GREEN SUPPLIER EVALUATION AND SELECTION FOR A FURNITURE SALES COMPANY

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การประเมินและคัดเลือกผู้จำหน่ายเฟอร์นิเจอร์สีเขียวสำหรับบริษัทขายเฟอร์นิเจอร์

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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เจียห่าว หลี่ : การประเมินและคัดเลือกผู้จำหน่ายเฟอร์นิเจอร์สีเขียวสำหรับบริษัทขายเฟอร์นิเจอร์. (GREEN SUPPLIER EVALUATION AND SELECTION FOR A FURNITURE SALES COMPANY) อ.ที่ปรึกษาหลัก : พิศิษฏ์ จารุมณีโรจน์

วิทยานิพนธ์ฉบับนี้นำเสนอวิธีการประเมินผู้จำหน่ายที่เป็นมิตรต่อสิ่งแวดล้อมสำหรับบริษัทเฟอร์นิเจอร์แห่งหนึ่งในประเทศจีน โดยวิธีการดังกล่าวจะมุ่งเน้นไปที่กระบวนการประเมินผู้จำหน่าย และความยั่งยืนของการดำเนินธุรกิจ เบื้องต้น ผู้ประเมินได้จัดประชุมร่วมกับผู้เชี่ยวชาญจากหลากหลายสาขา เพื่อรวบรวมข้อมูลเกี่ยวกับปัญหาในการประเมินและการคัดเลือกตัวบ่งชี้การประเมิน จากนั้นผู้วิจัยได้ทำการทบทวนวรรณกรรมที่เกี่ยวกับการประเมินผู้จำหน่ายเพื่อสร้างระบบการประเมินผู้จำหน่ายใหม่ที่เป็นมิตรต่อสิ่งแวดล้อม อันประกอบไปด้วย 5 ตัวชี้วัดหลัก และ 19 ตัวชี้วัดรอง เมื่อเลือกตัวชี้วัดในการประเมินแล้ว ผู้วิจัยได้เลือกเอาวิธีการ Fuzzy-entropy-TOPSIS มาใช้ในการการประเมินผู้จำหน่ายทั้งสิ้น 13 ราย ผ่านโปรแกรมที่เขียนขึ้นด้วย MATLAB ผลจากการศึกษาพบว่า ผู้จำหน่ายที่เหมาะสมที่สุด คือ S1 และ S11 ซึ่งมีประสิทธิภาพดีที่สุดในแง่ของความเป็นมิตรต่อสิ่งแวดล้อม คุณภาพ และความยืดหยุ่นในการตอบสนองความต้องการด้านความยั่งยืน และความเป็นมิตรต่อสิ่งแวดล้อมของบริษัทกรณีศึกษา นอกจากนี้ ผู้วิจัยยังได้ทำการวิเคราะห์ความอ่อนไหวของการประเมิน เพื่อตรวจสอบความเที่ยงธรรม และความมีเสถียรภาพของวิธีการ Fuzzy-entropy-TOPSIS ที่นำเสนอ โดยการเปลี่ยนค่าน้ำหนักของตัวแปร

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Jiahao Li : GREEN SUPPLIER EVALUATION AND SELECTION FOR A FURNITURE SALES COMPANY. Advisor: Assoc. Prof. Dr. PISIT JARUMANEEROJ

This paper proposes a supplier evaluation method for a furniture sales company in China that focuses on the evaluation process and sustainability of business operation. Firstly, we have arranged a meeting with experts from various fields to gather information concerning evaluation problems and choices of evaluation indicators. We then go through the literature in the field of supplier evaluations to create a new green supplier evaluation indicator system comprising of 5 first-level and 19 second-level evaluation indicators. Once selected, the Fuzzy-entropy-TOPSIS approach has been adopted for the evaluation of 13 suppliers via MATLAB. We find that, among these suppliers, S1 and S11 are the best suppliers in terms of greenness, quality, and flexibility to meet the case study company's sustainability and greenness needs. We also conduct a sensitivity analysis to verify objectivity and stability of the Fuzzy-entropy-TOPSIS approach by changing the subjective weight.

Field of Study:	Engineering Management	Student's Signature ....
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CHAPTER 1
INTRODUCTION

1.1 Introduction of JA Company

JA Furniture Sales Company, located in Zhongshan, Guangdong Province, focuses on furniture sales. It has always adhered to the development philosophy of "product safety as the core, customer first and win-win business" as a long-established furniture company in Guangdong Province. The kindergarten and parents are its major customer purchasing children furniture products for daily teaching and living use, due to the business concept of honest management, safe production and high quality. The main products include children and living furniture including tables, chairs, beds, display cabinets, etc.

1.2 Problem Statement

1.2.1 Simple Evaluation Indicator System

At present, the company's evaluation indicators include only four aspects: cost, product quality, delivery time and production capacity as shown in **Table 1.1**, while a complete evaluation indicator system should not only include these, but also some soft indicators such as innovation ability, environmental factors and sustainability which affect its long-term development. A small-scale and vague indicator system lacks of competitiveness and representativeness, so if JA evaluates suppliers by only these indicators, the selected supplier may not fully meet its development needs. Therefore, the company should rebuild a more comprehensive indicator system.

Table 1.1 JA company's current supplier evaluation system (internal source)

Evaluation indicators	Weight
Cost reduction ratio	40%
Material quality compliance rate	20%
On-time delivery rate	20%
Equipment compliance rate	20%

In addition, the indicator system with only one layer is unable to comprehensively evaluate suppliers, so the furniture may not meet market expectations and order requirements, leading to product stagnation, returns and complaints. For example, the furniture quality depends on not only the qualification rate of materials, but also structure, transportation quality and paint qualification rate. If evaluating the quality by only one rate, it may lead to additional economic and reputation losses. For example, in **Table 1.2**, we can clearly see that the number of returns and customer complaints due to the structure problem was rising in the second half of 2021.

Table 1.2 the number of structure problem per month in the second half of 2021 (internal source)

Month	Structural instability	Loose connection	Structural deformation
Jul	25	17	12
Aug	27	20	14
Sep	30	21	18
Oct	33	24	23
Nvo	37	32	27
Dec	42	37	32
Total	194	151	126
Economic Loss	423777	342800	287676

1.2.2 Unreliable Indicator Weight

Since cost is weighted at 40% and quality's weight is at 20%, most suppliers tend to reduce the quality to lower the quotation and obtain orders, leading to the deterioration of product quality and increase in extra costs. Taking **Table 1.3** as an example, last year, JA ordered the same wooden table a supplier four times. It is obvious that the quality of the product is directly proportional to the price offered (higher price, better quality, vice versa).

Table 1.3 the after-sales record of the supplier's products (internal source)

Order serial number	Unit price	Order quantity	Return Batch	Return Rate	Number of after-sales problems	Extra costs (CNY)
1	373	2600	135	5.19%	58	46900
2	386	2300	96	4.17%	32	21600
3	341	3100	205	6.02%	69	64500
4	326	3350	243	7.25%	93	81900
Total	-	11350	679	5.98%	252	214900

In conclusion, the weight of quality is too low, resulting in the reduction of quality and the increase of operation costs. Because the procurement and quality control departments can only continuously increase the inspectors' number and working time to check potential problems.

1.2.3 Ignorance of Green Indicator

1. In 2018, the Chinese government introduced stricter environmental protection regulations for the furniture industry, which imposes harsh limits on the waste and harmful emissions. For example, the environmental protection authority would test for formaldehyde and other harmful materials in furniture products with higher standard, if not passing, it will impose large fines or even the business closure. **Table 1.4** shows the fines incurred by JA's stores from Aug to Dec in 2021, and one store was required to shut down for one week.

Table 1.4 the penalty from government record in 2021

Month	Number of unqualified products	Fine Amount
Aug	23	4700
Sep	31	12800
Oct	43	36800
Nov	51	51600
Dec	53	76900

2. Consumers are paying more and more attention to the safety of harmful materials like formaldehyde and heavy metal from furniture. Therefore, Consumers are more willing to buy furniture with international quality IOS140000 certification, despite of the high price.

3. Consumers become more aware of the environmental protection and the green performance of furniture, such as whether the materials are non-polluting, degradable or recyclable and so on.

1.3 Introduction of Supplier Evaluation and Selection

Selecting the best supplier is the key to ensuring product quality and successful business operation, so companies need to establish the right process of supplier evaluation. Supplier selection steps are as follows and in **Figure 1.4:**

1. Analyse the competitive market environment. The company should understand market demand and supplier's characteristics to determine whether to make collaboration or not. When cooperation exists, it will need to continuously compare the product from supplier with market changes, if not capable any more, then it should search for other suppliers.
2. Define the features of the main products. The company must select suitable suppliers according to product features and market demands, and conduct a comprehensive evaluation of their production capacity.
3. Establish a professional evaluation team. The supplier selection & evaluation is a multi-department task including the teams related to production, technology, quality and others to make decisions, which can provide more professional advice to make right decision.
4. Develop supplier evaluation criteria. A comprehensive indicator system is the basis of making a correct supplier evaluation, which must represent the business operation and development requirements.
5. Determine the target of supplier selection. According to the supplier's production capacity, technical experience, equipment conditions and geographical environment and other circumstances of a comprehensive analysis of the supplier's supply capacity and long-term stability, choose the right long-term cooperation goals.
6. Supplier participation. Suppliers should provide the necessary information such as production capacity, equipment conditions, personnel quality, financial credit and other essential factors related to evaluation criteria.
7. Make a comprehensive evaluation of suppliers. The evaluation team will consider evaluation data about evaluation criteria and use evaluation to select the best supplier.
8. Establish long-term partnerships. The company will regularly carry out performance appraisals and implement corresponding incentives to establish long-term and stable relationships.

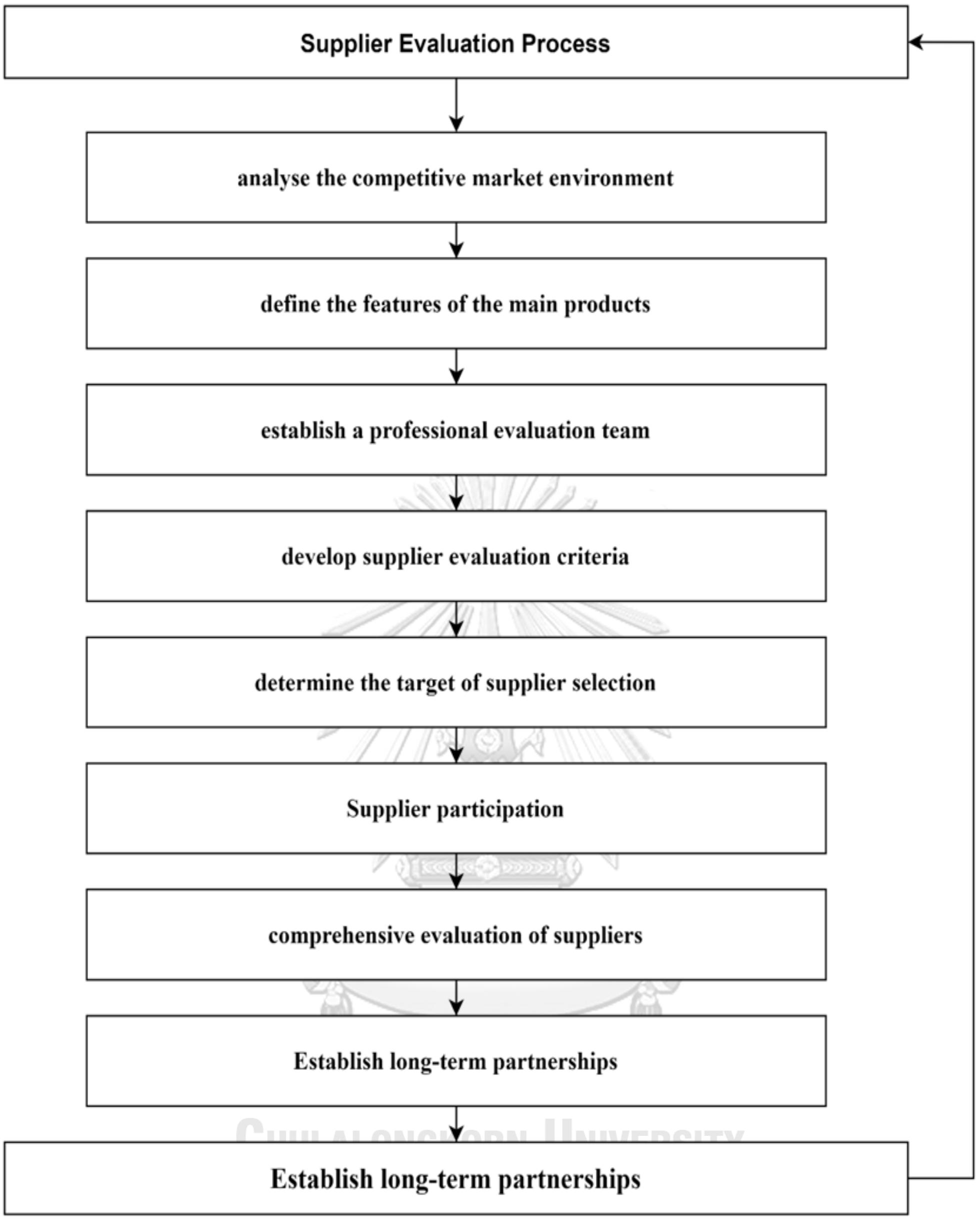

Figure 1.1 Supplier evaluation process

1.4 Research Objective

Identify the company's supplier evaluation problems and obtain recommendations for the selection of evaluation indicators through the expert meeting, construct a supplier evaluation indicator system based on the comment from experts and literature review, obtain indicator data (both quantitative and qualitative) by the evaluation questionnaire, and the Fuzzy-Entropy-TOPSIS successfully processes the data and derives an accurate result as the best supplier.

1.5 Research Questions

1. How to construct a reasonable evaluation indicator system.
2. How to arrange the reasonable weight of evaluation indicator.
3. How to add green factors into the supplier evaluation process.

1.6 Research Hypothesis

1. Indicators are chosen for their relevance to the development of the company.
2. Experts' scores for qualitative indicators are objective and reasonable.
3. The evaluation methodology allows for accurate processing of indicator data and produces accurate results.

1.7 Research Scope

The scope of this thesis focuses on addressing the problems of green supplier evaluation for JA Furniture Sales Company.

1.8 Methodology

1.8.1 Summary of Literature Review

The first important task is to establish a suitable indicator system of the green supplier evaluation, and the evaluator reviews the literature on the supplier evaluation to rebuild a new indicator system according to the feature of JA's business operation and its development requirements especially for the greenness. For example, quality is the heart of any commodity, and Dickson (1990) and Weber et al (1991)'s research also show it is one of the top criteria in many evaluation cases. Secondly, different evaluation methods have different cons and pros, then the evaluator should also compare various models by reviewing the research on supplier evaluation to select a suitable one for JA's evaluation background according to the evaluation characteristics such as the number of suppliers, trade volume and business scale. For example, if there are hundreds of suppliers, AHP can't process all the evaluation data resulting in inaccurate outcome. In general, the literature review should solve two basic research requirements including the construction of the indicator system and the determination of the evaluation model.

1.8.2 Combination of Quantitative and Qualitative Analysis

The evaluation indicator system includes both quantitative and qualitative indicators. The experts will provide evaluation data by filling the evaluation questionnaire to apply Fuzzy-entropy-TOPSIS evaluation model.

1.8.3 Questionnaire Approach

The dissertation will design questionnaires to obtain evaluation data from experts including transport coordinator, supply chain manager, environment expert and quality controller.

1.8.4 Case Study

The dissertation uses two supplier evaluation cases of a Furniture Sales Company as the case study to demonstrate the feasibility and effectiveness of the evaluation model and the green supplier evaluation indicator system.

1.8.5 Model Evaluation Approach

For JA's evaluation case, this dissertation will use fuzzy-entropy-TOPSIS (Fuzzy-entropy is to determine indicator weights, and fuzzy-TOPSIS is to rank suppliers).

1.8.6 Expert Meeting

There are two expert meetings before and after the supplier evaluation to find the problems of supplier evaluation, acquire suggestions about selecting indicators and discuss about the evaluation result.

1.8.7 Calculation Tool

Because the model application includes many equations and metrics, this research will process the data by setting programme in MATLAB to evaluate 13 suppliers and make the sensitivity analysis.

1.8.8 Sensitivity Analysis

This dissertation will use the sensitivity analysis from the first case study to verify the stability and objectivity of the evaluation result by changing the subjective weight, and also can further prove the applicability and practicability of the fuzzy-entropy-TOPSIS.

CHAPTER 2
LITERATURE REVIEW

2.1 Research on Supplier Evaluation Indicator and Green Factor

The supplier evaluation is based on the indicator system which should represent the requirement of the business operation, and the feature of the product and the development demand, and this research is to evaluate the green supplier, so the green factor is an important review point.

The study of supplier evaluation indicators began in the 1970s when the famous American scholar Dickson (1966) used a questionnaire to survey more than two hundred people from different companies who had extensive experience in procurement, and finally summarised 23 major evaluation indicators as shown in **Table 2.1**. Ellram (1990) added strategic objectives and development potentials to Dickson's system, so companies could more intuitively examine the development objectives and potential of suppliers and also help manufacturers to make the right choice. Weber, Current and Benton (1991) compiled literatures on supplier evaluation and selection between 1969 and 1990 and ranked the criteria importance according to the number of refences of different indicators as shown in **Table 2.1**, which ultimately identified quality, delivery, price and production facilities & capacity as the four most important factors. Porter (1995) argued that the higher the supplier's raw material utilisation rate, the more the manufacturer's production costs would be reduced, so he added the raw material consumption rate to the previous evaluation system. Sonesson and Berlin (2003) evaluated third-party logistics industry and established a new evaluation indicator system for logistics supplier, including three dimensions: delivery time, order fulfilment rate and finance situation. Fu-jiang, Ye-Zhuang & Xiao-lin (2006) studied the relationship between supplier service satisfaction and supplier selection, and concluded that the higher the service satisfaction, the greater the likelihood of selection, so eventually added the satisfaction to the evaluation system.

