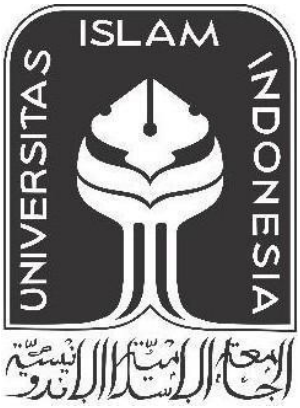
IMPLEMENTATION OF THE FUZZY ANALYTICAL HIERARCHY PROCESS (AHP) IN VENDOR SELECTION DECISION MAKING FOR SPARING PROCUREMENT: A CASE STUDY OF PT TUAH TURANGGA AGUNG, EAST JAKARTA

UNDERGRADUATE THESIS

Submitted to the International Undergraduate Program in Industrial Engineering in Partial Fulfilment of Requirement for the Degree of Sarjana Teknik at the Faculty of Industrial Technology Universitas Islam Indonesia



By

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UNDERGRADUATE PROGRAM IN INDUSTRIAL ENGINEERING

FACULTY OF INDUSTRIAL TECHNOLOGY

UNIVERSITAS ISLAM INDONESIA

YOGYAKARTA

2025

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For the sake of Allah SWT, I admit this work is the result of my own work, except for the excerpts and summaries from which I have explained the source. If in the future, it turns out that my confession is proven to be untrue and violates the legal regulations in the paper and intellectual property rights. In that case, I am willing to get a diploma that I have received to be withdrawn by Universitas Islam Indonesia.

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DEDICATION PAGE

This report is dedicated to my parents and family, whose constant support, guidance, and encouragement have been invaluable in the completion of this work. Their presence has remained a source of motivation and strength throughout this journey.

MOTTO

"Trust Allah, and He will take care of you."
(QS. At-Talaq: 3)

"Hope never ends with Allah's mercy."
(QS. Az-Zumar: 53)

"The best among you are those who have the best manners and character."
(HR. Bukhari & Muslim)

"Success comes only from Allah."
(QS. Hud: 88)

"Never alone, Allah is with you."
(QS. Al-Hadid: 4)

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This undergraduate thesis is a form of implementing the knowledge gained during academic studies as well as fulfilling one of the requirements to obtain a bachelor's degree in the Department of Industrial Engineering, Faculty of Industrial Technology, Islamic University of Indonesia.

The author realizes that in preparing this thesis report, many difficulties and challenges were encountered, both in terms of content and writing structure. However, thanks to the guidance, support, and encouragement of various parties, this thesis could finally be completed. With heartfelt sincerity, the author would like to express the deepest gratitude and appreciation to:

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Hopefully, this thesis report may bring meaningful benefits to readers in general and to the company in particular. The researcher is fully aware that this undergraduate thesis is far from perfect, and therefore with humility and sincerity, welcomes constructive criticism and valuable suggestions from readers as guidance for future improvement and research. May this work, though simple, contribute positively and inspire further development.

Yogyakarta, 25 August 2025



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ABSTRACT

Vendor selection is a critical process in supply chain management, particularly in industries that depend on the timely procurement of spare parts. This study investigates the application of the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) to optimize the vendor selection process for sparing procurement at PT Tuah Turangga Agung, a metalworking company in East Jakarta. Traditional vendor selection methods often rely on subjective judgments, leading to inefficiencies and uncertainty. Fuzzy AHP, an extension of the Analytical Hierarchy Process (AHP), incorporates fuzzy logic to address these challenges by providing a more accurate and flexible decision-making approach in real-world procurement scenarios.

The research identifies six key evaluation criteria: Quality, Cost, Delivery, Environment, Safety, and Morale. These criteria were derived through expert assessments and used in a pairwise comparison matrix, with fuzzy numbers applied to capture uncertainty in expert judgments. The results show that Fuzzy AHP offers a structured, reliable, and transparent framework for vendor evaluation, allowing for a more objective ranking of potential vendors. Vendor A4 emerged as the optimal choice, excelling in Quality, Environment, and Safety, which are essential for minimizing downtime and ensuring the availability of reliable spare parts.

This research improves the sparing procurement process by providing a systematic approach to vendor selection, thereby reducing risks and enhancing decision-making efficiency. Additionally, it offers insights into the practical application of Fuzzy AHP in procurement, contributing to its broader use in industries where uncertainty plays a significant role in decision-making.

Keywords: Sparing Procurement, Vendor Selection, Fuzzy AHP, Supply Chain Management, Multi-Criteria Decision-Making, Uncertainty, Vendor Evaluation.

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CHAPTER I
INTRODUCTION

1.1 Study Background

The effectiveness of supply chain management frequently hinges on how a firm evaluates and selects its vendors. In industries such as automotive repair, machinery maintenance, and heavy fabrication, the right supplier can be the dividing line between streamlined operations and chronic delay. Indonesia has recently witnessed a surge in the aftermarket-parts trade, driven by equipment owners who can neither afford nor tolerate long outages. Suryo et al. (2019) credit the momentum to a broadening industrial base that includes both local assembly plants and overseas insurers keen to protect their export equipment. Yet many Indonesian firms remain mired in trial-and-error sourcing because detailed scoring frameworks have yet to become standard practice.

The consequences show up in inflated costs and lost hours that could otherwise be billed to customers. PT Tuah Turangga Agung, a mid-sized metal shop located in East Jakarta, relies on uninterrupted service from its machining centres, every hour of downtime translates into tangible revenue evaporating. Haryanto and Irwansyah (2020) summarize the impact succinctly successful vendor choice determines both spare-part flow and the billable hours available during outages. Ineffective vendor selection can trigger serious operational drag, especially in time-sensitive industries like manufacturing, where spare-parts arrival must never lag (Wang et al. 2018). Building a shortlist begins with a rigorous dive into price, quality, lead-time reliability, and overall vendor responsiveness. Still, many buyers lean on gut feel or legacy partnerships, missing critical dimensions such as service consistency and resilience during downturns.

