6\}) = 0.45$, $\mu(\{C_3,C_4\}) = 0.53$,
$\mu(\{C_3,C_5\}) = 0.45$, $\mu(\{C_3,C_6\}) = 0.45$, $\mu(\{C_4,C_5\}) = 0.45$, $\mu(\{C_4,C_6\}) = 0.45$, $\mu(\{C_5,C_6\}) = 0.37$,
$\mu(\{C_1,C_2,C_3\}) = 0.76$, $\mu(\{C_1,C_2,C_4\}) = 0.76$, $\mu(\{C_1,C_2,C_5\}) = 0.71$, $\mu(\{C_1,C_2,C_6\}) = 0.71$,
$\mu(\{C_1,C_3,C_4\}) = 0.76$, $\mu(\{C_1,C_3,C_5\}) = 0.71$, $\mu(\{C_1,C_3,C_6\}) = 0.71$, $\mu(\{C_1,C_4,C_5\}) = 0.71$,
$\mu(\{C_1,C_4,C_6\}) = 0.71$, $\mu(\{C_1,C_5,C_6\}) = 0.65$, $\mu(\{C_2,C_3,C_4\}) = 0.7$, $\mu(\{C_2,C_3,C_5\}) = 0.65$,
$\mu(\{C_2,C_3,C_6\}) = 0.65$, $\mu(\{C_2,C_4,C_5\}) = 0.65$, $\mu(\{C_2,C_4,C_6\}) = 0.65$, $\mu(\{C_2,C_5,C_6\}) = 0.58$,
$\mu(\{C_3,C_4,C_5\}) = 0.65$, $\mu(\{C_3,C_4,C_6\}) = 0.65$, $\mu(\{C_3,C_5,C_6\}) = 0.58$, $\mu(\{C_4,C_5,C_6\}) = 0.58$,
$\mu(\{C_1,C_2,C_3,C_4\}) = 0.88$, $\mu(\{C_1,C_2,C_3,C_5\}) = 0.85$, $\mu(\{C_1,C_2,C_3,C_6\}) = 0.85$,
$\mu(\{C_1,C_2,C_4,C_5\}) = 0.85$, $\mu(\{C_1,C_2,C_4,C_6\}) = 0.85$, $\mu(\{C_1,C_2,C_5,C_6\}) = 0.8$,
$\mu(\{C_1,C_3,C_4,C_5\}) = 0.85$, $\mu(\{C_1,C_3,C_4,C_6\}) = 0.85$, $\mu(\{C_1,C_3,C_5,C_6\}) = 0.8$,
$\mu(\{C_1,C_4,C_5,C_6\}) = 0.8$, $\mu(\{C_2,C_3,C_4,C_5\}) = 0.8$, $\mu(\{C_2,C_3,C_4,C_6\}) = 0.8$,
$\mu(\{C_2,C_3,C_5,C_6\}) = 0.75$, $\mu(\{C_2,C_4,C_5,C_6\}) = 0.75$, $\mu(\{C_3,C_4,C_5,C_6\}) = 0.75$,
$\mu(\{C_1,C_2,C_3,C_4,C_5\}) = 0.95$, $\mu(\{C_1,C_2,C_3,C_4,C_6\}) = 0.95$, $\mu(\{C_1,C_2,C_3,C_5,C_6\}) = 0.92$,
$\mu(\{C_1,C_2,C_4,C_5,C_6\}) = 0.92$, $\mu(\{C_1,C_3,C_4,C_5,C_6\}) = 0.92$, $\mu(\{C_2,C_3,C_4,C_5,C_6\}) = 0.9$,
$\mu(\{C_1,C_2,C_3,C_4,C_5,C_6\}) = 1$.

4.1.3. Decision-making with the IVIFC integral operator

Step 1. First, the experts were asked to evaluate the alternatives according to the six criteria by IVIFs or transform the IFVs of the previous section to IVIFs as in Table 7.

Table 7. IVIFs decision matrix of alternative suppliers

	A1	A2	A3	A4
C1	([0.5,0.6],[0.3,0.4])	([0.2,0.4],[0.4,0.5])	([0.7,0.8],[0.1,0.2])	([0.5,0.7],[0.2,0.3])
C2	([0.4,0.5],[0.2,0.4])	([0.4,0.6],[0.2,0.4])	([0.5,0.7],[0.1,0.3])	([0.4,0.5],[0.1,0.3])
C3	([0.5,0.7],[0.1,0.2])	([0.6,0.7],[0,0.2])	([0.6,0.7],[0.2,0.3])	([0.5,0.7],[0.1,0.3])
C4	([0.4,0.5],[0.3,0.4])	([0.5,0.7],[0,0.2])	([0.6,0.7],[0.1,0.2])	([0.5,0.6],[0.2,0.3])
C5	([0.3,0.5],[0.4,0.5])	([0.1,0.3],[0.4,0.6])	([0.5,0.6],[0.2,0.3])	([0.3,0.5],[0.4,0.5])
C6	([0.3,0.5],[0.3,0.5])	([0.2,0.3],[0.6,0.7])	([0.4,0.5],[0.2,0.3])	([0.4,0.5],[0.2,0.3])

Step 2. After calculating the score and accuracy degrees, the IVIFs were reordered as shown in Table 8.