Table 2.1 Dickson and Weber, Current, and Benton's Evaluation Indicator System

Evaluation Criterion	Dickson		Weber, Current, and Benton	
	Importance Ranking	Importance Description	Number of Literature	Percentage (%)
Quality	1	Very high importance	40	53
Delivery	2	Very high importance	44	58
Performance History	3	Very high importance	7	9
Warranties & Claims Policies	4	Very high importance	0	0
Production Facilities and Capacity	5	Great importance	23	30
Price	6	Great importance	61	80
Technical Capacity	7	Great importance	15	20
Financial Position	8	Great importance	7	9
Procedural Compliance	9	Great importance	2	3
Communication System	10	Great importance	2	3
Reputation and Position in Industry	11	Great importance	8	11
Desire for Business	12	Great importance	1	1
Management and Organization	13	Great importance	10	13
Operating Control	14	Great importance	3	4
Repair Service	15	Medium importance	7	9
Attitude	16	Medium importance	6	8
Impression	17	Medium importance	2	3
Packaging Ability	18	Medium importance	3	4
Labor Relations Record	19	Medium importance	2	3
Geographical Location	20	Medium importance	16	21
Amount of Past Business	21	Medium importance	1	1
Training Aids	22	Medium importance	2	3
Reciprocal Arrangements	23	Low importance	2	3

Noci (1997) as one of the first scholars to study the green evaluation indicator, used the questionnaire to investigate green manufacturing companies and assess the green performance of suppliers, and eventually found that greenness, green cost and green production which would greatly influence the green performance of suppliers. Bai & Sarkis (2010) evaluated the green performance of suppliers by the emission rate of toxic waste and the waste treatment capacity as indicators, which expanded the green evaluation indicator system. Awasthi, Chauhan and Goyal (2010) suggested that the business cooperation with environmental organisations can effectively improve the greenness of suppliers and positively contribute to green development. Tseng and Chiu (2013) studied the operation characteristics of those companies which cooperated with high green performance suppliers to build a green indicator system, including the green certification, the green commitment, the green management, the staff training and the green culture, etc.

2.2 Compare and Research on Supplier Evaluation Models

As scholars research more supplier evaluation issues, there are more supplier evaluation methods, and different type with evaluation principles can deal with evaluation problems under different situations. Therefore, the study of evaluation methods not only needs to understand various evaluation models, but the evaluation background such as the scale and the industry. Due to the limitations of different evaluation methods, sometimes traditional methods cannot fulfill new evaluation demands, so researchers should innovatively create new methods or combine interdisciplinary knowledge from different fields with old evaluation models to solve new problems.

Akarte (2001) used Analytical Hierarchy Process (AHP) to evaluate suppliers in the luminaire industry, which compares every two indicators to determine weights and requires experts to score suppliers’ performance to select the best one. Guoyi & Xiaohua (2011) revaluated third-party logistics service suppliers by constructing new indicator system based on the industry features and business needs, and combined the AHP with Entropy as evaluation model. Zouggari and Benyoucef (2012) is based on fuzzy-TOPSIS to solve group multi-criteria supplier selection problem. Onder & Sundus (2013) firstly used AHP to determine the weights, then calculated the distance between each supplier solution and the ideal solution through TOPSIS to rank suppliers (the closer the solution is from the positive optimal solution, or the further the solution is from the negative optimal solution). Zhao and Guo (2014) combine fuzzy theory, entropy and TOPSIS as a new supplier evaluation method to evaluate the supplier of the thermal power equipment. Freeman and Chen (2015) take AHP and entropy to individually determine the subjective and objective weights to get the compromised weight, and also use TOPSIS to rank the supplier. Lima-Junior and Carpinetti combines SCOR model and fuzzy TOPSIS to evaluate the clutch manufacturer. Rashidi and Cullinane (2019) compare fuzzy-DEA with fuzzy TOPSIS in sustainable supplier evaluation and selection. Dos Santos, Godoy and Campos (2019) also use entropy-TOPSIS under fuzzy condition to evaluate green suppliers for a manufacturer of customized furniture. Paramaporn (2019) developed a strategic indicator system for an international food trading company and evaluated by AHP. Tsai and Phumchusai (2021) used Fuzzy-AHP to evaluate electronic component manufacturer.

By comparison of different MADM, Fuzzy-entropy-TOPSIS is relatively simple and economical with low operation cost; its weight determination process takes into account both subjectivity and objectivity; TOPSIS can find the optimal furniture supplier with better accuracy; although the calculation process is relatively complicate but the MATLAB can efficiently deal with it by setting programs; for small and medium-sized companies such as JA Furniture Sales, it is the most appropriate evaluation method because of lower costs and higher efficiency, if it is complex and difficult to apply, which would lead to low efficiency and high cost, and the comparison is shown in **Table 2.2**.

Table 2.2 The comparison of different supplier evaluation models

Evaluation Model	Application	Advantage	Disadvantage
Fuzzy-entropy-TOPSIS (Zhao & Guo, 2014)	Evaluate the green supplier of the thermal power equipment	handle data of different magnitudes (qualitative and quantitative data); less errors from human judgment; handle different directional indicators, such as cost-based and benefit-based indicators; Consider both objective and subjective weights	The calculation process is relatively complex, but the MATLAB can process evaluation data efficiently.
AHP-Entropy-TOPSIS (Freeman and Chen, 2015))	electronic machinery manufacturer	Same as the Fuzzy-entropy-TOPSIS	Hardly process the big volume of evaluation data; Weighting process is too complicate
Fuzzy-AHP (Tsai and Phumchusai, 2021)	evaluate electronic component manufacturer	Consider the expert judgment; The operation logic is relatively simple;	High subjectivity with human bias; Cannot process too many evaluation data when too many indicators or suppliers; The ranking process is not as accurate as TOPSIS
Fuzzy-TOPSIS (Rashidi and Cullinane, 2019)	group multi-criteria supplier selection problem	handle data of different magnitudes; handle different kinds of indicators;	More subjective; The weight determination process is too rough

Table 2.2 (Continued)

Evaluation Model	Application	Advantage	Disadvantage
AHP-TOPSIS (Onder & Sundus, 2013)	Cable company	Operation logic is simple; Can evaluate more suppliers compared with fuzzy-AHP and AHP;	Highly subjective; The weight determination process is complex
AHP-entropy (Guoyi & Xiaohua, 2011,)	The third-party logistics supplier evaluation	Consider both subjective and objective weights; The weight determination process is complex	The ranking process is not as accurate as TOPSIS The weight determination process is complex
AHP (Natchanok, 2019)	International food trading company	Operation logic is very simple;	Highly subjective; Cannot process large evaluation data when too many suppliers or indicators; Cannot process different kinds of indicators; Ranking process is very rough
TOPSIS (Santos, Godoy and Campos, 2019)	-	Can accurately examine the performance difference of suppliers; Process different kinds of indicator;	The change of suppliers involved in evaluation would lead to the movement of ranking; the non-meaningfulness of the resulting rankings in mixed data contexts

CHAPTER 3
THE CONSTRUCTION OF INDICATOR SYSTEM AND MODEL DEVELOPMENT

3.1 Construct the Green Supplier Evaluation Indicator System

Because there are many factors influencing green furniture supplier evaluation, such as cost, quality and production capacity, it is difficult to analyse all the indicators and corresponding performance, so this thesis should select representative indicator based on the industrial features and JA's business requirement to select the right supplier and support its development. Therefore, author firstly reads literatures on the green supplier evaluation to establish the initial indicator system, then obtained advice through expert meeting to refine it, eventually including five first-level indicators: quality, delivery rate, cost, flexibility and greenness.

3.1.1 Greenness Indicator Selection

Since the environmental records in China is not transparent, the indicators of the record openness are excluded. At the same time, the purpose of this research is to help JA evaluate green suppliers, so the indicators of reverse logistics and environmental pressure are eliminated too. Based on the current status of Chinese furniture industry like the requirements of green revolution and consumption trend, the second-level indicators (qualitative) under greenness are specifically significant and the content of the evaluation indicators is appropriately supplemented below. Noci (1997), Awasthi, Chauhan and Goyal (2010), Tseng & Chiu (2013) et al involve greenness factors in their supplier evaluation research.

Table 3.1 The second-level indicator under greenness

Indicators	Reference	Explanation
Pollution Emissions (D1)	Shen et al (2013); Environmental Expert	evaluate how much the pollution emitted by from the business operation of the supplier
Energy Consumption (D2)	Handfield and Melnyk (1998)	assess how the supplier consumes various resources such as water, electricity, and raw materials in production
Clean Technology (D3)	Pereira & Cunha (2018)	assess the green furniture production and the clean treatment of hazardous substances
Green Design (D4)	Berginc, Hrovatin et al (2011) and Sellitto, Luchese, et al (2017)	assess raw material recycling design, product recycling design and ecological design
Green Certification (D5)	Environmental Expert	evaluate whether the supplier's product passes the safety test and obtains green certificates
Environmental Management (D6)	Borchardt, Sellitto and Pereira (2010) and Gupta & Barua (2017)	evaluate whether the management system of suppliers meets the IOS14000 standard
Green Commitment (D7)	Mangla, Kumar, and Barua (2014)	assess whether suppliers are aware of the importance of the green management and what they will contribute

3.1.2 Flexibility Indicator Selection

In order to help JA successfully implement green transformation, the supplier should have the operation strength in flexibility to hold the market change, so the flexibility (qualitative) should be taken into the evaluation system as a first-level indicator. Wang & Jun (2015) and Zakeri & Keramati (2015) choose quantity flexibility, response speed, innovation capability, after-sales handling capability, service ability, customer satisfaction and other kinds of flexibility indicators to evaluate suppliers.

Table 3.2 The second-level indicator under flexibility

Indicators	Reference	Explanation
Response Speed (E1)	Fu-jiang, Ye-Zhuang & Xiao-lin (2006); Supply Chain Manager	assess the efficiency in completing the production orders, and the ability to follow the furniture consumption trend (designing products to meet the needs of consumers)
Innovation Ability (E2)	Ellram (1990); Supply Chain Manager	evaluate the R&D ability, technique innovation and new furniture design
Service Ability (E3)	Supply Chain Manager	evaluates whether the pre-sales and after-sales service capability of suppliers can satisfy consumers

3.1.3 Quality Indicator Selection

The primary consideration for consumers is still the quality of the furniture, so quality (quantitative) is indispensable in the evaluation indicator system as a first-level indicator. Hashim & Dawal (2012) suggest that furniture quality can be evaluated by surface smoothness, stability, material of the fabric, elasticity, structure, etc. Dickson (1966), Weber et al (1991) also regard quality as the primary evaluation criteria in many cases.

Table 3.3 The second-level indicator under quality

Indicators	Reference	Explanation
Quality Compliance Rate (A1)	Dickson (1966), Weber et al (1991), Quality Control Expert	quality compliance rate = the number of quality-standardized products in a given period/the total number of furniture products inspected in the same period*100%
Structural Compliance Rate (A2)	Hashim & Dawal (2012); Quality Control Expert	Structural compliance rate=the number of furniture structure-standardized products in a given period/the total number of products in the same batch and same period*100%
Transport Quality Compliance Rate (A3)	Quality Control Expert	Transport quality compliance rate=the number of intact products over long distances in a given period/the total number of furniture products in the same batch and same period*100%

3.1.4 Cost Indicator Selection

Many scholars also consider the cost as an indispensable evaluation indicator like that Dickson (1966) and Weber et al (1991) also regarded the price (cost) as one of the top three evaluation criteria, JA also takes cost as the primary factor in supplier evaluation. Thus, it saves cost (quantitative) as the first-level indicator into the green supplier evaluation indicator system.

Table 3.4 The second-level indicator under cost

Indicators	Reference	Explanation
Product Price (B1)	Dickson (1966), Weber et al (1991), Supply Chain Manager	The quotation
Transport Cost (B2)	Transport Expert	The average transport fee
Environmental Management Cost (B3)	Santos, Godoy and Campos (2019); Environmental Expert	The average investment of environmental management

3.1.5 Delivery Rate Indicator Selection

Because of the long production cycle of furniture products and the high relevance of the production chain, transport expert believes that delivery rate (quantitative) is a significant first-level evaluation indicator. Mangla, Kumar and Barua (2014) think the evaluation indicators of delivery should include on-time delivery rate, delivery cycle time and special orders completion rate.

Table 3.5 The second-level indicator under the deliver rate

Indicators	Reference	Explanation
On-time Delivery Rate (C1)	Dickson (1966), Weber et al (1991), Sonesson & Berlin (2003); Transport Expert	On-time delivery rate=the number of on-time deliveries in a given period/total number of deliveries in the same period*100%
Order Completion Rate (C2)	Sonesson & Berlin (2003); Transport Expert	Order completion rate=the number of orders completed on time by the supplier/the total number of orders by the supplier*100%
Special Order Completion Rate (C3)	Mangla, Kumar and Barua (2014); Transport Expert	Special order completion rate=the number of special orders completed on time by the supplier/the total number of special orders by the supplier*100%

3.1.6 Evaluation Indicator System

Referring to the suggestions from expert meeting and literatures on the supplier evaluation indicator, then this thesis finally utilises 5 first-level indicators including quality, cost, delivery rate, greenness and flexibility and 19 second-level indicators to establish an evaluation indicator system for the green furniture supplier.

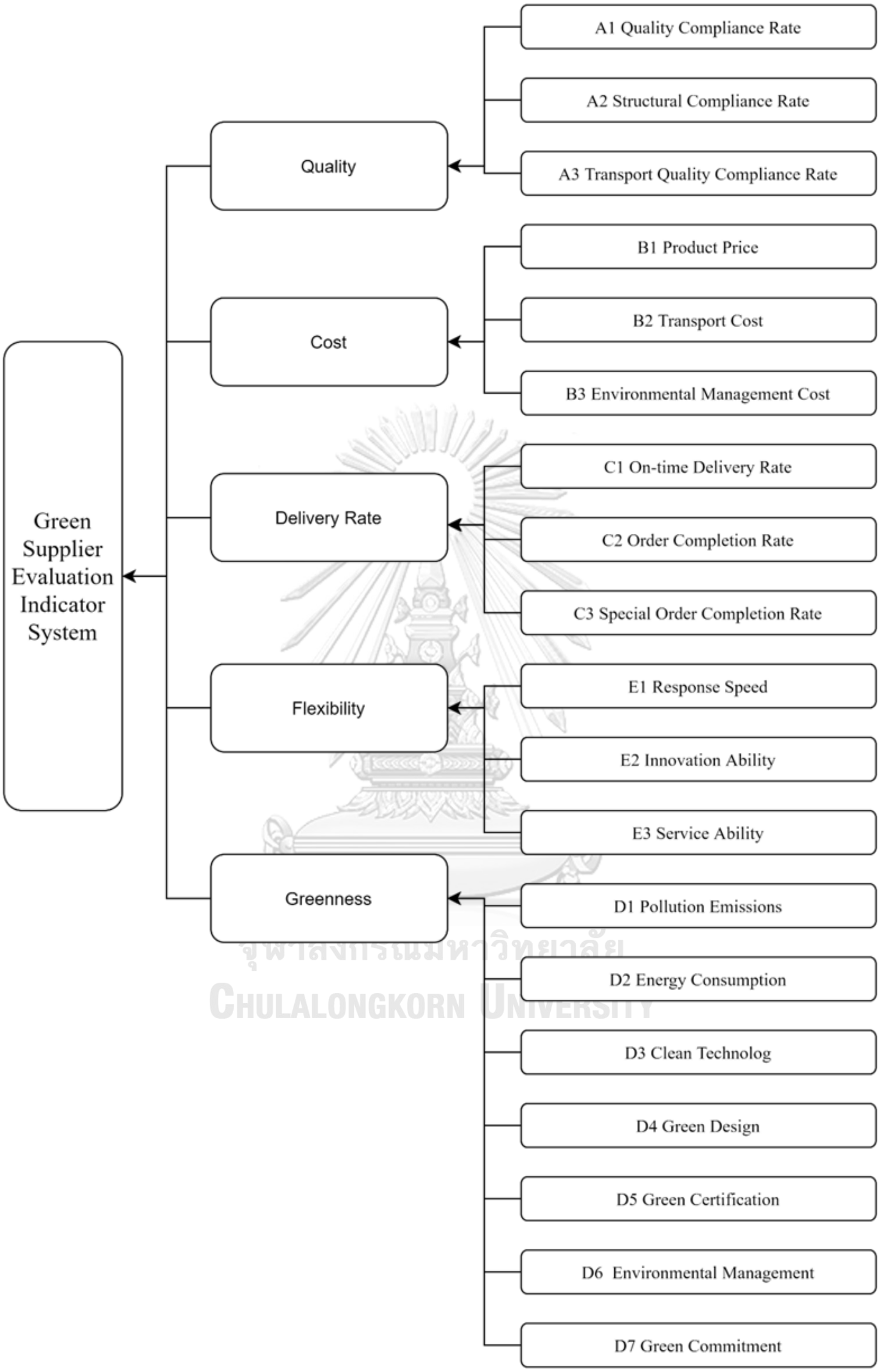

Figure 3.1 Green furniture supplier evaluation indicator system

3.2 Construction of Green Supplier Evaluation Model

Because different supplier evaluation methods apply different principles, a suitable evaluation method should consider the situation of the business operation and the evaluation scale. For example, if those middle-or-small companies adopt the complex evaluation model with various formula and vast data, which would lead to the waste of evaluation resource. The evaluation indicator system in this research adopts both quantitative and qualitative data, so the green supplier evaluation process is a multi-attribute decision problem under fuzzy conditions (Deng, Hu, et al, 2014). From previous researches on the supplier evaluation, the author finds that the combination of multiple evaluation methods can effectively solve the fuzzy nature of qualitative indicators and supplier ranking problems.

Entropy is usually used to describe an object's degree of disorder: the bigger the entropy, the greater the disorder and vice versa (Shannon, 1948), and it can also evaluate the orderliness of information and measure the order degree of the valid data too without the influence from subjective factors (Zou, Yun and Sun, 2006). Thus, the entropy theory is often used to determine the weight of quantitative indicators because of its high objectivity (Burillo and Bustince, 1996), and this dissertation will take it to determine the objective weight. Fuzzy-entropy combines fuzzy theory and entropy method to determine weights, which can process both subjective and objective indicators. Zhao & Guo (2014), Li, Zhang and Liu (2016) combine fuzzy theory (transforming the linguistic rating of the qualitative and quantitative indicators into fuzzy numbers) and the traditional entropy theory (calculating of entropy values of quantitative data to show the order degree with strong objectivity), so it considers both subjective and objective factors.

After the weight determination, the thesis needs to rank the green supplier in order to select the best green furniture supplier. The combination of the fuzzy theory and TOPSIS can solve fuzzy multi-objective decision-making problems like this case. Firstly, by the conversion rule from Zhao & Guo (2014), the evaluator will convert qualitative and quantitative evaluation data into triangular fuzzy numbers to construct a fuzzy evaluation matrix, then the evaluator will make the quantitative fuzzy number dimensionless and weight the dimensionless matrix to get a weighted matrix, and finally calculate the distance between each supplier and the positive and negative ideal solutions to rank suppliers. From the research of Gao & Zhang (2016), it can process various kinds of indicator like qualitative, quantitative, cost-based and benefit-based, and access any difference of supplier's performance, so this thesis will also adopt Fuzzy-TOPSIS to rank green suppliers. In conclusion, this thesis would take fuzzy-entropy to determine the comprehensive weight and fuzzy-TOPSIS to rank green suppliers.

In summary, this dissertation combines fuzzy set theory, entropy theory and TOPSIS to evaluate green supplier, specifically fuzzy-entropy to determine the objective and subjective weights then finally get the comprehensive weight, and TOPSIS to rank the green supplier by solving the matrices.