That gap has opened space for tools designed to wrestle uncertainty and vague trade-offs into workable numbers. The Analytic Hierarchy Process does exactly that, giving teams a formal grind for ranking a clutch of competing offers. Developed by Saaty in the early 1980s, the method chops big dilemmas into bite-sized pairwise comparisons, letting participants score prospects one attribute at a time. Even so, classic AHP rests on the shaky premise that all input values are crisp and certain-a claim most practitioners can no longer honestly defend. The classical Analytic Hierarchy Process works well enough in tidy assignments, but real-world vendor selection usually steps into murky waters. Enter the Fuzzy Analytical Hierarchy Process, a close cousin that swaps crisp numbers for fuzzy sets and softens the blow of subjective judgment. Zadeh first sketched the logic way back in 1965, arguing that his theory shines when facts wobble and certainty eludes experts. Empirical studies have since plugged Fuzzy AHP into purchasing scenarios as varied as manufacturing, IT, and public supply chains. Sharma and Mishra (2020) put it bluntly: in complex environments, fuzzy methods like Fuzzy AHP are no longer optional.

Field tests in Indonesia underscore the point. Price swings, currency jumps, late shipments, and the odd regional blockade can wreck forecasts overnight. Spare-

parts operations feel that crunch first, since any hitch translates to outright downtime. A mine contractor such as PT Tuah Turangga Agung weighs quality, cost, turnaround, and post-sale support, yet each of those criteria changes mood every quarter. Fuzzy AHP handles that uncertainty by treating the data as ranges or swarms, not as single point estimates. The result is a more coherent ranking that still respects the messy reality of everyday trade. Fuzzy AHP gives purchasing managers a framework for systematically ranking suppliers along both hard metrics-cost, lead time-and softer ones such as reliability and after-sales support, thereby reducing the likelihood of onboarding a poor-performing partner. Taha et al. (2021) observe that by embedding a fuzzy mechanism, the method fortifies conventional decision models against the usual slippage that comes from incomplete or murky data.

Hands-on, though, the technique still demands that the evaluators know their criteria inside and out and can translate their intuitive judgments into crisp numerical forms. Spare-parts sourcing is notoriously tricky in this regard, because buyers are forever juggling blunt figures and squishier inputs like vendor trustworthiness and responsiveness. Govindan et al. (2017) emphasize the appeal of Fuzzy AHP in settings just like this, arguing that it pulls both objective and subjective signals onto a single scale so firms can decide with greater confidence when uncertainty reigns. The present investigation applies the approach to PT Tuah Turangga Agungs own component-vendor selection challenge, hoping to see whether the method really delivers under live market conditions.A better vendor-selection routine can often close that final gap between good purchasing and great purchasing-what executive teams sometimes call a performance breakthrough.

By revisiting the checklist of criteria they already use and then folding in fuzzy AHP, this study aims to make the choice both quicker and more trustworthy. Amit (2019) puts it plainly: firms that lean on structured methods such as fuzzy AHP slash procurement risk and keep supplier picks in step with their broader strategic game plan.

1.2 Problem formulation

The problem formulation according to the study background of this research as the following:

1. What are the key criteria that should be considered when evaluating potential suppliers for SPARING procurement at PT Tuah Turangga Agung?
2. How can the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) be applied to evaluate the performance of these key criteria in the vendor selection process at PT Tuah Turangga Agung?
3. How does Fuzzy AHP handle uncertainty and subjectivity in the vendor evaluation process compared to traditional methods?
4. Based on the evaluation of vendor performance using Fuzzy AHP, what is the optimal vendor selection for SPARING procurement at PT Tuah Turangga Agung?
5. Based on the vendor selection model derived from Fuzzy AHP, what recommendations can be made to improve the procurement process and minimize risks associated with spare part procurement at PT Tuah Turangga Agung?

1.3 Research Objective

The objective of this research according to the study background of this researchare as the following:

1. To identify the key criteria for evaluating potential suppliers in SPARING procurement at PT Tuah Turangga Agung
2. To develop a Fuzzy AHP-based multi-criteria evaluation model for vendor selection, incorporating both quantitative and qualitative criteria
3. To evaluate supplier performance based on the established criteria using the Fuzzy AHP model
4. To provide actionable recommendations for improving the vendor selection process at PT Tuah Turangga Agung

1.4 Research Benefit

The benefit of this research for other people is as follows:

1. Developing a Vendor Selection Model**:** This research provides a Fuzzy AHP-based model that companies can use to improve how they evaluate vendors for SPARING procurement.
2. Foundation for Future Research: This study creates a base for future research, allowing others to adapt the Fuzzy AHP model to different industries or regions.
3. Improving Decision-Making: The research shows how Fuzzy AHP can help companies make better decisions by handling uncertainty and subjectivity in vendor evaluations.
4. Enhancing Procurement Efficiency and Reducing Risks: The model helps companies optimize their vendor selection process, reducing procurement risks like delays and poor-quality parts.
5. Practical Insights for Practitioners**:** This research provides valuable insights for procurement professionals, showing them how to use Fuzzy AHP to make more informed vendor selection decisions

1.5 Systematic Writing

The systematics writing of this report is needed for more structured writing for the benefit of the author as well for the reader of this report are as the following:

CHAPTER I INTRODUCTION

This chapter contains the study background on this research based on the researcher's observation of the topic situation and addresses the problem formulation that the researcher found as well as the objective and benefit of this research.

CHAPTER II LITERATURE REVIEW

This chapter contains the inductive study that the researcher used to gain more knowledge of the problem and found the tool to solve the problem and the deductive study that the

researcher used as a theoretical foundation to write this report.

CHAPTER III RESEARCH METHODOLOGY

This chapter contains the research object of this report, what data are being used, the tools to process those data, and a detailed flowchart that explains the flow of this research.

CHAPTER IV DATA COLLECTION AND PROCESSING

This chapter contains the collected data that the research has collected which is displayed using figures and tables and the detailed processing of the data to get the output.

CHAPTER V DISCUSSION

This chapter contains the result from the data processing of the previous chapter and the discussion of that result to find the conclusion as well as the suggestion.

CHAPTER VI CONCLUSION AND SUGGESTION

This chapter contains the conclusion that has been discussed as well as the suggestion of recommendations from the data that have been analyzed that can be implemented in the research object.

REFERENCE This chapter contains the reference used for this research to help the researcher expand its research knowledge by quoting other people quote that can be use in this research.

APPENDIX This chapter contains the attachment that are used for this research either diagram or table attachment.

CHAPTER II
LITERATURE REVIEW

2.1 Inductive Study

Inductive research provides a valuable foundation for this study, offering insights into how Fuzzy AHP has been applied in the procurement decision-making process, particularly in vendor selection. This section reviews relevant studies that highlight the use of Fuzzy AHP in evaluating suppliers, addressing the key criteria, and handling uncertainty and imprecision in decision-making.