Table 8. Reordered IVIFs

A1	A2	A3	A4
([0.3,0.5],[0.4,0.5])	([0.2,0.3],[0.6,0.7])	([0.4,0.5],[0.2,0.3])	([0.3,0.5],[0.4,0.5])
([0.3,0.5],[0.3,0.5])	([0.1,0.3],[0.4,0.6])	([0.5,0.6],[0.2,0.3])	([0.4,0.5],[0.2,0.3])
([0.4,0.5],[0.3,0.4])	([0.2,0.4],[0.4,0.5])	([0.5,0.7],[0.1,0.3])	([0.4,0.5],[0.1,0.3])
([0.4,0.5],[0.2,0.4])	([0.4,0.6],[0.2,0.4])	([0.6,0.7],[0.2,0.3])	([0.5,0.6],[0.2,0.3])
([0.5,0.6],[0.3,0.4])	([0.5,0.7],[0,0.2])	([0.6,0.7],[0.1,0.2])	([0.5,0.7],[0.2,0.3])
([0.5,0.7],[0.1,0.2])	([0.6,0.7],[0,0.2])	([0.7,0.8],[0.1,0.2])	([0.5,0.7],[0.1,0.3])

Step 3 and 4. By using fuzzy measures (Table 6) and Supplier evaluation values, the final IVIFs are calculated through the Choquet integral operator (Eq. 15). The produced IVIFs are as follow: ([0.45,0.6],[0.205,0.336]), ([0.44,0.6],[0,0.307]), ([0.62,0.73],[0.12,0.235]), ([0.47,0.645],[0.155,0.308]) for A1, A2, A3 and A4.

Step 5. To select the best supplier, we compared the final result of Step 4 and rearranged it (based on the score and accuracy degrees). It means that A3 > A2 > A4 > A1, so A3 is the best supplier.

4.2. Discussion

In this paper, an effective methodology to solve the supplier selection problem has been presented. The contribution of this paper is three-fold: (1) It can be counted among the scarce studies considering both economic (traditional) and sustainable (green) supplier selection criteria. (2) It is among the scarce studies utilising Choquet integral operators in two degrees of accuracy (IFVs & IVIFs) in the context of the supplier selection. (3) It is among the scarce studies using Choquet integral operators and fuzzy measures for the green supplier evaluation problem. The presented methodology can extract the expert knowledge and improve the supplier selection process due to a high level of expert involvement in decision-making and the usage of Fuzzy-related concepts to cope with uncertainties. Moreover, the integration of the modified Delphi method by the researchers extends the degree, to which the fuzziness of a problem can be dealt with. The assessment of candidate suppliers in the context of IFVs and IVIFs can be easily made, which is very useful for application in the real world. Since the Choquet integral operators can capture both the element's importance and the interdependencies between elements (Tan, Chen 2010; Xu 2010), the proposed methodology is applicable in every selection process in the real world, which inherently features dependencies or interactions among criteria. Also, the proposed methodology provided a list of criteria for a supplier selection, which could be helpful for firms in the car-making industry and their suppliers. Although this methodology is capable of dealing with a large number of criteria and sub-criteria, due to the complexity of calculating fuzzy measures for large numbers, which result in exponentially increasing of subsets, it is better to increase the number of sub-criteria to be evaluated under the criteria titles by the expert opinion. The use of this systematic process for supplier selection, which has relied on the expert judgment significantly improved the supplier selection process in our case study firm and added some insight into the issue which is relevant to firms on a constant basis.

Conclusions

In this study, the authors have investigated the supplier selection issue considering both conventional and green criteria. The use of both conventional and green criteria helps companies to achieve their goals in order to protect the environment and produce less polluting products and engage in greener SC activities. In the proposed methodology, after reviewing the literature comprehensively, the Delphi method has been used to collect proper criteria based on expert opinion. The subjective nature of judgment in the supplier selection paved the way to utilise the intuitionistic fuzzy sets to cope with the fuzzy nature and uncertainty of this selection. In fact, the experts can express their opinion on suppliers by a membership degree and a non-membership degree in the form of IFV or with an interval membership degree and an interval non-membership degree in the form of IVIF. The importance of criteria has been determined by fuzzy measures. Moreover, some operators have been used for aggregating IFVs and IVIFs with correlative weights based on the Choquet integral, which is able to consider both the elements of importance and the correlations among the elements. Although the Choquet integral operator is not a new tool for decision-making, fuzzy operators are concluded from it and are now prevalent and developing quickly. A proper case study has also been provided to test the applicability of the proposed method. Future studies can further deal with the difficulties of determining the weights for the aggregating operator using techniques of weight determination that can capture correlations or dependencies among the criteria. The proposed methodology can also be used in every selection process that contains fuzziness naturally and will occur in an environment with correlated preferences.

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