3.2.1 Fuzzy Set Theory

Text The fuzzy theory uses the membership grade of the fuzzy number to transform qualitative data into computable data, which can solve the uncertainty of the data (Gao and Zhang, 2016).

By defining the language set X through the membership function $u_{\tilde{a}}(x)$, any linguistic element x in the language set X can be mapped into the interval [0,1] through $u_{\tilde{a}}(x)$. In other words, the membership function can take any real number in [0,1] and use it to represent the corresponding linguistic evaluation. A triple can represent the triangular fuzzy numbers (Awasthi, Chauhan and Goyal, 2010): $\tilde{a} = [a^L, a^M, a^R]$ (as shown in Figure 3-1) and the function $\tilde{\mu}(x)$ as:

$$u_{\tilde{a}}(x) = \begin{cases} 0 & x < a^L \\ \dfrac{x - a^L}{a^M - a^L} & a^L \le x < a^M \\ \dfrac{a^R - x}{a^R - a^M}, & a^n \le x \le a^R \\ 0 & x > a^R \end{cases}$$

a^L, a^M, a^R are concrete real numbers and $-\infty < a^L \le a^M \le a^R < \infty$. When $x = a^M$, $u_{\tilde{a}}(x)$ achieves its maximum value and when $x = a^L$, $u_{\tilde{a}}(x)$ achieves its maximum value. a^L and a^R are the upper and lower bounds of the interval, respectively.

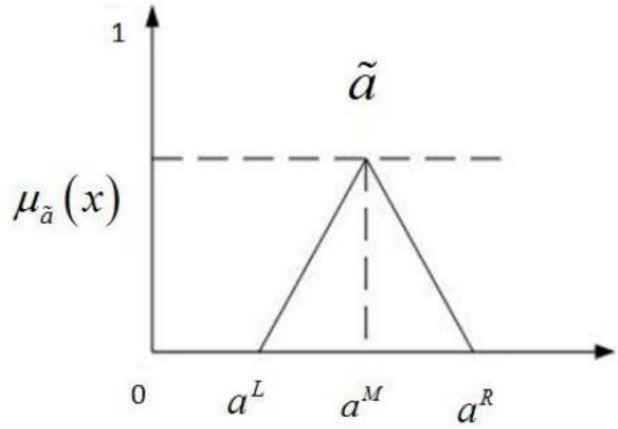

Figure 3.2 Triangular fuzzy number ã (Gao and Zhang, 2016)

Assume that there exist two trigonometric fuzzy numbers $\tilde{a} = [a^L, a^M, a^R]$, $\tilde{b} = [b^L, b^M, b^R]$ and the real number (λ), their operators:

1. $\tilde{a} \oplus \tilde{b} = (a^L + b^L, a^M + b^M, a^R + b^R)$
2. $\tilde{a} - \tilde{b} = (a^L - b^L, a^M - b^M, a^R - b^R)$
3. $\tilde{a} \otimes \tilde{b} \cong (a^L \times b^L, a^M \times b^M, a^R \times b^R), a^L \geq 0, b^L \geq 0$
4. $\tilde{a} \phi \tilde{b} \cong \left(\frac{a^L}{b^L}, \frac{a^M}{b^M}, \frac{a^R}{b^R}\right), a^L \geq 0, b^L \geq 0$
5. $\lambda \otimes \tilde{a} \cong (\lambda a^L, \lambda a^M, \lambda a^R), \lambda \geq 0$
6. $\lambda \phi \tilde{a} \cong (\lambda / a^R, \lambda / a^M, \lambda / a^L), \lambda \geq 0, a^L > 0$

3.2.2 Determine the weight of Indicator by Fuzzy-entropy

Make m green suppliers be A_i, r experts be D_j and n evaluation indicators (C_k for qualitative indicator and C_p for quantitative indicator). The steps of applying fuzzy-entropy to determine the weight are as follows.

Step 1: Establish the expert evaluation panel and the supplier evaluation indicator system. Based on JA's development needs and the performance of the supplier, the expert panel will rate the weights of first-level indicators and the second-level qualitative indicators.

Step 2: Set the triangular fuzzy numbers for each linguistic rating. In this thesis, the evaluation ratings for the first-level indicator weights are Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH), and the five corresponding triangular fuzzy numbers are (0, 0, 0.3), (0, 0.3, 0.5), (0.2, 0.5, 0.8), (0.5, 0.7, 1) and (0.7, 1, 1) according to the fuzzy number conversion rules from Zhao & Guo (2014).

Table 3.6 Linguistic ratings of the importance for the first-level indicator

Linguistic Rating	Abbreviations	Triangular Fuzzy Number
Very Low	VL	(0, 0, 0.3)
Low	L	(0, 0.3, 0.5)
Medium	M	(0.2, 0.5, 0.8)
High	H	(0.5, 0.7, 1)
Very High	VH	(0.7, 1, 1)

The linguistic ratings of the second-level qualitative indicators include Very Poor (VP), Poor (P), Fair (F), Good (G) and Very Good (VG), and the five corresponding triangular fuzzy numbers are (0, 0, 0.2), (0, 0.2, 0.4), (0.3, 0.5, 0.7), (0.6. 0.8, 1) and (0.8, 1, 1), according to the fuzzy number conversion rules from Zhao & Guo (2014).

Table 3.7 Linguistic ratings of the second-level qualitative indicator

Linguistic Rating	Abbreviations	Triangular Fuzzy Number
Very Low	VG	(0, 0, 0.3)
Low	G	(0, 0.3, 0.5)
Medium	F	(0.2, 0.5, 0.8)
High	P	(0.5, 0.7, 1)
Very High	VP	(0.7, 1, 1)

Step 3: Collect the importance rating from the expert for the first-level evaluation indicator. The triangular fuzzy number of the importance rating (C_l) from experts (D_j) is shown below:

$$\tilde{s}_{lj} = \left(s^{i}_{lj}, s^{M}_{lj}, s^{R}_{lj}\right), \quad 0 \le s^{i}_{lj} \le s^{m}_{lj} \le s^{R}_{lj} \le 1, l = 1,2,\dots,n, j = 1,2,\dots,r \quad (1)$$

average the triangular fuzzy number of the importance rating for each indicator as

$$\tilde{s}_l = \left(s^{L}_{l}, s^{M}_{l}, s^{R}_{l}\right)$$
$$\tilde{s}_l = \left(\frac{1}{r}\right) \otimes \left(\tilde{s}_{l1} \oplus \cdots \oplus \tilde{s}_{lj} \oplus \cdots \oplus \tilde{s}_{lr}\right) \quad (2)$$

Step 4: Calculate the subjective weight (u_1). This thesis takes the Graded Mean Integration Representation (GMIR) proposed by Chen (2000) to defuzzify the triangular fuzzy number, set as $R(\tilde{s}_1)$:

$$R(\tilde{s}_l) = \frac{l^{l}_{l} + 4l^{4}_{l} + l^{n}_{l}}{6} \quad (3)$$

Thus, the subjective weight of each indicator u_l is calculated as:

$$u_l = \frac{R(s_l)}{\sum_{l=1}^{n} R(\tilde{s}_l)}, l = 1, 2, \dots, n \quad (4)$$

Step 5: Calculate the objective weight (λ_p) of the quantitative indicator (C_P). The objective weight is determined by the entropy of quantitative data. The green supplier's (A_i) the triangular fuzzy number of the quantitative indicator (C_P) is expressed below:

$$\tilde{a}_{ip} = (a_{ip}^L, a_{ip}^M, a_{ip}^R), i = 1,2,\dots,m: p = 1,2,\dots,q \tag{5}$$

defuzzify the triangular fuzzy number, and for computational convenience, setting

$$h_{ip} = R(\tilde{a}_{ip}) \tag{6}$$

and then obtain the evaluation matrix $H= [h_{ip}]_{m\times q}$. (7)

Set the entropy of quantitative indicator as e_p with the equation as below:

$$e_p = -\frac{1}{ln\, m}\sum_{i=1}^{m} \frac{h_{ip}}{H_p} ln\frac{h_{ip}}{H_p}, i = 1,2,\dots,m; p = 1,2,\dots,q \tag{8}$$

Set the objective weight as λ_p, with the equation as below:

$$\lambda_p = \frac{1-e_p}{p-\sum_{p=1}^{q} e_p}, p = 1,2,\dots,q; 0 \le \lambda_p \le 1, \quad \sum_{p=1}^{4} \lambda_p = 1 \tag{9}$$

Step 6: Calculate the comprehensive weight of the quantitative evaluation indicators (z_p). Let the subjective weight of the quantitative indicators derived be u_p, and for ease of calculation let o_p be:

$$z_p = \left[\frac{\lambda_p \times o_p}{\sum_{p=1}^{q}(\lambda_p \times o_p)}\right] \times \left(\sum_{p=1}^{q} u_p\right) \tag{10}$$

Step 7: Calculate the comprehensive weight of the qualitative evaluation indicators (z_k). Set comprehensive weight of the qualitative indicators as z_k:

$$z_p = \frac{R(\tilde{s}_k)}{\sum_{k=1}^{t} R(\tilde{s}_k)}, k = 1, 2, \dots, t. \tag{11}$$

3.2.3 Rank Green Suppliers by TOPSIS

After the weight determination, the author will use TOPSIS to rank the green suppliers and finally select the optimum one. According to the research on TOPSIS from Khalili-Damghani, Sadi-Nezhad and Tavana (2013), the specific calculation process is as follows:

Step 1: Collect the linguistic rating of the qualitative indicator (C_k) from experts (D_j) for each furniture green supplier (A_i) and set the triangular fuzzy number as below:

$$\tilde{a}_{ikj} = (a_{ikj}^L, a_{ikj}^M, a_{ikj}^R), 0 \leq a_{ikj}^L \leq a_{ikj}^M \leq a_{ikj}^R \leq 1 \tag{12}$$

average the triangular fuzzy number of the ratings from experts, and set

$\tilde{a}_{ik} = (a_{ik}^L, a_{ik}^M, a_{ik}^R)$ as follow: (13)

$$\tilde{a}_{ik} = \left(\frac{1}{r}\right) \otimes (\tilde{a}_{ik1} \oplus \cdots \oplus \tilde{a}_{ikj} \oplus \cdots \oplus \tilde{a}_{ikr}), i = 1,2, \dots, m;\ k = 1,2, \dots, t; j = 1,2, \dots, r$$

Step 2: Construct the initial evaluation matrix of suppliers (Ai). Collect the initial evaluation fuzzy numbers $(\tilde{a}_{il})$ of the evaluation indicator (C_l) for each green supplier (Ai) and construct the initial evaluation matrix A:A $= (\tilde{a}_{il})_{m\times n}$, ($m$ is the number of suppliers and n is the number of evaluation indicators):

$$A = (\tilde{a}_{il})_{m\times n} = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{a}_{m1} & \tilde{a}_{m2} & \cdots & \tilde{a}_{mn} \end{bmatrix} \tag{14}$$

$$= \begin{bmatrix} (a_{11}^2, & a_{11}^M, & a_{11}^R) & (a_{12}^L, & a_{12}^M, & a_{12}^R) \cdots & (a_{1n}^L, & a_{1n}^M, & a_{1n}^R) \\ (a_{21}^2, & a_{21}^M, & a_{21}^R) & (a_{22}^2, & a_{22}^M, & a_{22}^R) \cdots & (a_{2n}^L, & a_{2n}^M, & a_{2n}^R) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \ \cdots & \vdots & \vdots & \vdots \\ (a_{m1}^2, & a_{m1}^M, & a_{m1}^R) & (a_{m2}^L, & a_{m2}^M, & a_{m2}^R) \cdots & (a_{mn}^L, & a_{mn}^M, & a_{mn}^R \end{bmatrix}$$

Step 3: Construct a standardised supplier evaluation matrix (B). The author needs to make data under quantitative indicators dimensionless to ensure compatibility between the quantitative and qualitative data. According to the literature of Khalili-Damghani, Sadi-Nezhad and Tavana (2013), the standardisation process involves distinguishing the quantitative benefit-based indicator and the quantitative cost-based indicator (The larger the former is, the better, while the smaller the latter is, the better). Furthermore, the triangular fuzzy number of the quantitative indicator (C_P) for each supplier (Ai) is shown as:

$$\tilde{a}_{ip} = (a_{ip}^L, a_{ip}^M, a_{ip}^R), i = 1,2, \dots, m: p = 1,2, \dots, q \tag{15}$$

The maximum triangular fuzzy number (t_P) of benefit-based indicators is:

$$t_P = \max_i \{a_{ip}^R\} \tag{16}$$

Thus, the standardised triangular fuzzy number ($\widetilde{\mathrm{b}}_{\mathrm{iP}}$) of the benefit-based indicator for each supplier (Ai) as:

$$\widetilde{b}_{ip} = \left(a_{ip}^{L}/t_p,\ \ a_{ip}^{M}/t_p,\ \ a_{ip}^{R}/t_p\right) \tag{17}$$

The minimum triangular fuzzy number ($\mathrm{c_P}$) of the cost-based indicator is:

$$c_P = \max_i\{a_{ip}^{L}\} \tag{18}$$

Set the standardized triangular fuzzy number of the cost-based indicator for each supplier (Ai) as $\widetilde{b}_{ij}$:

$$\widetilde{b}_{ip} = \left(c_p/a_{ip}^{R},\ \ c_p/a_{ip}^{M},\ \ c_p/a_{ip}^{L}\right) \tag{19}$$

make the triangular fuzzy number of the quantitative indicator dimensionless, the author needs to collect all standardised fuzzy numbers to construct standardized metrix $B = \left(\widetilde{b}_i\right)_{n\times m}$, ($m$ is the number of suppliers and n is the number of evaluation indicators):

$$B = \left(\tilde{b}_{ij}\right)_{m\times n} = \begin{bmatrix} \tilde{b}_{11} & \tilde{b}_{12} & \dots & \tilde{b}_{1n} \\ \tilde{b}_{21} & \tilde{b}_{22} & \cdots & \tilde{b}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{b}_{m1} & \tilde{b}_{m2} & \cdots & \tilde{b}_{mn} \end{bmatrix} \tag{20}$$

$$= \begin{bmatrix} (b_{11}^{L}, & b_{11}^{M}, & b_{11}^{R}) & (b_{12}^{L}, & b_{12}^{M}, & b_{12}^{R}) \cdots & (b_{1n}^{L}, & b_{1n}^{M}, & b_{1n}^{R}) \\ (b_{21}^{L}, & b_{21}^{M}, & b_{21}^{R}) & (b_{22}^{2}, & b_{22}^{M}, & b_{22}^{R}) \cdots & (b_{2n}^{L}, & b_{2n}^{M}, & b_{2n}^{R}) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \ \cdots & \vdots & \vdots & \vdots \\ (b_{m1}^{L}, & b_{m1}^{M}, & b_{m1}^{R}) & (b_{m2}^{L}, & b_{m2}^{M}, & b_{m2}^{R}) \cdots & (b_{mn}^{L}, & b_{mn}^{M}, & b_{mn}^{R} \end{bmatrix}$$

Step 4: Construct the weighted evaluation matrix (C). The comprehensive weight (z_n) times the standardised evaluation matrix (B) to obtain the weighted standardised evaluation matrix ($C = (c_{il})_{n\times m}$, m is the number of green suppliers and n is the number of evaluation indicators):

$$C = \left(\tilde{c}_{ij}\right)_{m\times n} = \begin{bmatrix} w_1\tilde{b}_{11} & w_2\tilde{b}_{12} & \dots & w_3\tilde{b}_{1n} \\ w_1\tilde{b}_{21} & w_2\tilde{b}_{22} & \cdots & w_3\tilde{b}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ w_1\tilde{b}_{m1} & w_2\tilde{b}_{m2} & \cdots & w_3\tilde{b}_{mn} \end{bmatrix} \tag{21}$$

$$= \begin{bmatrix} w_1 \times (b_{11}^{L}, & b_{11}^{M}, & b_{11}^{R}) & w_2 \times (b_{12}^{L}, & b_{12}^{M}, & b_{12}^{R}) \cdots & w_3 \times (b_{1n}^{L}, & b_{1n}^{M}, & b_{1n}^{R}) \\ w_1 \times (b_{21}^{L}, & b_{21}^{M}, & b_{21}^{R}) & w_2 \times (b_{22}^{2}, & b_{22}^{M}, & b_{22}^{R}) \cdots & w_3 \times (b_{2n}^{L}, & b_{2n}^{M}, & b_{2n}^{R}) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \ \cdots & \vdots & \vdots & \vdots \\ w_1 \times (b_{m1}^{L}, & b_{m1}^{M}, & b_{m1}^{R}) & w_2 \times (b_{m2}^{L}, & b_{m2}^{M}, & b_{m2}^{R}) \cdots & w_3 \times (b_{mn}^{L}, & b_{mn}^{M}, & b_{mn}^{R} \end{bmatrix}$$

Step 5: Confirm the fuzzy positive and fuzzy negative ideal solutions. According to Chen (2000), the author will set the positive solution (C^{+}) as $\widetilde{c_s^{+}}$ and the negative solution (C^{-}) as $\widetilde{c_s^{-}}$ (J_1 is the benefit-based indicator and J_2 is the cost-based indicator):

$$\begin{cases} C^{+} = \left(\widetilde{c_s^{+}}\right) = \left\{\left(\max_i c_{ij} \mid j \in J_1\right), \left(\min_i c_{ij} \mid j \in J_2\right)\right\} \\ C^{-} = \left(\tilde{c}_s^{-}\right) = \left\{\left(\min_i c_{ij} \mid j \in J_1\right), \left(\max_i c_{ij} \mid j \in J_2\right)\right\} \end{cases} \tag{22}$$

Step 6: Calculate the distance between each supplier and the positive and negative ideal solutions. According to Chen (2000), the author will set the distance between two fuzzy numbers $\tilde{a}i$ and $\tilde{a}j$ as d ($\tilde{a}i$, $\tilde{a}j$), which is calculated as follows:

$$d(\tilde{a}_i, \quad \tilde{a}_j) = \left\{\left[\left(a_i^L - a_j^L\right)^2 + 2\left(a_i^M - a_j^M\right)^2 + \left(a_i^R - a_j^R\right)^2\right]/4\right\}^{1/2} \tag{23}$$

the distance between supplier (Ai) and positive solution (d_i^{+}) as:

$$d_i^{+} = \left\{\sum_{k=1}^{n} \left\{\left\{\left[\left(c_{ik}^{2} - c_k^{+L}\right)^2 + 2\left(c_{ik}^{M} - c_k^{+M}\right)^2 + \left(c_{ik}^{R} - c_k^{+R}\right)^2\right]/4\right\}^{1/2}\right\}^2\right\}^{1/2} \tag{24}$$

the distance between supplier (Ai) and negative solution (d_i^{-})

$$d_i^{-} = \left\{\sum_{k=1}^{n} \left\{\left\{\left[\left(c_{ik}^{L} - c_k^{-L}\right)^2 + 2\left(c_{ik}^{M} - c_k^{-M}\right)^2 + \left(c_{ik}^{R} - c_k^{-R}\right)^2\right]/4\right\}^{1/2}\right\}^2\right\}^{1/2}$$

Step 7: Calculate the closeness degree (CCi) for each green supplier (Ai). The closeness degree (CCi) can express both the distance of the green supplier from the fuzzy positive ideal solution (C+) and the fuzzy negative ideal solution (C-), (1≥CCi≥0) as:

$$CC_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \tag{25}$$

Step 8: Rank green suppliers (Ai). The author needs to rank the furniture green suppliers in descending order according their closeness degree and the best supplier is with the largest closeness degree (CCi).