No	Tittle	Researcher (year)	Method	Result
1	Application of the Analytic Hierarchy Process and Grey Relational Analysis for Vendor Selection of Spare part Planning Software	Weng, S. S., Chen, K. Y., & Li, C. Y. (2019)	The study applies a combination of Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA) to evaluate and select vendors for Spare part planning software.	The researchers found that combining AHP and GRA helps in identifying key supplier selection criteria, including cost and delivery performance. They concluded that integrating these methods could improve decision-making in the procurement process by reducing uncertainty in vendor evaluation. The study highlights that the combination of these methods

No	Tittle	Researcher (year)	Method	Result
				provides a more systematic and reliable approach in uncertain vendor selection scenarios.
2	Supplier Selection Criteria Using Analytical Hierarchy Process (AHP)-Based Approach: A Study in Refractory Materials Manufacturers	Tan, C. L., Yeo, S. F., & Lin, G. H. (2023)	The paper uses the Analytic Hierarchy Process (AHP) for supplier selection criteria evaluation, emphasizing the decision-making process in the refractory materials manufacturing sector.	The researchers identified several criteria that significantly influence vendor selection, including price, quality, and delivery time. They found that AHP could effectively rank suppliers based on these criteria. The study further revealed that price was the most critical factor, followed by delivery time, while other factors like service quality were also important but to a lesser degree.

No	Tittle	Researcher (year)	Method	Result
3	Fuzzy Analytical Hierarchy Process for Evaluating and Selecting a Vendor in a Supply Chain Model	Haq, A. N., & Kannan, G. (2006)	This study uses Fuzzy AHP to evaluate and select vendors in a supply chain model, incorporating fuzzy logic to handle uncertainty and imprecision in decision-making.	The study found that Fuzzy AHP could effectively handle the uncertainty and vagueness inherent in vendor selection. The researchers identified that traditional methods often failed to consider qualitative aspects like vendor reliability and service, which were captured using Fuzzy AHP. This method helped prioritize vendors who offered more dependable and flexible services despite higher costs.
4	A Fuzzy-AHP Multi-Criteria Decision-Making Model for Procurement Process	Saad, S. M., & Kunhu, N. (2016)	The research implements a Fuzzy AHP decision-making model for evaluating procurement	The study revealed that Fuzzy AHP is an effective tool for managing complex procurement decisions that involve both

No	Tittle	Researcher (year)	Method	Result
			processes, considering multiple criteria such as cost, quality, and delivery time.	qualitative and quantitative factors. The researchers found that cost and quality were the most important factors when selecting a vendor, but flexibility and responsiveness also played crucial roles in improving procurement outcomes. They emphasized that Fuzzy AHP helped address subjectivity in decision-making.
5	Fuzzy AHP-Based Supplier Selection in E-Procurement	Benyoucef, M., & Canbolat, M. (2007)	The study proposes a Fuzzy AHP approach for supplier selection in e-procurement, integrating fuzzy logic to improve	The researchers found that traditional supplier selection methods often failed to account for uncertainties such as fluctuating market conditions and supplier risks. By applying Fuzzy AHP,

No	Tittle	Researcher (year)	Method	Result
			supplier evaluation accuracy.	they identified key performance indicators (KPIs) that could be used to evaluate suppliers more effectively. The study concluded that Fuzzy AHP provided a more structured and reliable approach to supplier selection in e-procurement environments.
6	A Practical Framework for Supplier Selection Decisions with an Application to the Automotive Sector	Hadian, H., & Chahardoli, S. (2020)	The study develops a practical framework that combines AHP and Fuzzy AHP for supplier selection, focusing on the automotive sector.	The researchers identified that AHP and Fuzzy AHP helped decision-makers handle both quantitative factors like cost and delivery time, as well as qualitative factors such as supplier reliability and service. They found that the framework enabled more

No	Tittle	Researcher (year)	Method	Result
				transparent decision-making by considering various factors in supplier evaluation, ultimately leading to better supplier selection decisions.
7	Using AHP to Evaluate the Criteria of Auto spare part Industry	Wu, H. H., & Tsai, Y. N. (2012)	AHP is applied to evaluate various criteria influencing vendor selection in the auto Spare part industry, specifically focusing on price, quality, and delivery performance.	The study revealed that AHP is highly effective in evaluating the trade-offs between different selection criteria in the auto Spare part industry. The researchers found that price and quality were the most significant factors, while vendor responsiveness and service quality were also essential but less important compared to cost and quality.
8	An integrated multi-criteria	Ghosh, S., Bhowmik, C.,	The study integrates multi-	The researchers explored the use of

No	Tittle	Researcher (year)	Method	Result
	decision-making and multivariate analysis towards sustainable procurement with application in the automotive industry	Sinha, S. (2023)	criteria decision-making (MCDM) methods and multivariate analysis to evaluate suppliers in the automotive industry	multi-criteria decision-making (MCDM) methods and multivariate analysis to enhance supplier selection in the automotive industry. The study found that integrating these methods helps to improve decision-making accuracy by assessing suppliers based on sustainability criteria. They emphasized the importance of addressing key factors like cost, delivery performance, and quality in supplier evaluation.
9	A two-stage multi-criteria supplier	TT Dang, NAT Nguyen, VTT Nguyen,	The study applies a two-stage multi-	This study applied a two-stage multi-criteria decision-

No	Tittle	Researcher (year)	Method	Result
	selection model for sustainable automotive supply chain under uncertainty	LTH Dang (2022)	criteria decision-making model for supplier selection under conditions of uncertainty in the automotive industry.	making model under uncertain conditions for supplier selection in the automotive supply chain. The researchers found that the proposed model enhances the supplier selection process by addressing critical factors such as cost, quality, and sustainability under varying uncertainty levels. They emphasized that such a model helps in improving supplier decision-making in an uncertain environment.
10	Supplier selection using fuzzy AHP and TOPSIS: a case study in the	V Jain, AK Sangaiah, S Sakhuja (2018)	The authors use fuzzy AHP and TOPSIS for supplier selection in the	The study successfully integrates fuzzy AHP and TOPSIS to improve supplier

No	Tittle	Researcher (year)	Method	Result
	Indian automotive industry		automotive industry, addressing multiple criteria such as quality, cost, and delivery time.	selection, demonstrating the methods' reliability and effectiveness in decision-making.

Table 1 inductive study

These inductive studies underscore the versatility of Fuzzy AHP in various industries, particularly where supplier selection involves both quantitative and qualitative criteria. Across the studies, cost, quality, and delivery performance consistently emerged as key criteria. However, only Fuzzy AHP-based studies such as those by Haq & Kannan (2006) and Benyoucef & Canbolat (2007) address the uncertainty inherent in supplier selection by incorporating subjective judgment, such as vendor reliability, service quality, and vendor flexibility. Moreover, these studies highlight Fuzzy AHP's ability to integrate multiple criteria for decision-making, especially in environments where market conditions fluctuate and data is uncertain. In particular, studies like those by Saad & Kunhu (2016) and Weng et al. (2019) emphasize that Fuzzy AHP's inclusion of fuzzy logic enhances the accuracy and robustness of vendor evaluations. Therefore, the Fuzzy AHP model is well-suited for PT Tuah Turangga Agung's spare part procurement process, where both objective data (e.g., cost) and subjective evaluations (e.g., vendor trustworthiness) must be considered under uncertain circumstances.

2.2 Deductive Study

2.2.1 Supply Chain Management (SCM)

Supply Chain Management or SCM is a fundamental business discipline, supply chain management (SCM) emphasizes on the effective flow of goods and services from the place of origin to the last consumer. SCM, according to Harland (1996), is the process of controlling the flow of resources, goods, services, and knowledge from raw material suppliers to the end user. This entails the movement, storage, processing, and fulfillment of raw materials which are finally turned into completed commodities and sold to the market.

Slack (n.d.) claims that SCM is seen as an interconnected network of channels cooperating to offer end users the necessary goods or services. It involves the coordination and integration of several organizational tasks and outside partners to guarantee the effective flow of resources along the supply chain. Minimizing expenses is the aim while maximizing the movement of goods and services throughout the network.

APICS (2016) offers a more comprehensive definition, characterizing SCM as the design, planning, execution, management, and monitoring of supply chain activities. Aimed at generating net value, this method promotes a competitive infrastructure, uses logistics, synchronizing supply and demand, and performance measurement. covering fields like industrial engineering, systems engineering, operations management, logistics, procurement, information technology, and marketing, SCM is naturally a multidisciplinary profession (Kozlenkova et al., 2015). It aims for a combined strategy combining several technologies, tactics, and approaches to maximize supply chain performance (Sanders & Wagner, 2011).

From the procurement of raw materials to the delivery of finished goods to end consumers, SCM aims to coordinate the whole supply chain while minimizing expenses (Sadeghi et al., 2016). Managing the flow of raw resources into a company, turning them into finished goods, and supervising the supply and transportation of these products to consumers are toward its main purposes. Additionally critical for improving customer demand fulfillment and reducing logistical running costs . Through enhancing the link between supply chain participants, SCM can enhance inventory visibility and simplify product flow (Hemold, 2016).

2.2.2 Supply Chain Component

The supply chain is a complex network that includes several interconnected components. Each component plays a pivotal role in the efficient flow of goods, services, and information. These components must be strategically managed to ensure the overall performance of the supply chain is optimized. Below are detailed description of the key components of the supply chain.

According to Chopra and Meindl (2016), the primary components of the supply chain include procurement, production, distribution, and customer service. These components are strategically managed to achieve optimal performance and minimize costs across the entire chain. Below is an overview of the main components of a supply chain :

1. Suppliers:
   Suppliers are the foundation of any supply chain, providing the raw materials, components, or services required for production. The supplier's role is crucial, as it directly influences the availability, cost, and quality of materials used in the production process. Effective supplier management is vital to maintaining a steady supply of inputs and ensuring production continuity. According to Monczka et al. (2009), managing supplier relationships and monitoring supplier performance are key to minimizing risks and ensuring the timely delivery of materials.
2. Procurement:
   Procurement involves the sourcing and purchasing of raw materials, components, and services from suppliers. This component is responsible for acquiring the necessary inputs required for production at the right time and cost. A well-managed procurement process ensures that the right quantities of quality materials are available when needed, which is critical to preventing production delays and minimizing inventory costs. In their study, Ballou (2007)

emphasizes the importance of a strategic procurement process that aligns with the company's broader goals and supply chain objectives.

3. Production:
   The production component involves the transformation of raw materials into finished goods. It includes processes such as manufacturing, assembly, and quality control. Efficient production is essential for meeting customer demand on time while minimizing costs associated with waste, rework, and production delays. Sanders and Wagner (2011) discuss the significance of lean manufacturing and agile manufacturing principles in enhancing production efficiency and responsiveness to changes in demand.
4. Inventory Management:
   Inventory management involves the storage and handling of raw materials, work-in-progress, and finished goods. Effective inventory management ensures that there is enough stock available to meet customer demand without overstocking, which can tie up capital and increase storage costs. As Christopher (2011) notes, maintaining an optimal level of inventory is a balancing act that requires careful forecasting and demand planning.
5. Distribution:
   Distribution is the process of delivering finished goods from production facilities to customers or retailers. This component includes warehousing, transportation, and order fulfilment. The efficiency of the distribution network directly impacts lead times, transportation costs, and customer satisfaction. Harrison and van Hoek (2011) highlight the role of distribution networks in meeting customer expectations, emphasizing the need for integrated logistics solutions that improve delivery speed and reduce costs.
6. Customer Service:
   Customer service in the supply chain focuses on ensuring that customer orders are fulfilled accurately and promptly. It also involves handling customer inquiries, returns, and complaints. High-quality customer service is crucial for building long-term relationships with customers and enhancing brand loyalty. According to Lee (2000), excellent customer service is a key driver of supply chain success, as it directly impacts customer satisfaction and retention.
7. Information Flow:
   Information flow is the backbone of a supply chain, enabling seamless coordination between suppliers, manufacturers, distributors, and customers. Effective communication and data sharing ensure that all stakeholders are aligned and can make informed decisions. Information systems, such as Enterprise Resource Planning (ERP) and Supply Chain Management (SCM) software, are essential for integrating these components and improving visibility across the supply chain (Simchi-Levi et al., 2003). Real-time data exchange helps optimize inventory levels, production schedules, and delivery routes.
8. Reverse Logistics:
   Reverse logistics refers to the process of managing product returns, recycling, or the disposal of goods at the end of their lifecycle. This component is increasingly important in industries such as electronics, automotive, and

consumer goods, where products may need to be returned for repair or recycling. Rogers and Tibben-Lembke (2001) emphasize that effective reverse logistics systems are critical for reducing waste and improving sustainability in supply chains.