3.2.4 The Application Procedure of fuzzy-entropy-TOPSIS

Stage 1: This part is majorly for the preparation of green supplier evaluation. Firstly, the company should select the suitable experts to form an evaluation panel to collect the existing supplier evaluation problems, the suggestion of evaluation indicator selection and screen suitable suppliers participating evaluation by reviewing the tender document; then, the evaluator needs to construct a green supplier evaluation indicator system based on the expert's suggestion and the literature review. Thirdly, experts fill the evaluation questionnaire by reviewing participating suppliers' documents to provide evaluation data including the linguistic rating of the indicator's importance, second-level qualitative indicators and the data of second-level quantitative indicators.

Stage 2: This stage is to determine the comprehensive weight of each first-level indicator. Firstly, the evaluator will convert all evaluation data into triangular fuzzy numbers according to the conversion rule (Zhao & Guo 2014); then process the linguistic ratings of importance for each first-level indicator's importance to get the subjective weight; thirdly, work the entropy of quantitative indicators out to get the objective weight; finally, consider both subjective and objective weights to determine the comprehensive weight for the quantitative indicator, and adjust the subjective weight of qualitative indicators to get their comprehensive weight.

Stage 3: The final phase is to rank the supplier by TOPSIS. First of all, the evaluator should construct an initial evaluation matrix by the evaluation data, then make it dimensionless to standardise the difference between qualitative and quantitative indicators, then weight standardised matrix; find the fuzzy positive and negative solutions and calculate the distance between each supplier and the solutions to rank green suppliers and final the optimum one.

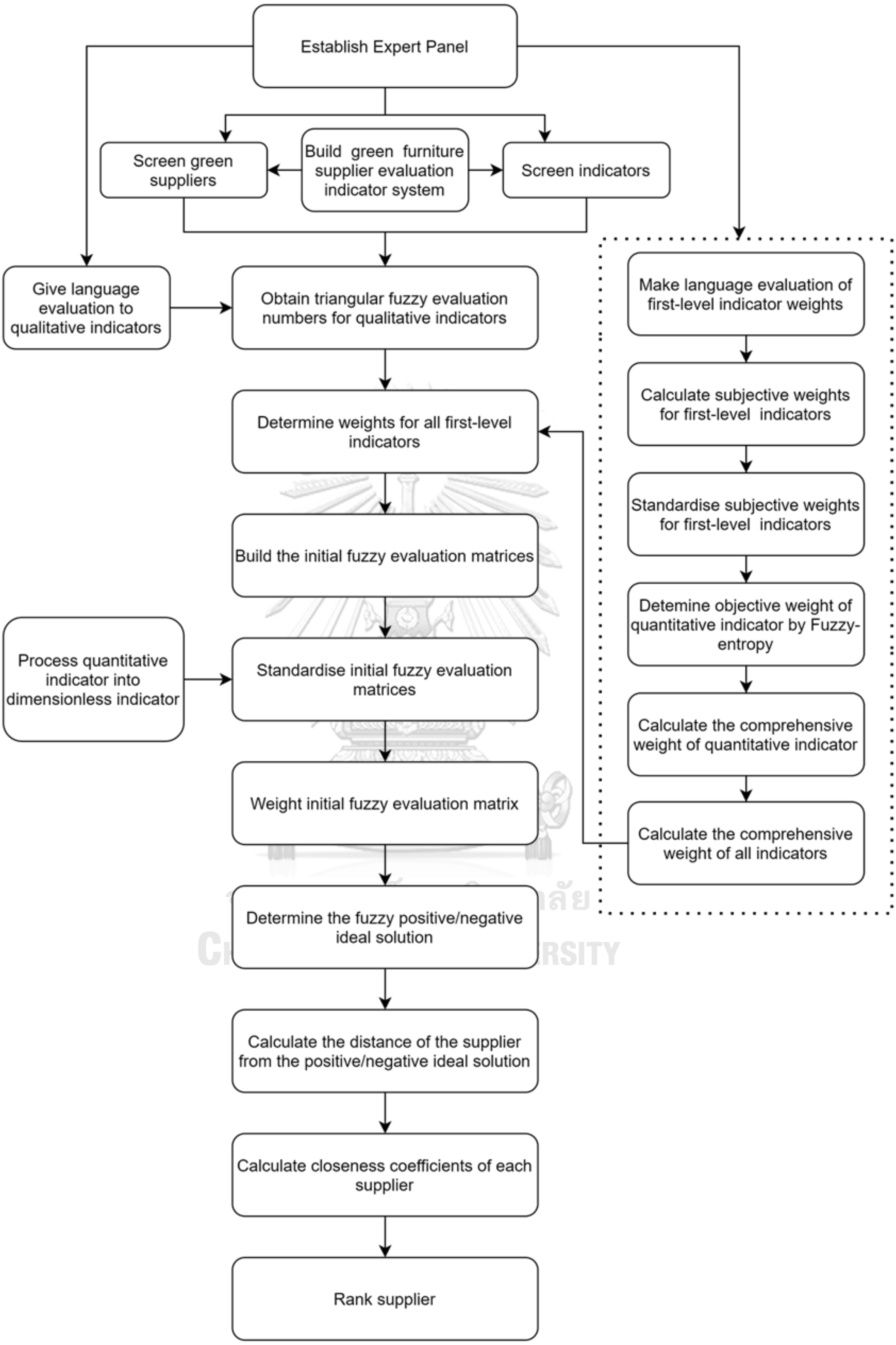

Figure 3.3 The evaluation process of fuzzy-entropy-TOPSIS (Zhao & Guo, 2014)

CHAPTER 4
THE CASE STUDY

4.1 Introduce the Background of Green Supplier Evaluation

JA Company received a furniture order from a kindergarten in July 2021 for 5,000 sets of study furniture within the due time of 3 months. JA needed to select a suitable green furniture supplier with two requirements, including the ability to deliver within 80 days and guaranteeing the greenness of the product (formaldehyde and heavy metal content must be tested by professional institutions to the meet national standard). 13 suppliers submitted their bids with full documents, and finally three suppliers (S1, S2, S3) with generally good performance were selected to be evaluated as the first case study to illustrate the application details of fuzzy-entropy-TOPSIS, then the rest will be evaluated too as the second case study for the further approval of practicability.

4.2 Form Expert Panel

The author invites four experts from the JA company and the environmental institution, including the supply chain manager, quality controller, transport coordinator and environmental expert to form an expert panel and hold expert meetings to discuss problems in the original evaluation process, to obtain advice on the selection of evaluation indicators and comment the effects of the evaluation result. In addition, they also need to fill in the Supplier Evaluation Questionnaire (rating the importance of each indicator and qualitative indicators, and providing the data for quantitative indicators) in the **Appendix A** with the following background on the four experts.

1. Supply Chain Manager: the manager of the supply chain department has responsibilities with ten-year working experience including supplier management, developing supply plans for production raw materials and products, arranging procurement plans, developing supply chain management and development strategies, etc.
2. Quality Controller: quality expert with four-year working experience in the quality management department has responsibilities including arranging sample acceptance plans, field visits to product, sampling production materials, reviewing product inspection certificates, etc.

3. Transport Coordinator: the transport coordinator with five-year working experience in the transport department has main responsibilities including arranging transport plans, finding suitable transport vehicles, controlling transport costs, tracking logistics information, drawing up transport documents, etc.
4. Environmental expert: a staff member with seven-year working experience in the Public Environmental Department has the main duties including monitoring the emissions from manufacturers, auditing the production qualifications, randomly inspecting production environment, sampling the waste generated by production, penalising non-compliant production, etc.

4.3 Process the rating of each indicator's importance

The expert panel rates the importance of the evaluation indicator to determine the subjective weight by the supplier evaluation questionnaire (**Appendix A**). The linguistic weight ratings include Very Low (VL), Low (L), Medium (Medium), High (H) and Very High (VH), and the rating result is shown in **Table 4.1**.

Table 4.1 Importance linguistic ratings for each first-level indicator

	Expert 1	Expert 2	Expert 3	Expert 4
I_1	M	H	M	H
I_2	M	L	L	H
I_3	H	H	M	M
I_4	L	M	M	H
I_5	H	M	H	L

The conversion rule (**Table 3.6**) will transform the linguistic rating into the triangular fuzzy number. For example, an expert evaluates the quality with as "H" whose triangular fuzzy number is (0.5,0.7,1). By analogy, all the linguistic ratings and the corresponding triangular fuzzy numbers are shown in **Table 4.2**.

Table 4.2 Triangular fuzzy numbers of importance linguistic ratings

	Expert 1	**Expert 2**	**Expert 3**	**Expert 4**
I_1	(0.2,0.5,0.8)	(0.5,0.7,1.0)	(0.2,0.5,0.8)	(0.7,1.0,1.0)
I_2	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.5,0.7,1.0)
I_3	(0.2,0.5,0.8)	(0.5,0.7,1.0)	(0,0.3,0.5)	(0.2,0.5,0.8)
I_4	(0.5,0.7,1.0)	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.5,0.7,1.0)
I_5	(0.2,0.5,0.8)	(0.2,0.5,0.8)	(0.5,0.7,1.0)	(0,0.3,0.5)

1. Set averaged triangular fuzzy numbers of the quality indicator (I_1) as $\tilde{s}_1 = (l_1^L, l_1^M, l_1^R)$ **:**

$l_1^L = \frac{1}{4} \times (0.2 + 0.5 + 0.2 + 0.7) = 0.400$

$l_1^M = \frac{1}{4} \times (0.5 + 0.7 + 0.5 + 1.0) = 0.675$

$l_1^R = \frac{1}{4} \times (0.8 + 1.0 + 0.8 + 1.0) = 0.900$

Then obtain $\tilde{s}_1 = \left(l_1^L, l_1^M, l_1^R\right) = (0.400, 0.675, 0.900)$**.**

2. Set averaged triangular fuzzy numbers of the cost indicator (I_2) as $\tilde{s}_2 = (l_2^L, l_2^M, l_2^R)$**:**

$$l_2^L = \frac{1}{4} \times (0.2 + 0.2 + 0.2 + 0.5) = 0.275$$

$$l_2^M = \frac{1}{4} \times (0.5 + 0.5 + 0.5 + 0.7) = 0.550$$

$$l_2^R = \frac{1}{4} \times (0.8 + 0.8 + 0.8 + 1.0) = 0.850$$

Then obtain $\tilde{s}_2 = \left(l_2^L, l_2^M, l_2^R\right) = (0.275, 0.550, 0.850)$.

3. Set averaged triangular fuzzy numbers of the delivery rate indicator (I_3) as $\tilde{s}_3 = (l_3^L, l_3^M, l_3^R)$:

$$l_3^l = \frac{1}{4} \times (0.2 + 0.5 + 0 + 0.2) = 0.225$$

$$l_3^M = \frac{1}{4} \times (0.5 + 0.7 + 0.3 + 0.5) = 0.500$$

$$l_3^R = \frac{1}{4} \times (0.8 + 1.0 + 0.5 + 0.8) = 0.775$$

Then obtain $\tilde{s}_3 = (l_3^L, l_3^M, l_3^R) = (0.225, 0.500, 0.775)$.

4. Set averaged triangular fuzzy numbers of the greenness indicator (I_4) as $\tilde{s}_4 = (l_4^L, l_4^M, l_4^R)$:

$$l_4^L = \frac{1}{4} \times (0.5 + 0.2 + 0.2 + 0.5) = 0.350$$

$$l_4^M = \frac{1}{4} \times (0.7 + 0.5 + 0.5 + 0.7) = 0.600$$

$$l_4^R = \frac{1}{4} \times (1.0 + 0.8 + 0.8 + 1.0) = 0.900$$

Then obtain $\tilde{s}_4 = \left(l_4^L, l_4^M, l_4^R\right) = (0.350, 0.600, 0.900)$.

5. Set averaged triangular fuzzy numbers of the flexibility indicator (I_5) as $\tilde{s}_5 = \left(l_5^L, l_5^M, l_5^R\right)$:

$$l_5^L = \frac{1}{4} \times (0.2 + 0.2 + 0.5 + 0) = 0.225$$

$$l_5^M = \frac{1}{4} \times (0.5 + 0.5 + 0.7 + 0.3) = 0.500$$

$$l_5^R = \frac{1}{4} \times (0.8 + 0.8 + 1.0 + 0.5) = 0.775$$

Then obtain $\tilde{s}_5 = \left(l_5^L, l_5^M, l_5^R\right) = (0.225,0.500,0.775)$.

Table 4.3 The averaged triangular fuzzy number of the importance for each first-level indicator

Evaluation Indicator	Average Triangular Fuzzy Number
I_1	(0.400,0.675,0.900)
I_2	(0.275,0.550,0.850)
I_3	(0.225,0.500,0.775)
I_4	(0.350,0.600,0.900)
I_5	(0.225,0.500,0.775)

4.4 Process evaluation data

The expert panel fills the supplier evaluation questionnaire (**Appendix A**) to provide evaluation data for all indicators, including quality (I_1), cost (I_2), delivery rate (I_3), greenness (I_4) and greenness (I_5).

Collect data on quantitative indicators for each supplier, including quality (I_1), cost (I_2) and delivery rate (I_3). The experts review the bidding documents and historical records to get the evaluation data. Because the data should be converted into triangular fuzzy numbers, according to the conversion method of Zhao & Guo (2014), the middle number is the exact data, while the triangular fuzzy numbers on either side are taken as its approximation. For example, the triangular fuzzy number of 30 is (29, 30, 31.2). The Quality Expert will provide data for the second-level indicators under quality, including Quality Compliance Rate, Structural Compliance Rate and Transport Quality Compliance Rate, then the author will take the average for each supplier as the evaluation data of the first-level quality indicator (I_1), as shown in **Table 4.4**.

Table 4.4 The evaluation data of quality indicator

	Quality Compliance Rate (%)	Structural Compliance Rate (%)	Transport Quality Compliance Rate (%)	Average (%)	Triangular Fuzzy Evaluation Number
S1	93.6	97.3	94.1	95	(93,95,95.4)
S2	92	83	89	88	(85,88,91)
S3	91	93.6	94.4	93	(91,93,96)

The Supply Chain Expert will provide data for the second-level indicator under cost, including Product Prices, Transport Cost and Environmental Management Cost, and then the author will take the summation of the second-level indicator under cost for each green supplier as the evaluation data for the first-level cost indicator (I_2), as shown in **Table 4.5**.

Table 4.5 The evaluation data of cost indicator

	Product Prices (ten thousand CNY)	Transport Cost (ten thousand CNY)	Environmental Management Cost (ten thousand CNY)	Summation	Triangular Fuzzy Evaluation Number
S1	363.7	7.8	28.9	406	(400,406,410)
S2	381.8	8.6	26.6	417	(412,417,425)
S3	360	7.4	30.6	398	(395,398,405)

The Transport Expert will provide data for the second-level indicators under the delivery rate, including On-time Delivery Rate,Order Completion Rate and Special Order Completion Rate, and then the author will take the average of the second-level indicators under delivery rate for each supplier as the evaluation data for the first-level indicator of delivery rate (I_3), as shown in **Table 4.6**.

Table 4.6 The evaluation data of the delivery rate

	On-time Delivery Rate (%)	Order Completion Rate (%)	Special Order Completion Rate (%)	Average (%)	Triangular Fuzzy Evaluation Number
S1	97	98	93	96	(95,96,97)
S2	96.6	97.2	88.2	94	(93,94,95)
S3	99	98.3	96.7	98	(97,98,99)

According to the conversion rule (**Table 3.7**) of the triangular fuzzy number, the author needs to convert the linguistic evaluation data into the corresponding fuzzy triangular numbers. For example, an expert evaluates Supplier S1 with a greenness of "Fair", which corresponds to a triangular fuzzy number of (0.3,0.5,0.7). Following the rule, the triangular fuzzy number of the greenness evaluation result is shown in **Table 4.7**.

1. Set the averaged triangular fuzzy numbers of supplier S1 under greenness indicator as $\tilde{a}_{14} = (a_{14}^L, a_{14}^M, a_{14}^R)$:

a_{14}^L=$\frac{1}{4} \times (0 + 0.6 + 0.6 + 0.3)$=0.375

a_{14}^M=$\frac{1}{4} \times (0 + 0.8 + 0.8 + 0.5)$=0.525

a_{14}^R=$\frac{1}{4} \times (0.2 + 1.0 + 1.0 + 0.7)$=0.725

Thus, obtain $\tilde{a}_{14} = \left(a_{14}^L, a_{14}^M, a_{14}^R\right) = (0.375, 0.525, 0.775)$.

2. Set the averaged triangular fuzzy numbers of supplier S2 under greenness indicator as $\tilde{a}_{24} = (a_{24}^L, a_{24}^M, a_{24}^R)$:

$$a_{24}^L = \frac{1}{4} \times (0.3 + 0.6 + 0.3 + 0.6) = 0.45$$

$$a_{24}^M = \frac{1}{4} \times (0.5 + 0.8 + 0.5 + 0.8) = 0.65$$

$$a_{24}^R = \frac{1}{4} \times (0.7 + 1.0 + 0.7 + 1.0) = 0.85$$

Thus, obtain $\tilde{a}_{24} = \left(a_{24}^L, a_{24}^M, a_{24}^R\right) = (0.45, 0.65, 0.85)$

3. Set the averaged triangular fuzzy numbers of supplier S3 under greenness indicator as $\tilde{a}_{34} = (a_{34}^L, a_{34}^M, a_{34}^R)$:

$$a_{34}^L = \frac{1}{4} \times (0.6 + 0.3 + 0 + 0.3) = 0.3$$

$$a_{34}^M = \frac{1}{4} \times (0.8 + 0.5 + 0 + 0.5) = 0.45$$

$$a_{34}^R = \frac{1}{4} \times (1.0 + 0.7 + 0.2 + 0.7) = 0.65$$

Thus, obtain $\left(a_{34}^L, a_{34}^M, a_{34}^R\right) = (0.300, 0.450, 0.650)$.