It is difficult to underestimate the value of supply chain management (SCM) in a company since strong rivalry inside the larger networked economy and on the market depends on an efficient supply chain (Baziotopoulos, 2004). The development of globalization and the spread of multinational corporations have underlined the importance of businesses using SCM techniques to keep their competitive advantage. Effective supply chains enable many businesses to incorporate lean manufacturing and agile manufacturing ideas, which will help them to be successful (MacDuffie & Helper, 1997). Furthermore, technical developments especially in communication technologies have been really important in improving the coordination among members of the supply chains, in order facilitating the information sharing and supply chain operations optimization.

2.2.3 Definition vendor

A vendor is an individual or business that sells goods and services to another business for payment. A vendor, in reference to supply chain management, is an important external partner that supplies vital resources, products, or services that a business company needs for its operations. Vendors span from raw material vendors to sophisticated service providers.

A vendor makes a business's supply chain compete for a certain level of efficiency, cost, and quality. Monczka et al. (2009) state that "Vendors are integral to the effective flow of goods and services, which is vital for maintaining operational continuity and meeting production deadlines.". A business and a vendor relationship is often maintained through a formal agreement or contract outlining terms of delivery, pricing, quality, and delivery timelines. These types of agreements alleviate the burden of guarantees from both parties, allowing responsibilities to be achieved and the procurement process to be efficient. Vendors can be categorized into different groups as per their functions in a supply chain as a primary source of raw materials, secondary source of services or components, and tertiary providers like logistics companies or IT support companies.

Vendors, irrespective of their category, play a key part in influencing the cost and quality of the end products or services the organization provides. Meeting delivery schedules, maintaining product quality, and providing competitive pricing are crucial for any organization in procurement. A vendor's performance affects the production process's efficiency, the quality of the final product, and the company's market standing in terms of profitability and reputation. Wang et al. (2018) state, "The choice of a vendor has long-term implications, impacting cost structures, product quality, and overall supply chain performance." A dependable vendor not only provides goods or services in a timely manner and of excellent quality, but also supports agile business adjustments responsive to market shifts, thereby making such vendors invaluable partners for businesses looking to streamline procurement and reduce risk.

2.2.4 Vendor selection

Identifying the right vendor sits at the heart of any procurement effort and ultimately shapes how swiftly, affordably, and reliably goods or services flow through an organizations supply chain. That task is seldom straightforward, cost, product quality, delivery history, and the vendor own financial stability may each command attention. A selection process that weighs those factors evenly-Luthra and Jha, 2016-find, tends to shield firms from the hidden shocks of late shipments or defective inventories. Wang, Brown, and sales 2018 drive the point home by recalling a midsize machinery plant where one missed spare-part order rippled through production for weeks.

Their example keeps the stakes vivid and reminds decision-makers that the right partner is rarely the cheapest name on the shortlist. Choosing a vendor involves more than lining up unit costs beside promised ship dates. Decision-makers now weigh hard figures against subtler measures, including whether the vendor can hit the same quality mark quarter after quarter and whether complaints get answered before the next payroll. A study by Taha et al. (2021) notes that routine checklist approaches overlook the true, messy world of procurement, where prices whip up and subjective ratings swing with every earnings call. Those external bumps, left unfiltered, quietly smear the signal and throw off the election of a short-list partner.

Safeguarding against that drift still requires good prices, to be sure, yet the final thumbs-up also leans on less tangible things such as the sellers honest reputation, the smoothness of day-to-day service, and the chemistry of the working relationship. Saad and Kunhu (2016) argue that balancing cold metrics with these warmer signals is not a box-tick luxury but a core tactic for lining up vendor who really match an organizations strategic map. Getting that balance right, they add, does not just lower the odds of procurement nightmares it builds the kind of alliances that keep production humming year after year. According to Pujawan & Mahendrawathi (2017), there are 22 criteria that can be used as a guide to making decisions to make selections based on vendor performance.

Criteria	score
Quality	3.5
Delivery	3.4
Performance history	3.0
Warranties and claim policies	2.8
Price	2.8
Technical Capability	2.8

Financial Position	2.5
Procedural compliance	2.5
Communication system	2.5
Reputation and position in industry	2.4
Desire of business	2.4
Management and organization	2.3
Operating control	2.2
Repair service	2.2
Attitudes	2.1
Impression	2.1
Packaging ability	2.0
Labor relation records	2.0
Geographical location	1.9
Amount of past business	1.6
Training aids	1.5
Reciprocal arrangements	0.6

Table 2 guidence to making decision

2.2.5 Definition of procurement

Procurement describes the formal activity of securing goods, services, or construction work from outside providers so that an organization can meet its distinct requirements. Viewed from a strategic vantage point, the function aims to align timing, quality, legal compliance, and cost in each purchasing decision. Monczka et al. (2009) characterize the undertaking as a critical supply-chain lever that directly influences performance and, by extension, organizational success. When managed well, procurement keeps operations fluid, curbs runaway expenses, and delivers essential inputs when production schedules demand them. The workload of a procurement practitioner usually unfolds in discrete, consecutive steps. First, the team identifies what is needed, next it surveys available suppliers, then it evaluates bids, negotiates deal points, and finally signs a contract that governs the relationship. Taha et al. (2021) underscore that these deliberative phases help to soften risk, guarantee timely arrivals, and consequently bolster overall supply-chain efficiency. If even one step falters, delays, quality lapses, and other disruptive ripples may quickly reach the shop floor. The procurement discipline can

be distilled into several foundational activities, each demanding careful judgment. Needs identification, supplier exploration, and vendor endorsement recur so often that many practitioners treat them as sequential pillars of practice. the steps to carry out procurement process is following :

1. Identifying Procurement Needs
   The first pillar, needs identification, requires a frank inventory of what the organization must acquire and by when. Specifications are drafted alongside estimates of quantity and delivery dates so subsequent actions are guided by a fixed frame rather than moving targets.
2. Supplier Sourcing
   Once requirements are clear, attention shifts to supplier sourcing, the step where potential market partners are catalogued and compared. Monczka, Trent, and Handfield (2009) characterize this as the preliminary scouting that allows an organization to shortlist firms capable of satisfying its written needs.
3. Vendor Selection
   With candidates in hand, the actual selection hinges on cost, product quality, delivery dependability, and the overall health of supplier relations. Wang, et al. (2018) caution that a careless choice at this juncture can ripple through the supply chain, jeopardizing manufacturing uptime whenever crucial SPARING fall short.
4. Negotiation and Contracting
   After a vendor is chosen, the buyer pivots to bargaining over price, lead times, and quality thresholds. Saad and Kunhu (2016) observe that a meticulously negotiated contract removes ambiguity, aligning expectations and thereby forestalling later disputes.
5. Order Placement and Expediting
   With the contract signed, the procurement office formally places the purchase order. Expediting then demands close monitoring of shipment milestones to guard against slippage and ensure prompt arrival.
6. Receiving and Inspection
   When the delivery finally arrives, staff carry out a physical inspection to confirm that the goods satisfy both the specification sheets and the stipulated quality benchmarks.
7. Payment and Documentation
   Once verification is complete, payment is released, accompanied by the necessary invoices and shipping papers, thus closing the transaction in line with the pre-agreed terms.
8. Supplier Relationship Management
   Purchasing goods or services is only half the story, keeping the supplier engaged is the other half. Persistent dialogue, timely performance reviews, and a willingness to make adjustments are what turn a contract into a partnership. Monczka and colleagues observe that without this steady attention, problems linger longer than they should and improvements drift out of reach.
9. Post-Procurement Evaluation
   The work of sourcing does not stop the moment a shipment arrives. A thoughtful post-purchase audit asks whether the entire sequence met

expectations, where any weak links appeared, and how each supplier stood up to the original promise. Christopher argues that these periodic snapshots keep the buying effort in step with broader organizational aims and signal where fresh targets for efficiency lie.

In the end, procurement looks less like a single act and more like a relay race with multiple handoffs. Decision points, especially vendor selection, dictate speed and safety by weighting performance, cost, reliability, and risk. Get that choice right, and the rest of the process tends to fall into place.

2.2.6 Procurement objective

Procurement is not merely a transactional activity, it stands as the mechanism by which an organization secures whatever it needs to function without interruption. Cost, timing, and quality are the habitual triad, yet sturdy supplier relationships and risk mitigation dwell at the outer rim of the same circle. When these elements synchronize, operations run smoothly and strategic targets drift less out of reach. Such thinking appears in the early work of Gaspersz (2004) and Armstrong (2006) and continues to inform contemporary practice. It include the following :

1. Supply continuity
   Without a constant stream of materials or services, assembly lines stall, invoices pile up, and revenue leaks away. Experienced purchasers cultivate dependable vendors precisely to stop that clock from ticking. Delays, once they arrive, prove costly not merely in dollars but in reputation.
2. Quality
   protects the brand long after an invoice is filed. Inferior parts can ruin a product in seconds yet take months to forgive. Gaspersz (2004) puts it bluntly only those items that clear a company specific quality threshold ever see the factory floor. Meeting that threshold is not optional, it keeps regulators satisfied and customers loyal.
3. Cost Optimization
   Cost containment sits at the very heart of procurement strategy. The chief aim is to secure each item or service at the lowest feasible outlay, yet without sliding past the minimum quality and delivery thresholds the enterprise has set. As Armstrong (2006) observes, successful procurement marries thrift with reliability by matching spending decisions against explicit requirements for performance and lead time. That blend of vigilance and discipline allows the purchasing function to stretch its budget while sustaining, rather than sacrificing, operational capability.
4. Vendor Relationships
   Beyond price tags, procurement is also in the business of friendships- or at least, functional partnerships. Long-term ties with dependable suppliers often translate into quicker order fulfillment, preferential terms, and an inside track during material shortages. A vendor who knows your organization, and who senses that trust is reciprocal, tends to juggle production lines and shipping schedules just a little more nimbly. Armstrong (2006) reminds readers that negotiations never truly end, they evolve, and that evolution rests on ongoing collaboration rather than one-off transactions.

5. Delivery time
   For procurement professionals, securing a shipment on the right schedule often matters as much-or more-than negotiating a bargain price. An unanticipated lag in SPARING can grind a production line to a standstill, so the clock is a constant companion in the supply chain. Expediting orders, tracking transport milestones, and pestering carriers all become routine duties when the finish line is measured in days rather than weeks. Without those small, sometimes tedious interventions, customer promises quickly sour and the bottom line is left exposed.
6. Compliance with Legal and Ethical Standards
   Buying anything in the twenty-first century means reading the fine print long before an invoice arrives. Procurement teams must check that a shipment clears environmental codes, sidesteps prohibited materials, and does not lean on sketchy labor practices hidden offshore. Missing one of those boxes can cost the firm a headline-grabbing lawsuit or, worse, a reputation that took decades to build. In that sense, compliance is less an afterthought than the invisible glue holding modern purchasing decisions together.
7. Managing Risks
   A central component of procurement strategy is the early identification and subsequent mitigation of risks linked to the sourcing of goods and services. Such exposure often manifests in sudden price spikes, an unreliable supply chain base, geopolitical flashpoints, and general market volatility. Careful supplier selection, shrewd contract negotiation, and ongoing market surveillance serve as the toolkit for curtailing disruptions. As Gaspersz (2004) bluntly puts it, the function cannot afford to ignore potential price hikes, scarcity episodes, or other capricious market twists.
8. Maintaining Optimal Inventory Levels
   Procurement sits at the intersection of purchasing rhythm and inventory cadence, striving to secure just the right slug of materials when production lines demand it. Overstocking immobilizes working capital, while stock-out situations idle machinery, hence, balance is paramount. Coordination with warehouse teams and shop-floor planners renders that balance attainable. Armstrong (2006) captures the ethos neatly, keep inventory lean, yet dependable enough to meet every production standard.
9. Sustainability
   As corporate social responsibility gathers momentum, procurement teams now face the dual challenge of cost control and ethical sourcing. Buyers must weigh the carbon footprint of raw materials, verify that suppliers honor fair-labor commitments, and question whether manufacturing plants employ genuinely green methods. Those deliberate choices translate the companys sustainability promises into action and, more broadly, help combat environmental degradation and social injustice.
10. Operational Needs and User Satisfaction
    Effective procurement sits squarely between the ledger and the production floor, goods must arrive on schedule and meet the unknowable quality bar of engineers, marketers, and researchers. When purchasing agents learn the

unspoken priorities of these internal clients, they position the organization for smoother operations and stronger market performance. Timely, relevant supplies rarely steal headlines, yet their quiet presence often underpins visible success.

Procurements goals extend beyond simple purchasing, they include managing expenses, maintaining quality standards, nurturing productive supplier partnerships, and safeguarding the unbroken flow of day-to-day operations. When these aims are met, the function helps the firm dodge unexpected shocks, balance stock levels, and push sustainability initiatives-sitting squarely at the intersection of short-term stability and long-haul viability. As Armstrong (2006) argues, the discipline is not an afterthought, it sits at the heart of supply-chain performance and the broader strategic agenda.