Table 4.7 The triangular fuzzy number of the evaluation data under greenness

Supplier	Average Weighted Fuzzy Number
S1	(0.375,0.525,0.725)
S2	(0.450,0.650,0.850)
S3	(0.300,0.450,0.650)

Next, the linguistic rating of the flexibility indicator for three suppliers is shown as the **Table 4.8.**

Table 4.8 The linguistic rating of the flexibility

I_5	Expert 1	Expert 2	Expert 3	Expert 4
S1	G	G	F	F
S2	G	F	F	F
S3	F	F	P	G

The conversion rule is the same as the steps of process greenness indicator, so the triangular fuzzy number of the flexibility for all supplier are shown in **Table 4.9**.

Table 4.9 The triangular fuzzy number of the evaluation data under flexibility

I_5	Expert 1	Expert 2	Expert 3	Expert 4
S1	(0.6,0.8,1.0)	(0.6,0.8,1.0)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
S2	(0.6,0.8,1.0)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
S3	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0,0,0.2)	(0.6,0.8,1.0)

1. Set the averaged triangular fuzzy numbers of supplier S1 under flexibility indicator as $\tilde{a}_{15} = \left(a_{15}^{L}, a_{15}^{M}, a_{15}^{R}\right)$:

$a_{15}^{L}=\frac{1}{4} \times (0.6 + 0.6 + 0.3 + 0.3)=0.450$

$a_{15}^{M}=\frac{1}{4} \times (0.8 + 0.8 + 0.5 + 0.7)=0.650$

$a_{15}^{R}=\frac{1}{4} \times (1.0 + 1.0 + 0.7 + 0.7)=0.850$

Thus, obtain $\tilde{a}_{15} = \left(a_{15}^{L}, a_{15}^{M}, a_{15}^{R}\right) = (0.450,0.650,0.850)$.

2. Set the averaged triangular fuzzy numbers of supplier S2 under flexibility indicator as $\tilde{a}_{15} = \left(a_{15}^{L}, a_{15}^{M}, a_{15}^{R}\right)$:

$$a_{25}^{2} = \frac{1}{4} \times (0.6 + 0.3 + 0.3 + 0.3) = 0.375$$

$$a_{25}^{M} = \frac{1}{4} \times (0.8 + 0.5 + 0.5 + 0.5) = 0.575$$

$$a_{25}^{R} = \frac{1}{4} \times (1.0 + 0.7 + 0.5 + 0.7) = 0.725$$

Thus, obtain $\tilde{a}_{25} = \left(a_{25}^{L}, a_{25}^{M}, a_{25}^{R}\right) = (0.375,0.575,0.725)$.

3. Set the averaged triangular fuzzy numbers of supplier S3 under flexibility indicator as $\tilde{a}_{15} = \left(a_{15}^{L}, a_{15}^{M}, a_{15}^{R}\right)$:

$$a_{35}^{l} = \frac{1}{4} \times (0.3 + 0.3 + 0 + 0.6) = 0.300$$

$$a_{35}^{M} = \frac{1}{4} \times (0.5 + 0.5 + 0 + 0.8) = 0.450$$

$$a_{35}^{R} = \frac{1}{4} \times (0.7 + 0.7 + 0.2 + 1.0) = 0.650$$

Thus, obtain $\tilde{a}_{35} = \left(a_{35}^{l}, a_{35}^{M}, a_{35}^{R}\right) = (0.300,0.450,0.650)$.

Table 4.10 The triangular fuzzy number of the evaluation data under flexibility

Supplier	Average Weighted Fuzzy Number
S1	(0.450,0.650,0.850)
S2	(0.375,0.575,0.775)
S3	(0.300,0.450,0.650)

Table 4.11 The triangular fuzzy number of all evaluation data

	I_1	I_2	I_3	I_4	I_5
S1	(93,95,95.4)	(400,406,410)	(95,96,97)	(0.375,0.525,0.725)	(0.450,0.650,0.850)
S2	(85,88,91)	(412,417,425)	(93,94,95)	(0.450,0.650,0.850)	(0.375,0.575,0.775)
S3	(91,93,96)	(395,398,405)	(97,98,99)	(0.300,0.450,0.650)	(0.300,0.450,0.650)

4.5 Calculate the comprehensive weight of each indicator by Fuzzy-entropy

After collecting all the evaluation data from experts, Fuzzy-entropy will process it to get the weight. The first three steps are about collecting the importance of each indicator from experts, which has now been completed available in **Table 4.3**, so the procedure can be carried out from **Step 4**.

Step 4: Calculate the subjective weights of the evaluation indicators (u_l). The author will defuzzify the triangular fuzzy number of the importance for each indicator.

1. Set the fuzzy weight value of quality indicator as $R(\tilde{s}_1)$:

$$R(\tilde{s}_1) = \frac{0.400 + 4 \times 0.675 + 0.900}{6} = 0.6667$$

2. Set the fuzzy weight value of cost indicator as $R(\tilde{s}_2)$:

$$R(\tilde{s}_2) = \frac{0.275 + 4 \times 0.550 + 0.850}{6} = 0.5542$$

3. Set the fuzzy weight value of delivery rate indicator as $R(\tilde{s}_3)$:

$$R(\tilde{s}_3) = \frac{0.225 + 4 \times 0.500 + 0.775}{6} = 0.5000$$

4. Set the fuzzy weight value of greenness indicator as $R(\tilde{s}_4)$:

$$R(\tilde{s}_4) = \frac{0.350 + 4 \times 0.600 + 0.900}{6} = 0.6083$$

5. Set the fuzzy weight value of flexibility indicator as $R(\tilde{s}_5)$:

$$R(\tilde{s}_5) = \frac{0.225 + 4 \times 0.500 + 0.775}{6} = 0.5000$$

Sum all the fuzzy weight values: $\sum_{l=1}^{5} R(\tilde{s}_l) = 2.8292$

calculate subjective weights (u_l) of all first-level indicators as below:

1. Set the subjective weight of quality indicator as u_1:

$u_1 = \frac{0.6667}{2.8292} = 0.2239$

2. Set the subjective weight of cost indicator as u_2:

$u_2 = \frac{0.5542}{2.8292} = 0.1959$

3. Set the subjective weight of delivery rate indicator as u_3:

$u_3 = \frac{0.5000}{2.8292} = 0.1767$

4. Set the subjective weight of greenness indicator as u_4:

$u_4 = \frac{0.6083}{2.8292} = 0.2150$

5. Set the subjective weight of flexibility indicator as u_5:

$u_5 = \frac{0.5000}{2.8292} = 0.1767$

Table 4.12 The subjective weight for each indicator and its rank

Indicator	Quality	Cost	Delivery Rate	Greenness	Flexibility
Subjective Weight	0.2239	0.1959	0.1767	0.2150	0.1767
Rank	Quality>Greenness>Cost>Flexibility=Delivery Rate				

Step 5: Calculate the objective weights (λ) for each quantitative indicator (quality, cost and delivery rate). The objective weight is determined by their entropy.

1. Set the triangular fuzzy numbers of three suppliers under quality indicator (I_1) as $\tilde{a}_{i1}$ (i = 1, 2, 3):

Set fuzzy evaluation value of S1 under I_1 as $\hbar_{11} = R(\tilde{a}_{11})$:

$$h_{11} = \frac{93 + 4 \times 95 + 95.4}{6} = 94.7333$$

Set fuzzy evaluation value of S2 under I_1 as $\hbar_{21} = R(\tilde{a}_{21})$:

$$h_{21} = \frac{85 + 4 \times 88 + 91}{6} = 88$$

Set fuzzy evaluation value of S3 under I_1 as $\hbar_{31} = R(\tilde{a}_{31})$:

$$h_{31} = \frac{91 + 4 \times 93 + 96}{6} = 93.1667$$

2. Set the triangular fuzzy numbers of three suppliers under cost indicator (I_2) as $\tilde{a}_{i2}$ (i = 1, 2, 3):

Set fuzzy evaluation value of S1 under I_2 as $\hbar_{12} = R(\tilde{a}_{12})$:

$$h_{12} = \frac{400 + 4 \times 406 + 410}{6} = 405.6667$$

Set fuzzy evaluation value of S2 under I_2 as $\hbar_{22} = R(\tilde{a}_{22})$:

$$h_{22} = \frac{412 + 4 \times 417 + 425}{6} = 417.5000$$

Set fuzzy evaluation value of S3 under I_2 as $\hbar_{32} = R(\tilde{a}_{32})$:

$$h_{32} = \frac{395 + 4 \times 398 + 405}{6} = 398.6667$$

3. Set the triangular fuzzy numbers of three suppliers under delivery indicator (I_3) as a˜_i3 (i = 1, 2, 3):

Set fuzzy evaluation value of supply S1 under I_3 as $\hbar_{13} = R(\tilde{a}_{13})$:

$$h_{13} = \frac{95 + 4 \times 96 + 97}{6} = 96$$

Set fuzzy evaluation value of supply S2 under I_3 as $\hbar_{23} = R(\tilde{a}_{23})$:

$$h_{23} = \frac{93 + 4 \times 94 + 95}{6} = 94.3333$$

Set fuzzy evaluation value of supply S3 under I_3 as $\hbar_{33} = R(\tilde{a}_{33})$:

$$h_{33} = \frac{97 + 4 \times 98 + 99}{6} = 98.3333$$

Sum the fuzzy evaluation values of three suppliers under quantitative indicators to get H_i (i = 1, 2, 3):

S1 = $H_1 = \sum_{i=1}^{3} \hbar_{i1} = 275.9000$;

S2 = $H_2 = \sum_{i=1}^{3} \hbar_{i2} = 1221.8333$;

S3 = $H_3 = \sum_{i=1}^{3} \hbar_{i3} = 288.6667$.

Calculate the entropy (e_p) of all quantitative indicators (quality, cost and delivery rate).

1. The quality indicators (I_1) of suppliers (S1, S2, S3) are processed as below:

S1: $\frac{h_{11}}{H_1} = \frac{94.7333}{275.9000} = 0.3434$, $ln\frac{h_{11}}{H_1} = \ln\frac{94.7333}{275.9000} = -1.0690$

S2: $\frac{h_{21}}{H_1} = \frac{88}{275.9000} = 0.3190$, $ln\frac{h_{21}}{H_1} = \ln\frac{88}{275.9000} = -1.1427$

S3: $\frac{h_{31}}{H_1} = \frac{93.1667}{275.9000} = 0.3377$, $ln\frac{h_{31}}{H_1} = ln\frac{93.667}{275.9000} = -1.0856$

Set the entropy of the quality indicator (I_1) as e_1:

$$e_1 = -\frac{1}{ln\,3}\sum_{i=1}^{3}\left(\frac{\hbar_{i1}}{H_1} ln\frac{\hbar_{i1}}{H_1}\right) = 0.9996$$

2. The cost indicators (I_2) of suppliers (S1, S2, S3) are processed as below:

S1: $\frac{h_{12}}{H_2} = \frac{405.6667}{1221.8333} = 0.3320$, $ln\frac{h_{12}}{H_2} = ln\frac{405.6667}{1221.8333} = -1.1026$

S2: $\frac{h_{22}}{H_2} = \frac{417.5000}{1221.8333} = 0.3417$, $ln\frac{h_{22}}{H_2} = ln\frac{417.5000}{1221.8333} = -1.0738$

S3: $\frac{h_{32}}{H_2} = \frac{398.6667}{1221.8333} = 0.3263$, $ln\frac{h_{32}}{H_2} = ln\frac{398.6667}{1221.8333} = -1.1200$

Set the entropy of the cost indicator (I_2) as e_2:

$e_2 = -\frac{1}{ln3}\sum_{l=1}^{3}\left(\frac{h_{i2}}{H_2} ln\frac{h_{i2}}{H_3}\right) = 0.9998$

3. The delivery rate indicators (I_3) of suppliers (S1, S2, S3) are processed as below:

S1: $\frac{h_{13}}{H_3} = \frac{96}{288.6667} = 0.3326$, $ln\frac{h_{13}}{H_3} = ln\frac{96}{288.6667} = -1.1009$

S2: $\frac{h_{23}}{H_3} = \frac{94.3333}{288.6667} = 0.3268$, $ln\frac{h_{23}}{H_3} = ln\frac{94.3333}{288.6667} = -1.1184$

S3: $\frac{h_{33}}{H_3} = \frac{98.3333}{288.6667} = 0.3406$, $ln\frac{h_{33}}{H_3} = ln\frac{98.3333}{288.6667} = -1.0769$

Set the entropy of delivery rate indicator (I_3) as e_3:

$e_3 = -\frac{1}{ln3}\sum_{l=1}^{3}\left(\frac{h_{i3}}{H_3} ln\frac{h_{i3}}{H_3}\right) = 0.9999$

Set the summation of entropies for three quantitative indicators as *E:*

$E = \sum_{p=1}^{3} e_p = 2.9993$

Calculate the objective weights (λ_p, p =1,2,3) of all quantitative indicators:

1. Set the objective weight of quality indicator (I_1) as λ_1:

$$\lambda_1 = \frac{1-e_1}{3-E} = \frac{1-0.9996}{3-2.9993} = 0.6009$$

2. Set the objective weight of cost indicator (I_2) as λ_2:

$$\lambda_2 = \frac{1-e_2}{3-E} = \frac{1-0.9998}{3-2.9993} = 0.2219$$

3. Set the objective weight of delivery rate indicator (I_3) as λ_3:

$$\lambda_3 = \frac{1 - e_3}{3 - E} = \frac{1 - 0.9999}{3 - 2.9993} = 0.1772$$

Table 4.13 The entropy and objective weight of all quantitative indicators

Indicator	I_1	I_2	I_3
e_i	0.9996	0.9998	0.9999
λ_i	0.6009	0.2219	0.1772

Step 6: work out o_p(p = 1,2,3) of quantitative indicators:

1. Set quality indicator (I_1)as o_1:

$$o_1 = \frac{u_1}{\sum_{p=1}^{3} u_p} = \frac{0.2356}{0.6082} = 0.3874$$

2. Set cost indicator (I_2) as o_2:

$$o_2 = \frac{u_2}{\sum_{p=1}^{3} u_p} = \frac{0.1959}{0.6082} = 0.3220$$

3. Set delivery rate indicator (I_3) as o_3:

$$o_3 = \frac{u_3}{\sum_{p=1}^{3} u_p} = \frac{0.1767}{0.6082} = 0.2906$$

Calculate the comprehensive weights (z_p, p = 1,2,3) of quantitative indicators:

1. Set the comprehensive weight of the quality indicator (I_1) as z_1:

$$z_1 = \left[\frac{\lambda_1 \times o_1}{\sum_{p=1}^{3}(\lambda_p \times o_p)}\right] \times \left(\sum_{p=1}^{3} u_p\right) = \frac{0.2328}{0.3557} \times 0.6082 = 0.3980$$

2. Set the comprehensive weight of the cost indicator (I_2) as z_2:

$$z_2 = \left[\frac{\lambda_2 \times o_2}{\sum_{p=1}^{3}(\lambda_p \times o_p)}\right] \times \left(\sum_{p=1}^{3} u_p\right) = \frac{0.0715}{0.3557} \times 0.6082 = 0.1222$$

3. Set the comprehensive weight of the delivery rate indicator (I_3) as z_3:

$$z_3 = \left[\frac{\lambda_3 \times o_3}{\sum_{p=1}^{3}(\lambda_p \times o_p)}\right] \times \left(\sum_{p=1}^{3} u_p\right) = \frac{0.0515}{0.3557} \times 0.6082 = 0.0881$$

Step 7: calculate the comprehensive weights (z_k, k = 4,5) of qualitative indicators (greenness and flexibility).

1. Set the comprehensive weight of the greenness indicator as z_4:

$R(\tilde{s}_4) = \frac{0.350+4\times0.600+0.900}{6} = 0.6083$, $z_4 = \frac{0.6083}{2.8292} = 0.2150$

2. Set the comprehensive weight of the flexibility indicator as z_5:

$R(\tilde{s}_5) = \frac{0.225+4\times0.500+0.775}{6} = 0.5000$, $z_5 = \frac{0.5000}{2.8292} = 0.1767$

Table 4.14 The comprehensive weight and the rank of all evaluation indicators

z	I_1	I_2	I_3	I_4	I_5
Comprehensive Weight	0.3980	0.1222	0.0881	0.2150	0.1767
Rank (Top-Bottom)	$I_1 > I_4 > I_5 > I_2 > I_3$				

4.6 Rank Green Suppliers by TOPSIS

After settling all comprehensive weights, fuzzy-TOPSIS will rank three green suppliers. According to application steps of fuzzy-TOPSIS, the evaluation data of the qualitative indicator and the weights have been carried out, so it will start in the second step:

Step 2: construct the initial fuzzy evaluation matrix A from the data of **Table 4.11** to get $A = (\tilde{a}_{ii})_{3\times5}$:

$$A = \begin{bmatrix} (93,95,95.4)(400,406,410)(95,96,97)(0.375,0.525,0.725)(0.450,0.650,0.850) \\ (85,88,91)\ (412,417,425)(93,94,95)(0.450,0.650,0.850)(0.375,0.575,0.775) \\ (91,93,96)\ (395,398,405)(97,98,99)(0.300,0.450,0.650)(0.300,0.450,0.650) \end{bmatrix}$$

Step 3: construct standardised fuzzy evaluation matrix B, but the quality (I_1) and delivery rate (I_3) are benefit-based indicators, while the cost (I_2) is cost-based indicator:

1. Set the triangular fuzzy numbers of suppliers (S1, S2, S3) under quality indicator (I_1) as:

$\tilde{a}_{i1} = \left(a_{ip}^L, a_{ip}^M, a_{ip}^R\right)$, i = 1, 2, 3.

$\tilde{a}_{11}$= (93,95,95.4), $\tilde{a}_{21}$= (85,88,91), $\tilde{a}_{31}$ = (91,93,96)

Set the largest fuzzy number as t_1:

t_1= max{95.4,91,96} = 96

Sandardise the triangular fuzzy number of the quality indicator for suppliers (S1, S2, S3):

$\tilde{b}_{i1} = \left(b_{i1}^L, b_{i1}^M, b_{i1}^R\right)$, i = 1, 2, 3.

Set standardized the triangular fuzzy number of the quality (I_1) for S1 as:

$\widetilde{b}_{11}$= (a_{11}^L/t_1 ,a_{11}^M/t_1 ,a_{11}^R/t_1)=(0.9688,0.9896,0.9938)

Set standardized the triangular fuzzy number of the quality (I_1) for S2 as:

$\widetilde{b}_{21}$= (a_{21}^L/t_1 ,a_{21}^M/t_1 ,a_{21}^R/t_1)= (0.8854,0.9167,0.9798)

Set standardized the triangular fuzzy number of the quality (I_1) for S3 as:

$\widetilde{b}_{31}$= (a_{31}^L/t_1,a_{31}^M/t_1 ,a_{31}^R/t_1)= (0.9479,0.9688,1)

2. Set the triangular fuzzy numbers of suppliers (S1, S2, S3) under the delivery rate indicator (I_3) as:

$\widetilde{a}_{i3}$ = (a_{i3}^L,a_{i3}^M,a_{i3}^R), i = 1,2,3.