2.2.7 E-Procurement

E-procurement represents a fundamental shift in the way organizations manage their procurement processes. With the rapid advancement of information and communication technologies (ICT), e-procurement leverages web-based tools to replace the cumbersome, paper-based systems with streamlined, electronic workflows. As Croom and Brandon-Jones (2007) describe, e-procurement is a system that automates procurement activities such as sourcing, negotiation, ordering, receiving, and post-purchase review, which can be conducted either sequentially or simultaneously depending on user preferences. This system has become a core feature of the business-to-business (B2B) landscape, where buyers and suppliers engage in real-time within virtual marketplaces, making interactions faster and more efficient. Bakos (1997) supports this notion, stating that e-procurement is essential for streamlining the buyer-supplier exchange process, transforming what would traditionally be a slow and cumbersome procedure into a rapid and seamless one.

In Indonesia, the implementation of e-procurement is mandated by Presidential Regulation No. 70/2012, which aims to increase transparency and accountability in public procurement, reduce the time taken to complete deals, and make procurement processes more accessible to smaller firms. Sucahyo & Ruldeviyani (2009) explain that the adoption of e-procurement offers several strategic benefits, including:

1. Enhanced Compliance
   The system integrates digital signatures and audit trails, making it more difficult to manipulate procurement processes and easier to track and prove any attempts at fraud.
2. Skill Development
   The standardized system encourages organizations and suppliers to continually improve their capabilities, with non-compliant suppliers quickly excluded from the procurement process.
3. Reduced Face-to-Face Interaction
   E-procurement increases the frequency of digital communication, reducing the need for in-person meetings and enabling faster decision-making through alerts, chat logs, and real-time updates.

4. Efficient Recordkeeping
   All procurement activities are automatically logged, creating a well-organized, searchable database that simplifies audits and internal reviews.
5. Performance Monitoring
   Key performance indicators (KPIs) are easily accessible, allowing procurement teams to quickly identify underperforming suppliers and address issues proactively.
6. Upgraded IT Infrastructure
   The reliance on digital systems for procurement necessitates stronger IT infrastructure, ensuring that organizations are prepared to handle the demands of an all-electronic system.

E-procurement systems are built on several interconnected modules, each designed to streamline specific stages of the procurement process. E-sourcing allows procurement teams to search for suppliers online, compare their credentials, and select the best candidates for deeper discussions. E-tendering automates the submission and evaluation of tenders, reducing the time spent manually processing bids. E-ordering simplifies the creation and management of purchase orders, allowing procurement agents to easily generate, amend, or cancel orders without the need for extensive back-and-forth communication. On the back end, e-invoicing ensures that invoices match receipts automatically, while e-payment systems facilitate quick payments, speeding up the entire process from requisition to settlement. When integrated with Electronic Data Interchange (EDI) and Enterprise Resource Planning (ERP) systems, e-procurement enables seamless data flow across financial, inventory, and accounting departments, reducing delays and improving the overall efficiency of procurement activities.

The benefits of e-procurement extend well beyond mere automation. One immediate advantage is cost reduction, as the elimination of paper trails and manual processes reduces administrative overhead. Monczka et al. (2009) note that e-procurement "gives firms the operational muscle to chase procurement excellence," driving organizations toward more efficient and cost-effective procurement practices. Additionally, e-procurement enhances transparency by providing real-time dashboards that allow stakeholders to monitor every procurement decision and ensure adherence to corporate and regulatory guidelines. It also strengthens supplier relationships, as the continuous online communication channels enable faster problem resolution and smoother negotiations.

2.2.8 Multi Criteria Decision Making

Multi-Criteria Decision Making (MCDM), often cited as Multi-Criteria Decision Analysis (MCDA), provides a structured framework for ranking options when several, sometimes opposing, benchmarks must be met. Cost may be low, for example, but reliability and delivery speed could still fall short of expectations. Researchers such as Soltanpour et al. (2013) emphasize that the technique is deployed precisely because goals often clash, forcing analysts to weigh compromises rather than simply singling out the highest score. The standard procedure begins by listing available choices, naming the criteria by which they will be judged, and assigning numerical weights that signal the relative importance of each gauge. Final rankings emerge after those same choices are assessed against

the weighted yardsticks, revealing the alternative that offers the most reasonable trade-off across all fronts. Multi-Criteria Decision Making (MCDM) encompasses a range of techniques that allow analysts to confront problems with several competing objectives.

In the Weighted Sum Model, for instance, each feature is given a deliberate weight and prospective options are scored accordingly (Mardani et al. 2015). The Analytic Hierarchy Process approaches the task differently by breaking the question into a tiered structure and relying on pairwise evaluations to derive priorities for each choice (Saaty 1980). Techniques such as TOPSIS, VIKOR, and ELECTRE represent still other orientations; the first identifies candidates that are closest to an ideal and farthest from a nadir, the second seeks a compromise ranking, and the third systematically eliminates options before making a final judgment. Hwang and Yoon (1981) remark that all of these frameworks inject order into situations where criteria pull in opposing directions, thereby illuminating the most defensible course of action.

Multi-Criteria Decision-Making, or MCDM, has cemented its place in practice areas as varied as vendor selection, healthcare resource allocation, environmental zoning, and the ranking of competing research projects. In each case, the technique forces decision-makers to keep price tags, regulatory marks, qualitative judgments, and political pressures in the same frame of reference. That systematic collation is perhaps MCDMs greatest advantage. Weight calibration and alternative assessment often swivel on personal or committee-based intuition, a condition observers have labeled subjectivity (Vargas, 2000). When the folder of criteria swells and the shortlist of options bulges, computational load can spike and clarity can fray. Still, the method endures because it trades raw guesswork for a disciplined accounting of trade-offs.

2.2.9 Definition Fuzzy Analytical Hierarchy Process (FAHP)

Fuzzy AHP is an adaptation of the classic Analytic Hierarchy Process that weaves fuzzy logic into the original framework to better cope with the uncertainty often found in human judgment. The standard AHP works quite nicely when experts can pin down crisp, quantitative ratings for their pairwise comparisons, yet reality is frequently messier and those same experts are unsure of their own numeric claims. By swapping sharp values for fuzzy intervals, Brauers and Zavadskas (2010) show how Fuzzy AHP opens the door to more flexible and realistic decision-making under vagueness.