$\widetilde{a}_{13}$= (95,96,97), $\widetilde{a}_{23}$= (93,94,95), $\widetilde{a}_{33}$ = (97,98,99)

Set the largest fuzzy number as t_3:

t_3= max{97,95,99} = 99

Sandardise the triangular fuzzy numbers of the delivery rate for suppliers (S1, S2, S3):

$\widetilde{b}_{i3}$ = (b_{i3}^L, b_{i3}^M, b_{i3}^R), i = 1,2,3.

Set standardized triangular fuzzy number of delivery rate (I_3) for S1 as:

$\widetilde{b}_{13}$= (a_{13}^L/t_3 ,a_{13}^M/t_3 ,a_{13}^R/t_3)=(0.9596,0.9697,0.9798)

Set standardized triangular fuzzy number of delivery rate (I_3) for S2 as:

$\widetilde{b}_{23}$= (a_{23}^L/t_3 ,a_{23}^M/t_3 ,a_{23}^R/t_3)=(0.9394,0.9495,0.9596)

Set standardized triangular fuzzy number of delivery rate (I_3) for S3 as:

$\widetilde{b}_{33}$= (a_{33}^L/t_3 ,a_{33}^M/t_3 ,a_{33}^R/t_3)=(0.9798,0.9899,1)

3. Set the triangular fuzzy numbers of suppliers (S1, S2, S3) under the cost indicator (I_2) as:

$\widetilde{a}_{i2}$ = (a_{i2}^L, a_{i2}^M, a_{i2}^R), i = 1,2,3.

$\widetilde{a}_{12}$= (400,406,410), $\widetilde{a}_{22}$= (412,417,425), $\widetilde{a}_{32}$ = (395,398,405)

Set the smallest fuzzy number as c_2:

c_2= min{400,412,395} = 395

Sandardise the triangular fuzzy numbers of the cost indicator for suppliers (S1, S2, S3):

$\widetilde{b}_{i2}$ = (b_{i2}^L, b_{i2}^M, b_{i2}^R) , i = 1,2,3.

Set the standardized triangular fuzzy number of the cost (I_2) for S1 as:

$\widetilde{b}_{12}$= (c_2/a_{12}^R, c_2/a_{12}^M ,c_2/a_{12}^L)=(0.9634,0.9729,0.9634)

Set the standardized triangular fuzzy number of the cost (I_2) for S2 as:

$\tilde{b}_{22}$= $(c_2/a_{22}^R, c_2/a_{22}^M, c_2/a_{22}^L)$=(0.9294,0.9472,0.9587)

Set the standardized triangular fuzzy number of the cost (I_2) for S3 as:

$\tilde{b}_{32}$= $(c_2/a_{32}^R, c_2/a_{32}^M, c_2/a_{32}^L)$=(0.9753,0.9925,1)

Make quantitative indicators dimensionless, the author sets standardised fuzzy evaluation matrix as $B=(\tilde{b}_{il})_{3\times5}$:

$$\begin{bmatrix} (0.9688,0.9896,0.9938) & (0.9634,0.9729,0.9634) & (0.9596,0.9697,0.9798) & (0.375,0.525,0.725) & (0.450,0.650,0.850) \\ (0.8854,0.9167,0.9798) & (0.9294,0.9472,0.9587) & (0.9394,0.9495,0.9596) & (0.450,0.650,0.850) & (0.375,0.575,0.775) \\ (0.9479,0.9688,1) & (0.9753,0.9925,1) & (0.9798,0.9899,1) & (0.300,0.450,0.650) & (0.300,0.450,0.650) \end{bmatrix}$$

Step 4: weight standardized fuzzy evaluation matrix *C*. The comprehensive weight of the evaluation indicator is available in **Table 4.14**, which multiplies with the matrix *B* to obtain weighted fuzzy evaluation matrix $\mathrm{C} = (\tilde{c}_{il})_{3\times5}$:

$$\begin{bmatrix} (0.3856,0.3939,0.3955) & (0.1177,0.1189,0.1177) & (0.0845,0.0845,0.0863) & (0.0806,0.1129,0.1559) & (0.0795,0.1149,0.1502) \\ (0.3524,0.3648,0.3773) & (0.1136,0.1157,0.1171) & (0.0827,0.0836,0.0845) & (0.0968,0.1398,0.1828) & (0.0663,0.1016,0.1370) \\ (0.3773,0.3856,0.3980) & (0.1192,0.1213,0.1222) & (0.0863,0.0872,0.0881) & (0.0645,0.0968,0.1398) & (0.0530,0.0795,0.1149) \end{bmatrix}$$

Step 5: find the positive and negative ideal solutions.

C^{+}=[(0.3856,0.3939,0.3955)(0.1136,0.1157,0.1717)(0.0863,0.0872,0.0881)(0.0968,0.1398,0.1828)(0.0795,0.1149,0.1502)]

C-=[(0.3524,0.3648,0.3773)(0.1192,0.1213,0.1222)(0.0827,0.0836,0.0845)(0.0645,0.0968,0.1398)(0.0530,0.0795,0.1149)]

Step 6: obtain the distances between the supplier and positive & negative ideal solutions. Set the distance between suppliers (A_i) and positive ideal solution (C^{+}) as d_i^{+}:

1. calculate the distance between weighted triangular fuzzy numbers of all indicators for S1 and the positive ideal solution:

$$D_{11} = [(c_{11}^L - c_1^{+L})^2 + 2(c_{11}^M - c_1^{+M})^2 + (c_{11}^R - c_1^{+R})^2]/4 = 0.00077935600444693$$

$$D_{12} = \left[\left(c_{12}^L - c_2^{+L}\right)^2 + 2\left(c_{11}^M - c_2^{+M}\right)^2 + \left(c_{12}^R - c_2^{+R}\right)^2\right]/4 = 0$$

$$D_{13} = \left[\left(c_{13}^L - c_3^{+L}\right)^2 + 2\left(c_{13}^M - c_3^{+A}\right)^2 + \left(c_{13}^R - c_3^{+R}\right)^2\right]/4 = 0.00001265673519630$$

$$D_{14} = \left[\left(c_{14}^L - c_4^{+L}\right)^2 + 2\left(c_{14}^M - c_4^{+M}\right)^2 + \left(c_{14}^R - c_4^{+R}\right)^2\right]/4 = 0$$

$$D_{15} = [(c_{1s}^L - c_5^{+L})^2 + 2(c_{15}^M - c_5^{+M})^2 + (c_{15}^R - c_5^{+R})^2]/4 = 0.00017568936385267$$

the distance (d_i^{+}) between S1 and the positive ideal solution as below:

$$d_1^{+} = (D_{11} + D_{12} + D_{13} + D_{14} + D_{15})^{1/2} = 0.024885839090131$$

2. calculate the distance between weighted triangular fuzzy numbers of all indicators for S2 and the positive ideal solution:

$$D_{21} = \left[\left(c_{21}^{L} - c_{1}^{+L}\right)^2 + 2\left(c_{21}^{M} - c_{1}^{+M}\right)^2 + \left(c_{21}^{R} - c_{1}^{+R}\right)^2\right]/4 = 0$$

$$D_{22} = [(c_{22}^{L} - c_{2}^{+L})^2 + 2(c_{22}^{M} - c_{2}^{+M})^2 + (c_{22}^{R} - c_{2}^{+R})^2]/4 = 0.00000931299418043$$

$$D_{23} = [(c_{23}^{L} - c_{3}^{+L})^2 + 2(c_{23}^{M} - c_{3}^{+M})^2 + (c_{23}^{R} - c_{3}^{+R})^2]/4 = 0.00000316418379907$$

$$D_{24} = [(c_{24}^{L} - c_{4}^{+L})^2 + 2(c_{24}^{M} - c_{4}^{+M})^2 + (c_{24}^{R} - c_{4}^{+R})^2]/4 = 0.00060682780924039$$

$$D_{25} = \left[\left(c_{25}^{L} - c_{5}^{+L}\right)^2 + 2\left(c_{25}^{M} - c_{5}^{+M}\right)^2 + \left(c_{25}^{R} - c_{5}^{+R}\right)^2\right]/4 = 0$$

the distance (d_i^+) between S2 and the positive ideal solution as below:

$$d_2^+ = (D_{21} + D_{22} + D_{23} + D_{24} + D_{25})^{1/2} = 0.031107910625690$$

3. calculate the distance between weighted triangular fuzzy numbers of all indicators for S3 and the positive ideal solution:

$$D_{31} = \left[\left(c_{31}^{L} - c_{1}^{+L}\right)^2 + 2\left(c_{31}^{M} - c_{1}^{+M}\right)^2 + \left(c_{31}^{R} - c_{1}^{+R}\right)^2\right]/4 = 0.00005311446964581$$

$$D_{32} = \left[\left(c_{32}^{L} - c_{2}^{+L}\right)^2 + 2\left(c_{32}^{M} - c_{2}^{+M}\right)^2 + \left(c_{32}^{R} - c_{2}^{+R}\right)^2\right]/4 = 0.00002947920536030$$

$$D_{33} = \left[\left(c_{33}^{L} - c_{3}^{+L}\right)^2 + 2\left(c_{33}^{M} - c_{3}^{+M}\right)^2 + \left(c_{33}^{R} - c_{3}^{+R}\right)^2\right]/4 = 0$$

$$D_{34} = \left[\left(c_{34}^{L} - c_{4}^{+L}\right)^2 + 2\left(c_{34}^{M} - c_{4}^{+M}\right)^2 + \left(c_{34}^{R} - c_{4}^{+R}\right)^2\right]/4 = 0.00164710405365200$$

$$D_{35} = \left[\left(c_{35}^{L} - c_{5}^{+L}\right)^2 + 2\left(c_{35}^{M} - c_{5}^{+M}\right)^2 + \left(c_{35}^{R} - c_{5}^{+R}\right)^2\right]/4 = 0.00111269930440000$$

the distance (d_i^+) between S3 and the positive ideal solution as below:

$$d_3^+ = (D_{31} + D_{32} + D_{33} + D_{34} + D_{35})^{1/2} = 0.053314135396336$$

Table 4.15 The distance between the supplier and the positive ideal solution

d_1^+	d_2^+	d_3^+
0.0294	0.0311	0.0533

Set the distance between suppliers (A_i) and the negative ideal solution (C^-) as d_i^-:

1. calculate the distance between weighted triangular fuzzy numbers of all indicators for supplier S1 and the negative ideal solution:

$$E_{11} = \left[\left(c_{11}^{L} - c_{1}^{-L}\right)^2 + 2\left(c_{11}^{M} - c_{1}^{-M}\right)^2 + \left(c_{11}^{R} - c_{1}^{-R}\right)^2\right]/4 = 0.00077935600444693$$

$$E_{12} = \left[\left(c_{12}^{L} - c_{2}^{-L}\right)^2 + 2\left(c_{12}^{M} - c_{2}^{-M}\right)^2 + \left(c_{12}^{R} - c_{2}^{-R}\right)^2\right]/4 = 0.00000837792908427$$

$$E_{13} = \left[\left(c_{13}^{L} - c_{3}^{-L}\right)^2 + 2\left(c_{13}^{M} - c_{3}^{-M}\right)^2 + \left(c_{13}^{R} - c_{3}^{-R}\right)^2\right]/4 = 0.00000316418379907$$

$$E_{14} = \left[\left(c_{14}^{L} - c_{4}^{-L}\right)^2 + 2\left(c_{14}^{M} - c_{4}^{-M}\right)^2 + \left(c_{14}^{R} - c_{4}^{-R}\right)^2\right]/4 = 0.00026006906110303$$

$$E_{15} = \left[\left(c_{15}^{L} - c_{5}^{-L}\right)^2 + 2\left(c_{15}^{M} - c_{5}^{-M}\right)^2 + \left(c_{15}^{R} - c_{5}^{-R}\right)^2\right]/4 = 0.00111269930440000$$

Calculates the distance (d_i^-) between S1 and the negative ideal solution as below:

$$d_1^- = (E_{11} + E_{12} + E_{13} + E_{14} + E_{15})^{1/2} = 0.046515228504583$$

2. calculate the distance between weighted triangular fuzzy numbers of all indicators for supplier S2 and the negative ideal solution:

$$E_{21} = \frac{\left[\left(c_{21}^{L} - c_{1}^{-L}\right)^2 + 2\left(c_{21}^{M} - c_{1}^{-M}\right)^2 + \left(c_{21}^{R} - c_{1}^{-R}\right)^2\right]}{4} = 0$$

$$E_{22} = \frac{\left[\left(c_{22}^{L} - c_{2}^{-L}\right)^2 + 2\left(c_{22}^{M} - c_{2}^{-M}\right)^2 + \left(c_{22}^{R} - c_{2}^{-R}\right)^2\right]}{4} = 0.00002947920536030$$

$$E_{23} = \frac{\left[\left(c_{23}^{L} - c_{3}^{-L}\right)^2 + 2\left(c_{23}^{M} - c_{3}^{-M}\right)^2 + \left(c_{23}^{R} - c_{3}^{-R}\right)^2\right]}{4} = 0$$

$$E_{24} = \frac{\left[\left(c_{24}^{L} - c_{4}^{-L}\right)^2 + 2\left(c_{24}^{M} - c_{4}^{-M}\right)^2 + \left(c_{24}^{R} - c_{4}^{-R}\right)^2\right]}{4} = 0.00164710405365200$$

$$E_{25} = \left[\left(c_{25}^{L} - c_{5}^{-L}\right)^2 + 2\left(c_{25}^{M} - c_{5}^{-M}\right)^2 + \left(c_{25}^{R} - c_{5}^{-R}\right)^2\right] = 0.00040994184898957$$

Calculates the distance (d_i^-) between S2 and the negative ideal solution as below:

$$d_2^- = (E_{21} + E_{22} + E_{23} + E_{24} + E_{25})^{1/2} = 0.045678497216988$$

3. calculate the distance between weighted triangular fuzzy numbers of all indicators for supplier S3 and the negative ideal solution:

$$E_{31} = \left[\left(c_{31}^{L} - c_{1}^{-L}\right)^2 + 2\left(c_{31}^{M} - c_{1}^{-M}\right)^2 + \left(c_{31}^{R} - c_{1}^{-R}\right)^2\right]/4 = 0.00047699887788713$$

$$E_{32} = \left[\left(c_{32}^{L} - c_{2}^{-L}\right)^2 + 2\left(c_{32}^{M} - c_{2}^{-M}\right)^2 + \left(c_{32}^{R} - c_{2}^{-R}\right)^2\right]/4 = 0$$

$$E_{33} = \left[\left(c_{33}^{L} - c_{3}^{-L}\right)^2 + 2\left(c_{33}^{M} - c_{3}^{-M}\right)^2 + \left(c_{33}^{R} - c_{3}^{-R}\right)^2\right]/4 = 0.00001265673519630$$

$$E_{34} = \left[\left(c_{34}^{L} - c_{4}^{-L}\right)^2 + 2\left(c_{34}^{M} - c_{4}^{-M}\right)^2 + \left(c_{34}^{R} - c_{4}^{-R}\right)^2\right]/4 = 0$$

$$E_{35} = \left[\left(c_{35}^{L} - c_{5}^{-L}\right)^2 + 2\left(c_{35}^{M} - c_{5}^{-M}\right)^2 + \left(c_{35}^{R} - c_{5}^{-R}\right)^2\right]/4 = 0$$

Calculates the distance (d_i^-) between S2 and the negative ideal solution as below:

$$d_3^- = (E_{31} + E_{32} + E_{33} + E_{34} + E_{35})^{1/2} = 0.022128163346365$$

Table 4.16 The distance between the supplier and the negative ideal solution

d_1^-	d_2^-	d_3^-
0.0465	0.0457	0.0221

Step 7: calculate the relative closeness degree (CC_i, i= 1,2,3) of suppliers (Ai):

1. Set the relative closeness degree of supplier S1 as CC_1:

$CC_1=\frac{d_1^-}{d_1^- + d_1^+}=0.6515$

2. Set the relative closeness degree of supplier S2 as CC_2:

$CC_2=\frac{d_2^-}{d_2^- + d_2^+}= 0.5949$

3. Set the relative closeness degree of supplier S3 as CC_3:

$CC_3=\frac{d_3^-}{d_3^- + d_3^+}= 0.2933$

Step 8: Rank green suppliers by the relative closeness degree (CC_i, i= 1,2,3) of suppliers (Ai):

$CC_1 > CC_2 > CC_3$

By comparing the relative closeness degree (CC_i, i= 1,2,3) of all suppliers (Ai), it is obvious that S1 is the optimum supplier with the largest relative closeness degree.

4.7 Additional Practical Analysis

To further demonstrate the applicability of the evaluation model (Fuzzy-entropy-TOPSIS), the author will increase the number of suppliers to prove that the effectiveness is not affected by the change of the number of supplier or the evaluation scale.

The first case study only evaluates three suppliers, which may not be sufficient to illustrate the validity of Fuzzy-entropy-TOPSIS. Therefore, it is necessary to evaluate extra 10 suppliers and the evaluation process is consistent with the first one, so the evaluation detail will not be described in detail.

4.7.1 Collect and process evaluation data for 10 suppliers

The second case will follow the subjective weight of the first case study, so it can skip the process. The author will collect evaluation data from experts through the evaluation questionnaire too, and the original evaluation data from **Table 4.17-4.19**.

Table 4.17 The data of all quantitative indicators for 10 suppliers

	I_1	I_2	I_3
S4	86.20%	406	92.74%
S5	89.70%	408	96.11%
S6	85.30%	404	92.34%
S7	87.70%	385.47	96.44%
S8	84.30%	416	93.90%
S9	90.50%	407.48	94.82%
S10	83.40%	407.48	91.10%
S11	91.70%	413.98	91.80%
S12	81.50%	417	93.70%
S13	82.80%	398	92.50%

Table 4.18 The linguistic rating under the greenness for 10 suppliers

I_4	Expert 1	Expert 2	Expert 3	Expert 4
S4	F	G	F	VP
S5	P	F	P	G
S6	P	VG	F	F
S7	VG	P	G	F
S8	F	F	VG	F
S9	G	P	VP	F
S10	F	F	F	G
S11	VG	VG	G	F
S12	VG	G	F	F
S13	P	P	F	VP

Table 4.19 The linguistic rating under the flexibility for 10 suppliers

I_5	Expert 1	Expert 2	Expert 3	Expert 4
S4	G	G	F	VP
S5	VG	F	P	G
S6	VG	VG	F	F
S7	F	VG	G	P
S8	G	G	VG	F
S9	VG	P	G	F
S10	G	F	F	P
S11	VG	F	VG	G
S12	F	G	G	P
S13	G	F	G	VP

The corresponding triangular fuzzy number of the evaluation data is shown in **Tables 4.20-4.21**.

Table 4.20 The triangular fuzzy number under the greenness for 10 suppliers

I_4	Expert 1	Expert 2	Expert 3	Expert 4
S4	(0.3,0.5,0.7)	(0.6,0.8,1)	(0.3,0.5,0.7)	(0,0,0.2)
S5	(0,0.2,0.4)	(0.3,0.5,0.7)	(0,0.2,0.4)	(0.6,0.8,1)
S6	(0,0.2,0.4)	(0.8,1,1)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
S7	(0.8,1,1)	(0,0.2,0.4)	(0.6,0.8,1)	(0.3,0.5,0.7)
S8	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.8,1,1)	(0.3,0.5,0.7)
S9	(0.6,0.8,1)	(0,0.2,0.4)	(0,0,0.2)	(0.3,0.5,0.7)
S10	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.6,0.8,1)
S11	(0.8,1,1)	(0.8,1,1)	(0.6,0.8,1)	(0.3,0.5,0.7)
S12	(0.8,1,1)	(0.6,0.8,1)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
S13	(0,0.2,0.4)	(0,0.2,0.4)	(0.3,0.5,0.7)	(0,0,0.2)

Table 4.21 The triangular fuzzy number under the greenness for 10 suppliers

I_5	Expert 1	Expert 2	Expert 3	Expert 4
S4	(0.6,0.8,1)	(0.6,0.8,1)	(0.3,0.5,0.7)	(0,0,0.2)
S5	(0.8,1,1)	(0.3,0.5,0.7)	(0,0.2,0.4)	(0.6,0.8,1)
S6	(0.6,0.8,1.0)	(0.8,1,1)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
S7	(0.3,0.5,0.7)	(0.8,1,1)	(0.6,0.8,1)	(0,0.2,0.4)
S8	(0.6,0.8,1)	(0.6,0.8,1)	(0.8,1,1)	(0.3,0.5,0.7)
S9	(0.8,1,1)	(0,0.2,0.4)	(0.6,0.8,1)	(0.3,0.5,0.7)
S10	(0.6,0.8,1)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0,0.2,0.4)
S11	(0.8,1,1)	(0.3,0.5,0.7)	(0.8,1,1)	(0.6,0.8,1)
S12	(0.3,0.5,0.7)	(0.6,0.8,1)	(0.6,0.8,1)	(0,0.2,0.4)
S13	(0.6,0.8,1)	(0.3,0.5,0.7)	(0.6,0.8,1)	(0,0,0.2)

Transform the evaluation data of quantitative indicators and average the ratings of qualitative indicator into triangular fuzzy numbers, as shown in **Table 4.22**.

Table 4.22 The triangular fuzzy number of all evaluation data for 10 suppliers

	I_1	I_2	I_3	I_4	I_5
S4	(84,86.2,88)	(400,406,410)	(90,92.74,95)	(0.30,0.45,0.65)	(0.38,0.53,0.73)
S5	(88,89.7,90)	(406,408,410)	(95,96.11,98)	(0.23,0.43,0.63)	(0.43,0.63,0.78)
S6	(83,85.3,87)	(402,404,410)	(90,92.34,95)	(0.35,0.55,0.70)	(0.50,0.70,0.85)
S7	(85,87.7,89)	(383,385.47,387)	(94,96.44,98)	(0.43,0.63,0.78)	(0.43,0.63,0.78)
S8	(82,84.3,86)	(414,416,418)	(90,93.9,95)	(0.43,0.63,0.78)	(0.58,0.78,0.93)
S9	(89,90.5,91)	(405,407.48,409)	(93,94.82,95)	(0.23,0.38,0.58)	(0.43,0.63,0.78)
S10	(81,83.4,85)	(405,407.48,409)	(90,91.1,93)	(0.38,0.58,0.78)	(0.30,0.50,0.70)
S11	(89,91.7,93)	(410,413.98,415)	(89,91.8,93)	(0.63,0.58,0.78)	(0.63,0.83,0.93)
S12	(79,81.5,83)	(412,417,425)	(91,93.7,95)	(0.50,0.70,0.85)	(0.38,0.58,0.78)
S13	(80,82.8,85)	(395,398,405)	(90,92.5,94)	(0.08,0.23,0.43)	(0.38,0.53,0.73)

4.7.2 Calculate the comprehensive weight for each indicator and rank more suppliers

After collecting all the triangular evaluation fuzzy numbers, the author will use fuzzy-entropy to determine the comprehensive weight for each indicator. By step 1-5 of fuzzy-entropy, it can get the entropy (e_i) and the objective weight (λ_i) of quantitative evaluation indicators as shown in **Table 4.23**.

Table 4.23 The entropy and objective weight of quantitative indicators for 10 suppliers

	I_1	I_2	I_3
$\mathbf{e_i}$	0.9997	0.9999	0.9999
$\boldsymbol{\lambda_i}$	0.6468	0.2142	0.1390

After step 6-7 of Fuzzy-entropy, get the comprehensive weight of all as shown in **Table 4.24**.

Table 4.24 The comprehensive weight of all indicators for 10 suppliers

Z	I_1	I_2	I_3	I_4	I_5
Comprehensive Weight	0.4234	0.1166	0.0682	0.2150	0.1767
Rank (Top-Bottom)	$I_1 > I_4 > I_5 > I_2 > I_3$				

After the determination of the comprehensive weight, fuzzy-TOPSIS ranks 10 green suppliers. By step 1-6 of fuzzy-TOPSIS, the fuzzy positive/negative ideal solution distance as shown in **Table 4.25 and 4.26**.

Table 4.25 The distances between the positive deal solution and 10 suppliers

d_4^+	d_5^+	d_6^+	d_7^+	d_8^+	d_9^+	d_{10}^+	d_{11}^+	d_{12}^+	d_{13}^+
0.090 23482 24995 751	0.088 34433 01572 688	0.066 59983 74674 993	0.056 41844 27582 974	0.052 79449 00792 888	0.095 43758 28851 555	0.081 83944 85827 827	0.003 84581 52938 1523	0.268 1575 5277 6746	0.338 5171 9949 2114

Table 4.26 The distances between the negative deal solution and 10 suppliers

d_4^-	d_5^-	d_6^-	d_7^-	d_8^-	d_9^-	d_{10}^-	d_{11}^-	d_{12}^-	d_{13}^-
0.054 09701 95891 365	0.059 00164 62414 270	0.075 19385 08504 400	0.087 88616 37673 773	0.094 58927 51814 842	0.056 42153 77590 796	0.073 52400 91327 589	0.140 5527 2980 1490	0.272 7223 8820 8085	0.316 5138 1975 7795

After step 7-8 of fuzzy-TOPSIS, get the closeness degree of all suppliers as shown in **Table 4.26**.

Table 4.27 The closeness degree of 10 suppliers and its rank

CC_4	CC_5	CC_6	CC_7	CC_8	CC_9	CC_{10}	CC_{11}	CC_{12}	CC_{13}
0.374 8	0.400 4	0.530 3	0.60 9	0.641 8	0.371 5	0.473 2	0.973 4	0.504 2	0.483 2
S11>S8>S7>S6>S12>S13>S10>S5>S4>S9									

Thus, it is obvious that the best green furniture supplier is S11 with largest closeness degree.

4.8 Sensitivity Analysis

In the last part, the dissertation takes the first case study to make a sensitivity analysis which can test the stability of the evaluation method and identify the influence of subjective factors on the final evaluation result, which will change subjective weights of first-level indicators regularly and compare the outcome with the case study.

The change rule of the subjective weight uses all unique combinations of the linguistic weight rating like VL-L, M-H and H-VL, and regularly moves the weights to each indicator including 50 experiments shown in the **Table 4.28**.

Table 4.28 The change rule of sensitivity analysis

The subjective weight of first-level indicators	
W_1 =(0,0.3,0.5); W_{2-5} =(0,0,0.3)	W_1 =(0.5,0.7,1); W_{2-5} =(0,0.3,0.5)
W_2 =(0,0.3,0.5); $W_{1,3,4,5}$ =(0,0,0.3)	W_2 =(0.5,0.7,1); $W_{1,3,4,5}$ =(0,0.3,0.5)
W_3 =(0,0.3,0.5); $W_{1,2,4,5}$ =(0,0,0.3)	W_3 =(0.5,0.7,1); $W_{1,2,4,5}$ =(0,0.3,0.5)
W_4 =(0,0.3,0.5); $W_{1,2,3,5}$ =(0,0,0.3)	W_4 =(0.5,0.7,1); $W_{1,2,3,5}$ =(0,0.3,0.5)
W_5 =(0,0.3,0.5); W_{1-4} =(0,0,0.3)	W_5 =(0.5,0.7,1); W_{1-4} =(0,0.3,0.5)
W_1 =(0.2,0.5,0.8); W_{2-5} =(0,0,0.3)	W_1 =(0.7,1,1); W_{2-5} =(0,0.3,0.5)
W_2 =(0.2,0.5,0.8); $W_{1,3,4,5}$ =(0,0,0.3)	W_2 =(0.7,1,1); $W_{1,3,4,5}$ =(0,0.3,0.5)
W_3 =(0.2,0.5,0.8); $W_{1,2,4,5}$ =(0,0,0.3)	W_3 =(0.7,1,1); $W_{1,2,4,5}$ =(0,0.3,0.5)
W_4 =(0.2,0.5,0.8); $W_{1,2,3,5}$ =(0,0,0.3)	W_4 =(0.7,1,1); $W_{1,2,3,5}$ =(0,0.3,0.5)
W_5 =(0.2,0.5,0.8); W_{1-4} =(0,0,0.3)	W_5 =(0.7,1,1); W_{1-4} =(0,0.3,0.5)
W_1 =(0.5,0.7,1); W_{2-5} =(0,0,0.3)	W_1 =(0.5,0.7,1); W_{2-5} =(0.2,0.5,0.8)
W_2 =(0.5,0.7,1); $W_{1,3,4,5}$ =(0,0,0.3)	W_2 =(0.5,0.7,1); $W_{1,3,4,5}$ =(0.2,0.5,0.8)
W_3 =(0.5,0.7,1); $W_{1,2,4,5}$ =(0,0,0.3)	W_3 =(0.5,0.7,1); $W_{1,2,4,5}$ =(0.2,0.5,0.8)
W_4 =(0.5,0.7,1); $W_{1,2,3,5}$ =(0,0,0.3)	W_4 =(0.5,0.7,1); $W_{1,2,3,5}$ =(0.2,0.5,0.8)
W_5 =(0.5,0.7,1); W_{1-4} =(0,0,0.3)	W_5 =(0.5,0.7,1); W_{1-4} =(0.2,0.5,0.8)
W_1 =(0.7,1,1); W_{2-5} =(0,0,0.3)	W_1 =(0.7,1,1); W_{2-5} =(0.2,0.5,0.8)
W_2 =(0.7,1,1); $W_{1,3,4,5}$ =(0,0,0.3)	W_2 =(0.7,1,1); $W_{1,3,4,5}$ =(0.2,0.5,0.8)
W_3 =(0.7,1,1); $W_{1,2,4,5}$ =(0,0,0.3)	W_3 =(0.7,1,1); $W_{1,2,4,5}$ =(0.2,0.5,0.8)
W_4 =(0.7,1,1); $W_{1,2,3,5}$ =(0,0,0.3)	W_4 =(0.7,1,1); $W_{1,2,3,5}$ =(0.2,0.5,0.8)
W_5 =(0.7,1,1); W_{1-4} =(0,0,0.3)	W_5 =(0.7,1,1); W_{1-4} =(0.2,0.5,0.8)
W_1 =(0.2,0.5,0.8); W_{2-5} =(0,0.3,0.5)	W_1 =(0.7,1,1); W_{2-5} =(0.5,0.7,1)
W_2 =(0.2,0.5,0.8); $W_{1,3,4,5}$ =(0,0.3,0.5)	W_2 =(0.7,1,1); $W_{1,3,4,5}$ =(0.5,0.7,1)
W_3 =(0.2,0.5,0.8); $W_{1,2,4,5}$ =(0,0.3,0.5)	W_3 =(0.7,1,1); $W_{1,2,4,5}$ =(0.5,0.7,1)
W_4 =(0.2,0.5,0.8); $W_{1,2,3,5}$ =(0,0.3,0.5)	W_4 =(0.7,1,1); $W_{1,2,3,5}$ =(0.5,0.7,1)
W_5 =(0.2,0.5,0.8); W_{1-4} =(0,0.3,0.5)	W_5 =(0.7,1,1); W_{1-4} =(0.5,0.7,1)

The author will follow the evaluation process of the case study to rank the green supplier by Fuzzy-entropy-TOPSIS, and the outcome data of 50 experiments is shown in **Appendix C** and **Figure 4.1**. The result shows that S1 as the best green supplier appears 36 times (36/50 = 72%), which is consistent with the result of the case study, which proves the stability and objectivity of the evaluation result, because the subjective weight comes from the expert's rating.

Table 4.29 The result of sensitivity analysis of the first case study

Supplier	Optimum Time	Ratio
CC1	36	0.72
CC2	12	0.24
CC3	2	0.04

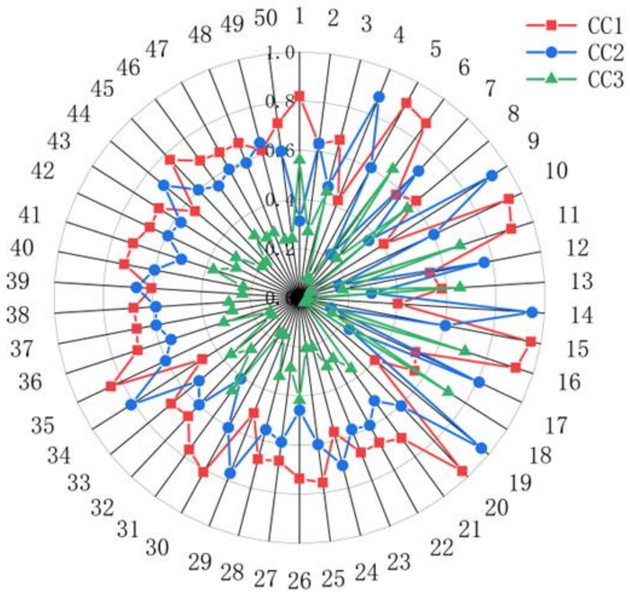

Figure 4.1 The result of Sensitivity Analysis

CHAPTER 5
DISCUSSION

In recent years, so many new factors restrict the development of furniture industry like the environmental policy, new consumer demand and the increasing operation cost which also have a significant negative impact on JA's business development. Therefore, the green transformation is the key to its sustainable development and the green furniture supplier evaluation can facilitate the green supply chain management, the greenness of products and the customer satisfaction. The dissertation is to help JA to overcome the problems of supplier evaluation including simple evaluation indicator system, unreliable indicator weight and ignorance of green indicators.

5.1 Evaluation indicator system

The first important part of this thesis is about how to construct a suitable green supplier evaluation indicator system. The main methods include the expert meeting to collect the suggestion of indicator selection by consideration of the development requirement, and reading supplier evaluation literature to refine the indicator system.

After reviewing the literature on supplier evaluation and referring to expert opinion, the author selects five first-level evaluation indicators (Quality, Cost, Delivery Rate, Flexibility, Greenness) and 19 second-level evaluation indicators, as shown in **Figure 3.1**. The indicator from the literature review is professional, because the scholar has researched on its effectiveness, and the suggestion from experts with full working experience in the company can represent the business development needs. For example, Mangla, Kumar, and Barua (2014) prove that the leader's green commitment can show the willingness of the green business operation like green training for employees, and the transport expert believes the structural compliance rate is very necessary due to the special feature of furniture product. Comparing with the previous research like Lima-Junior & Carpinetti (2016) and Dos Santos, Godoy and Campos (2019), they only review the literature to construct the evaluation indicator system, which may deviate the actual business needs. The author takes the average or sum of the second-level quantitative evaluation indicators as the value of the first-level quantitative indicator, and the primary or middle linguistic rating of the second-level qualitative indicators as the linguistic rating of the first-level qualitative indicators from the filled questionnaire. For example, the first-level cost indicator includes three second-level indicators: Product Price (363.7), Transport Cost (7.8) and Environmental Management Cost (28.9), so the value of the first-level indicator is the sum (406) of those second-level. The rational evaluation indicator system and method of taking evaluation data can make green supplier evaluation more comprehensive and accurate, which can also overcome the problem of the simple evaluation indicator system. The evaluation value for the first-level indicator, determined by the second-level indicators (mean, sum, median and plurality), can improve the efficiency of supplier evaluation for SMEs, reduce evaluation costs and errors, as it reduces 19 indicators to only five first-level indicators to be processed.

In addition, the greenness indicators like Green Certificate, Green Image and Green Commitment, which overcomes the ignorance of green indicator. Before adding the greenness indicator, the evaluation team did not consider the environment and health factors seriously, leading to increasing legal problems, complaint cases and fines, because the consumer has stronger health and environment-protection awareness and the government introduces more strict environmental laws. With the adoption of the greenness indicator, every supplier AJ works with will have their products fully tested by a third party for environmental protection and have a 100% pass rate for hazardous substances sampling, meaning that the probability of fines, customer complaints and legal risks will be significantly reduced in the future.

The scientific approach of selecting indicators is the basis for the successful green supplier evaluation. The combination of qualitative and quantitative indicators ensures a balance of subjectivity and objectivity in the evaluation results. Therefore, the literature review and expert meeting can build the supplier evaluation system with the representativeness of the development needs and product characteristics.

5.2 Evaluation model

The second part is the model development, specifically including fuzzy-entropy to determine the weight of indicator and fuzzy-TOPSIS to rank green suppliers.

The combination of fuzzy set theory and entropy considers both subjective and objective weights to get the comprehensive weight, which can reduce the subjectivity generated by human evaluation, because the entropy comes from the orderliness of quantitative data with full objectivity. In addition to subjective evaluation, the entropy does influence the weight of each indicator to make it more objective, because in the first case study the addition of objective weight lowers the cost by one place compared with the rank of the subjective weight. AHP (Natchanok, 2019), AHP-TOPSIS (Onder & Sundus, 2013), Fuzzy-TOPSIS (Rashidi and Cullinane, 2019) and Fuzzy-AHP (Tsai and Phumchusai, 2021) only consider subjective weight from human judgement, which is less objective than fuzzy-entropy-TOPSIS and easier to make bias errors. Moreover, fuzzy set theory does quantify the performance of qualitative indicators and the importance of each indicator by the triangular fuzzy number, and the distribution of the membership function can effectively differentiate suppliers' performance (Zhao & Guo, 2014).

Through literature review, most supplier evaluation researchers usually combine fuzzy set theory with TOPSIS to solve fuzzy multi-objective decision making problems, and the green supplier evaluation also falls into this category. Fuzzy-TOPSIS can process the difference in order of magnitude and nature between different types of indicators, because it can make quantitative indicators (more than 1) dimensionless to be equivalent to the qualitative indicator (0-1), and take the data in opposite direction as the ideal solutions to solve the opposite nature of benefit-based and cost-based indicators (e.g. the lowest value as the positive ideal solution for the cost-based, but the highest for the benefit-based). In addition, the distance between supplier's performance and the ideal solution can accurately identify any slight difference amongst suppliers for any kind of indicators. Guoyi and Xiaohua (2011) take AHP to determine the subjective weight and entropy for the objective weight to get comprehensive weight, but the comparison of every-two indicators is too complicate and its ranking method is too rough to show the performance difference of suppliers. Dos Santos, Godoy and Campos (2019) also use fuzzy-entropy-TOPSIS, while the case only evaluates qualitative indicators, so its objectivity is less than the entropy of quantitative indicators. Zhao and Guo evaluate thermal power equipment suppliers by the same model, while its number of supplier and indicator are much less than this dissertation, and there is no sensitivity analysis, so it cannot demonstrate its practicability and applicability as deeply as this dissertation.

All in all, the green evaluation indicator system and fuzzy-entropy-TOPSIS consider the most of evaluation situation like various kinds of indicator and data, so the successful case studies can prove the evaluation method of this dissertation is applicable and practical.

5.3 Evaluation result analysis

Firstly, the author makes two case studies to verify the validity of the green supplier evaluation indicator system and supplier evaluation model based on JA's green furniture supplier evaluation case. In addition, there is the sensitivity analysis of the first case study to certify the stability and objectivity of the evaluation result.

The rank of the subjective weight is quality> greenness >cost>flexibility =delivery rate as shown in **Table 4.12** which indicates that experts more emphasize on quality, flexibility and greenness, and it is different from the comprehensive weight which may change due to the changeable entropy for each case, so the furniture manufacturers should more develop the competitiveness in these aspects such as improving the production technique, reducing the waste emissions and sourcing more recyclable materials. However, the ranks of the comprehensive weight are similar for two case studies but different from the rank of the subjective weight (Quality, Greenness and Flexibility being the top three), so the manufacturer also needs to strengthen its general performance.

The best suppliers for two cases are S1 and S11 whose performance in Greenness, Quality and Flexibility are the top comparing with others, so the evaluation results are reasonable and accurate, and the second case can prove that its effectiveness would not be influenced by the number of suppliers. When taking the first case to make sensitivity analysis by changing the sequence of the subjective weight, 36 out of 50 sensitivity experiments agree with S1 as the optimum supplier (72%), as shown in **Appendix C**, which proves the objectivity and stability of evaluation method. After evaluation, another expert meeting does approve the result and recommends it as the new evaluation way to improve the evaluation procedure and the general competitiveness.

In summary, the construction method of evaluation indicator system and evaluation model (Fuzzy-entropy-TOPSIS) in this dissertation allows for a comprehensive evaluation of various green supplier performance and effectively ranking suppliers to make optimal choices.

5.4 Research Limitation

As the old saying goes, there is no such thing as a perfect study. Although this dissertation involves most of evaluation factors and provides a detailed description of the construction of indicator system and the evaluation model to draw two case studies, but there are still three limitations:

Firstly, the context in which the model is applied is ideal, so in other firms it may not have the same validity. For example, the author and experts are inclined to trust the documents provided by the supplier without verification, but the realistic situation should verify the authenticity. In addition, in the data collection process, the evaluator fully trusts and directly uses the subjective evaluation data from the experts, but practical application should set an elimination rule to screen the unreasonable data.

Secondly, the number of participating suppliers is still relatively small, so the evaluation method may only suit to SMES instead of large enterprises. The future study can take more suppliers and evaluation data to test whether it is still useful and practical.

Thirdly, the general procedure of this evaluation method is relatively complex including the construction of indicator system, the organization of expert meeting, the collection of evaluation data, and the application of fuzzy-entropy-TOPSIS, although the method of taking evaluation data and MATLAB have simplifies it a lot. Thus, the future study also should consider how to make it more efficient and economical.

The above three points are the main research limitations of this dissertation, but in practice, the evaluation method can effectively help the company solve the evaluation problems.

5.5 The general application procedure

Firstly, the procurement team has to propose and define a new green supplier evaluation system to replace the old one in the managers' meeting; then all the future suppliers to be evaluated are asked to provide evaluation documents according to the evaluation system, such as third-party quality test certificates, percentage of highly polluting equipment and environmental investment, etc.; the corresponding professionals, such as quality controller, transport coordinator and supply chain manager, are required to review the evaluation documents and fill supplier evaluation questionnaire to provide valid evaluation data; the evaluation data is entered into the

MATLAB program to obtain the evaluation result (best supplier); finally, the General Manager's meeting finalises the result and if correct, the company will send a representative to sign a cooperation agreement with the best supplier to start cooperation. From now and then, there is no any difficulty when implementing.

CHAPTER 6
CONCLUSIONS

The supplier evaluation process of JA Furniture Sales Company has issues including simple evaluation indicator system, unreliable indicator weight and ignorance of green indicators which negatively influence it business development. This dissertation uses fuzzy-entropy-TOPSIS with the new evaluation indicator system can effectively solve these problems and proves the effectiveness of the evaluation model.

Evaluator by the literature review on supplier evaluation and the expert meeting collects the evaluation indicator to build a new green indicator system including 5 first-level and 19 second-level indicators as shown in **Figure 3.1**. The original indicator system only contained one layer and 5 indicators, so cannot comprehensively evaluate suppliers and fully meet the development requirement, leading to the extra business cost like the loss in **Table 1.2** and **Table 1.3**. However, the experts all agree that the new indicator system can also push suppliers to improve the green operation and the response efficiency, because now JA requires them to provide the tender document with the data of new indicators, so it does make the green supplier chain management, the business operation and the furniture product more efficient and environmental-friendly. For example, the new greenness indicators can increase the environmental-friendliness and sustainability in the business operation and the flexibility can improve the market satisfaction. Although the price is higher than the previous procurement for this case, the quality and the general after-sales service are much better too after implementing the new indicator system.

In addition, the research takes the fuzzy-entropy to determine the weight with the consideration of both subjectivity and objectivity, so the weight is changeable, because the objective weight comes from the quantitative evaluation data, so every evaluation case has different weight. The original fixed indicator weights cannot flexibly evaluate the importance of each indicator for different cases with strong subjectivity, because the original indicator system and weights were decided by the leadership based on empirical judgement, leading to a decline in average product quality and a high risk of customer complaints.

However, the comprehensive weight with the consideration of the essential property of the quantitative data (entropy and ordinality) is more objective, and the quality test pass rate keeps 100% after implementation, so the quality expert comments that the new evaluation model is very helpful in improving the competitiveness and market satisfaction of the products. Furthermore, fuzzy-TOPSIS identifies the positive and negative ideal solutions from the evaluation data for each indicator, and then measures the distance between each supplier's performance and the ideal solution, so that the difference in performance can be specifically identified to accurately rank the suppliers. The original ranking method is very crude, although there were weights and evaluation data, multiplying them together can immediately select the optimal solution, but often in the decision-making meeting each manager will express different views (the selected supplier is not the most suitable), resulting in inefficient evaluation and time cost loss, so it needs multiple decision-making meetings and voting to select the optimal supplier. The new indicator system integrates the experts' requirements for suppliers and professional research outcomes, and the fuzzy-TOPSIS provides a comprehensive and precise analysis of performance differences between suppliers, so in the future the new evaluation method requires only one decision meeting to determine the optimal supplier, which greatly increases the efficiency of the evaluation.

Moreover, the subjective weight rank shows that the expert considers the Quality, Greenness and Flexibility as the top three of weights which are important for the business development and regards Quality as the most important, so furniture green suppliers should continuously improve the general quality of the furniture, green operation and market response speed. S1 as the best supplier can provide higher-quality and eco-friendly products compared to other suppliers, including advantages such as good green production technology, eco-friendly raw materials, good green image, high level of technological innovation and keen market response speed and so on.

Through two case studies and the second expert meeting, the experts conclude that the evaluation effect of Fuzzy-entropy-TOPSIS is consistent with their expectation, which means good accuracy and practicality. Meanwhile, the weight and the evaluation data of each indicator are consistent with the supplier rank. For example, the top 3 of the comprehensive weight is quality, greenness and flexibility, and S1 and S11's these performances are the best when comparing with other suppliers, and the major outcome of the sensitivity analysis is S1 (36/50) too, so the evaluation result is accurate, reasonable and stable.

For the future research, the application scope of the model could be expanded by adapting the evaluation indicator system of new areas such as logistics, communication and chemicals, while the increase of the number of suppliers and indicators could further validate the practicality and generality of fuzzy-entropy-TOPSIS. Finally, as the overall application process is still relatively complex, future research could seek to reduce some of the non-essential steps.

All in all, the new indicator system and fuzzy-entropy-TOPSIS have made JA's supplier evaluation process more systematic, standardised and scientific, which has greatly improved the efficiency, accuracy and effectiveness of its green supplier evaluation and solves all evaluation problems to enhance its competitiveness, sustainability and market satisfaction.

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APPENDICES

Appendix A: Supplier Evaluation Questionnaire for Furniture Supplier

Name of Expert（姓名）:

Position（职务）:

Supplier (Code, 供应商代码):

Date（日期）:

Part 1: The Importance of First-level Indicator（一级评价指标的重要性）

1. Quality(质量)
   ☐ Very Low ☐ Low ☐ Medium ☐ High ☐ Very High

2. Cost(成本)
   ☐ Very Low ☐ Low ☐ Medium ☐ High ☐ Very High

3. Delivery Rate(交付率)
   ☐ Very Low ☐ Low ☐ Medium ☐ High ☐ Very High

4. Greenness(绿色度)
   ☐ Very Low ☐ Low ☐ Medium ☐ High ☐ Very High

5. Flexibility(柔性)
   ☐ Very Low ☐ Low ☐ Medium ☐ High ☐ Very High

Part 2: The Ratings of Second-level Qualitative Indicators (二级定性指标评级)

1. Greenness(绿色度指标)

1) Pollution Emissions(污染物排放)
☐ Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good

2) Energy Consumption(能源消耗)
☐ Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good

3) Clean Technology(清洁技术)
☐ Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good

4) Green Design(绿色设计)
☐ Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good

5) Green Certification(绿色认证)
☐ Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good

6) Environmental Management(环保管理)
☐ Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good

7) Green Commitment(绿色承诺)
☐ Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good

2. Flexibility(柔性指标)

1) Response Speed(反应速度)
☐ Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good

2) Innovation Ability(创新能力)
☐ Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good

3) Service Ability(服务能力)
☐ Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good

Part 3: The Data of Second-level Quantitative Indicators
(二级定量指标的数据)

1. Quality (for quality controller only) 质量(仅由质控填写)

1) Quality Compliance Rate(质量合格率):

2) Structural Compliance Rate(结构合格率):

3) Transport Quality Compliance Rate(运输质量合格率):

2. Cost (for supply chain manager only) 成本(仅由供应链经理填写)

1) Product Prices(产品价格):

2) Transport Cost(运输成本):

3) Environmental Management Cost(环保治理成本):

3. Delivery Rate (for transport coordinator only) 交付率(仅由运输协调员填写)

1) On-time Delivery Rate(及时交付率):

2) Order Completion Rate(订单完成率):

3) Special Order Completion Rate(特殊订单完成率):

Appendix B: The Discussion Topics of Expert Penal Meeting

1. What are the problems in the supplier evaluation and selection process?
2. What indicators can help JA company evaluate green furniture and green transport suppliers more accurately and correctly?
3. Evaluate the performance and effect of the Supplier Evaluation and Selection Method in the Thesis.

Appendix C: The outcome of sensitivity analysis

CC1 : 36 times; CC2: 12 times; CC3: 4 times

CC1 : 36/50= 0.72

CC2 : 12/50= 0.24

CC3 : 2/40= 0.04

The weights (C_l) of first-level indicators	CC1	CC2	CC3	Optimum Supplier
W_1 =(0,0.3,0.5); W_{2-5} =(0,0,0.3)	0.8192	0.3127	0.5603	CC1
W_2 =(0,0.3,0.5); $W_{1,3,4,5}$ =(0,0,0.3)	0.6620	0.4667	0.4446	CC2
W_3 =(0,0.3,0.5); $W_{1,2,4,5}$ =(0,0,0.3)	0.9028	0.6039	0.0852	CC1
W_4 =(0,0.3,0.5); $W_{1,2,3,5}$ =(0,0,0.3)	0.8761	0.2184	0.6465	CC2
W_5 =(0,0.3,0.5); W_{1-4} =(0,0,0.3)	0.6174	0.3654	0.5695	CC1
W_1 =(0.2,0.5,0.8); W_{2-5} =(0,0,0.3)	0.9421	0.6042	0.0506	CC1
W_2 =(0.2,0.5,0.8); $W_{1,3,4,5}$ =(0,0,0.3)	0.9063	0.1679	0.6863	CC2
W_3 =(0.2,0.5,0.8); $W_{1,2,4,5}$ =(0,0,0.3)	0.9589	0.6043	0.0360	CC1
W_4 =(0.2,0.5,0.8); $W_{1,2,3,5}$ =(0,0,0.3)	0.9258	0.1345	0.7086	CC2
W_5 =(0.2,0.5,0.8); W_{1-4} =(0,0,0.3)	0.9686	0.6043	0.0274	CC1
W_1 =(0.5,0.7,1); W_{2-5} =(0,0,0.3)	0.7073	0.5180	0.3567	CC1
W_2 =(0.5,0.7,1); $W_{1,3,4,5}$ =(0,0,0.3)	0.6736	0.5924	0.2831	CC2
W_3 =(0.5,0.7,1); $W_{1,2,4,5}$ =(0,0,0.3)	0.6778	0.5764	0.3014	CC3
W_4 =(0.5,0.7,1); $W_{1,2,3,5}$ =(0,0,0.3)	0.7582	0.6015	0.2080	CC2
W_5 =(0.5,0.7,1); W_{1-4} =(0,0,0.3)	0.7368	0.4577	0.4173	CC1
W_1 =(0.7,1,1); W_{2-5} =(0,0,0.3)	0.6696	0.5920	0.2878	CC1
W_2 =(0.7,1,1); $W_{1,3,4,5}$ =(0,0,0.3)	0.6791	0.5542	0.3301	CC2
W_3 =(0.7,1,1); $W_{1,2,4,5}$ =(0,0,0.3)	0.8113	0.6025	0.1642	CC3
W_4 =(0.7,1,1); $W_{1,2,3,5}$ =(0,0,0.3)	0.7639	0.4075	0.4673	CC2
W_5 =(0.7,1,1); W_{1-4} =(0,0,0.3)	0.6618	0.5976	0.2877	CC1
W_1 =(0.2,0.5,0.8); W_{2-5} =(0,0.3,0.5)	0.6777	0.5307	0.3610	CC1
W_2 =(0.2,0.5,0.8); $W_{1,3,4,5}$ =(0,0.3,0.5)	0.8483	0.6031	0.1326	CC1
W_3 =(0.2,0.5,0.8); $W_{1,2,4,5}$ =(0,0.3,0.5)	0.6932	0.5501	0.3240	CC1
W_4 =(0.2,0.5,0.8); $W_{1,2,3,5}$ =(0,0.3,0.5)	0.6741	0.5947	0.2793	CC2
W_5 =(0.2,0.5,0.8); W_{1-4} =(0,0.3,0.5)	0.6764	0.5864	0.2889	CC1

The weights (C_l) of first-level indicators	**CC1**	**CC2**	**CC3**	**Optimum Supplier**
W_1 =(0.5,0.7,1); W_{2-5} =(0,0.3,0.5)	0.7263	0.6009	0.2332	CC1
W_2 =(0.5,0.7,1); $W_{1,3,4,5}$ =(0,0.3,0.5)	0.7128	0.5061	0.3687	CC1
W_3 =(0.5,0.7,1); $W_{1,2,4,5}$ =(0,0.3,0.5)	0.6731	0.5919	0.2843	CC1
W_4 =(0.5,0.7,1); $W_{1,2,3,5}$ =(0,0.3,0.5)	0.6782	0.5724	0.3065	CC2
W_5 =(0.5,0.7,1); W_{1-4} =(0,0.3,0.5)	0.5516	0.7177	0.1989	CC1
W_1 =(0.7,1,1); W_{2-5} =(0,0.3,0.5)	0.7695	0.6017	0.1989	CC1
W_2 =(0.7,1,1); $W_{1,3,4,5}$ =(0,0.3,0.5)	0.6884	0.5616	0.3122	CC1
W_3 =(0.7,1,1); $W_{1,2,4,5}$ =(0,0.3,0.5)	0.6741	0.5957	0.2777	CC1
W_4 =(0.7,1,1); $W_{1,2,3,5}$ =(0,0.3,0.5)	0.6758	0.5897	0.2848	CC2
W_5 =(0.7,1,1); W_{1-4} =(0,0.3,0.5)	0.6189	0.6507	0.2423	CC1
W_1 =(0.5,0.7,1); W_{2-5} =(0.2,0.5,0.8)	0.7144	0.6006	0.2423	CC1
W_2 =(0.5,0.7,1); $W_{1,3,4,5}$ =(0.2,0.5,0.8)	0.8192	0.3127	0.5603	CC1
W_3 =(0.5,0.7,1); $W_{1,2,4,5}$ =(0.2,0.5,0.8)	0.6620	0.4667	0.4446	CC1
W_4 =(0.5,0.7,1); $W_{1,2,3,5}$ =(0.2,0.5,0.8)	0.9028	0.6039	0.0852	CC2
W_5 =(0.5,0.7,1); W_{1-4} =(0.2,0.5,0.8)	0.8761	0.2184	0.6465	CC1
W_1 =(0.7,1,1); W_{2-5} =(0.2,0.5,0.8)	0.6174	0.3654	0.5695	CC1
W_2 =(0.7,1,1); $W_{1,3,4,5}$ =(0.2,0.5,0.8)	0.9421	0.6042	0.0506	CC1
W_3 =(0.7,1,1); $W_{1,2,4,5}$ =(0.2,0.5,0.8)	0.9063	0.1679	0.6863	CC1
W_4 =(0.7,1,1); $W_{1,2,3,5}$ =(0.2,0.5,0.8)	0.9589	0.6043	0.0360	CC2
W_5 =(0.7,1,1); W_{1-4} =(0.2,0.5,0.8)	0.9258	0.1345	0.7086	CC1
W_1 =(0.7,1,1); W_{2-5} =(0.5,0.7,1)	0.9686	0.6043	0.0274	CC1
W_2 =(0.7,1,1); $W_{1,3,4,5}$ =(0.5,0.7,1)	0.7073	0.5180	0.3567	CC1
W_3 =(0.7,1,1); $W_{1,2,4,5}$ =(0.5,0.7,1)	0.6736	0.5924	0.2831	CC1
W_4 =(0.7,1,1); $W_{1,2,3,5}$ =(0.5,0.7,1)	0.6778	0.5764	0.3014	CC2
W_5 =(0.7,1,1); W_{1-4} =(0.5,0.7,1)	0.7582	0.6015	0.2080	CC1

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