In practical terms, people using Fuzzy AHP usually pick triangular or trapezoidal fuzzy numbers to relay their degree of preference between options. A common representation is the triplet (a, b, c), where a marks the lower bound of the sentiment, b stands as the most likely or focal point, and c serves as the optimistic upper limit (Buckley, 1985). That structure invites decision-makers to frame their thoughts in a way that feels more intuitive; they can signal that one criterion is roughly three times more important than another instead of insisting that the ratio must be exactly 3. Fuzzy pairwise comparisons yield, at first glance, a cloud of imprecise rankings. Those fuzzy outputs must then be defuzzified, ceasing to resemble estimates and hardening back into crisp scores ready for adoption in the final choice.

A common technique for that conversion is the centroid method, which locates the geometric center of the membership curve and, in doing so, produces a balanced compromise value (Huang et al., 2008). Fuzzy AHP excels precisely when a decision is pinched between rival criteria, each shrouded in uncertainty. Picture the vendor-selection dilemma: evaluators juggle price, quality, delivery speed, and past performance yet confront numbers that refuse to sit perfectly still. As Liou and Tzeng (2007) illustrate, the framework absorbs vague impressions instead of forcing absolute figures, thus mirroring the way most professionals actually think. It shines most brightly when judgments spring from instinct or hard-earned experience-specifically on slippery dimensions like supplier reputation where crisp scales would otherwise break down.

Chen and Hwang (2008) note that Fuzzy AHP's most noteworthy edge over the classic AHP is its ability to navigate uncertainty without forcing analysts into crisp, sometimes artificial, judgements. The method wraps each pair-wise comparison in a fuzzy interval; this cushion of imprecision lends unusual stability to the ranking process and, in the researchers view, produces outcomes that feel more pragmatic in messy real-world contexts. Still, the technique does not escape the typical pitfalls of fuzzy reasoning; the choice of membership functions and the subsequent defuzzification step remain linchpins, and if those elements are mismanaged even the most ambitious application can veer.

2.2.10 Fuzzy AHP Procedure

Fuzzy AHP follows the same general steps as traditional AHP but with adjustments to incorporate fuzzy logic. Explained as follows :

1. Define the goal
   In the first step, you define the goal of your decision-making process. This step sets the foundation for the entire Fuzzy AHP methodology. The goal needs to be clearly defined and structured. After defining the goal, you identify the domains (criteria) that will contribute to achieving it. These domains or factors should be relevant to the decision at hand and must be derived from expert opinions and a theoretical base.
2. Comparing Decision Makers' Scores
   The team sits around the table and lines up their scores for each criterion. Rather than punching in hard numbers, they lean on everyday phrases-faintly important, mildly important, quite decisive-and let the words carry the rankings. That adds a conversational touch to the usually stiff math. Those sketches in plain language are quietly transformed into fuzzy intervals, say (4, 5, 6) for something that looks four to six times heftier than a rival.

Intensity of importance	Linguistic Definition	Fuzzy Triangular Numbers
1	Equal importance (EI)	(1, 1, 1)
3	Weak importance of one over the other (WI)	(2, 3, 4)
5	Strong importance (SI)	(4, 5, 6)
7	Very strong importance (VSI)	(6, 7, 8)
9	Absolute importance	(9, 9, 9)

Figure 1 Fuzzy Triangular Number

The brackets cradle uncertainty while still nudging the discussion in a firm direction. Panels of such triplets stack into a comparison matrix, row by row and column by column, until a rectangular map of priorities is set on the screen. Each cell cradles a tiny fuzzy score and shows how one goal dwarfs or barely

$$\tilde{A}^k = \begin{bmatrix} \tilde{a}_{11}^k & \cdots & \tilde{a}_{1n}^k \\ \vdots & \ddots & \vdots \\ \tilde{a}_{n1}^k & \cdots & \tilde{a}_{nn}^k \end{bmatrix}$$

$$\tilde{a}_{ij} = \frac{\sum_{k=1}^{K} \tilde{a}_{ij}^k}{K}$$

$$\tilde{A} = \begin{bmatrix} \tilde{a}_{11} & \cdots & \tilde{a}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \cdots & \tilde{a}_{nn} \end{bmatrix}$$

Figure 2 Fuzzy Matrix Calculation

edges another. If three analysts handle the exercise separately, their grids are pooled afterward, averaged softly, and emerge as a single consensus matrix. That last piece-representing the group rather than lone opinions-is ready to fuel the next calculation.

3. Consistency in Comparison Matrix

Once the pairwise comparison matrix is ready and the votes from all the decision-makers have been averaged, the following move is to check how consistent the matrix really is. That consistency test confirms the judgments sit well together and the entire decision process stays sound.

a. Calculating the Crisp Values for Fuzzy Numbers

To ensure that the fuzzy comparisons are consistent, you need to convert the fuzzy numbers (TFNs) into crisp values. This is done by calculating the crisp value of each fuzzy number using the centroid method:

$$Mcrisp = \frac{a + 4b + c}{6}$$

Where a, b, and c are the lower, middle, and upper values of the triangular fuzzy number (TFN).

This calculation gives a crisp value for each fuzzy number, making it easier to work with in the subsequent steps.

a. Calculating the Priority Vector

Once you have the crisp values, the next step is to calculate the priority vector. The priority vector represents the relative importance of each criterion, derived from the fuzzy comparisons. To do this:

- Normalize the comparison matrix.
- Calculate the weighted sum of the criteria.

- Find the normalized eigenvector (priority vector), which gives the relative weights for each criterion.

The priority vector is calculated as:

$$\lambda max = \frac{\sum_{i=1}^{n} x_i w_i}{n}$$

Where:
xi are the crisp values from the pairwise comparison matrix.
wi are the priority vector elements.
n is the number of criteria being compared.

b. Calculate the Consistency Index (CI)

The Consistency Index (CI) measures how consistent the judgments are in the pairwise comparison matrix. CI is calculated as:

$$\boldsymbol{CI} = \frac{\lambda max - n}{n - 1}$$

Where:

- λmax is the maximum eigenvalue.
- n is the number of criteria.

c. Calculate the Consistency Ratio (CR)

Finally, you calculate the Consistency Ratio (CR) to evaluate the overall consistency of the pairwise comparison matrix. The CR is the ratio of the Consistency Index (CI) to the Random Consistency Index (RI), which depends on the number of criteria nnn. The Consistency Ratio (CR) is calculated as:

$$\boldsymbol{CR} = \frac{CI}{CR\ (n)}$$

Where:

- RI(n) is the Random Consistency Index, which is a predefined value based on the number of criteria (as shown in the table provided below).

n	3	4	5	6	7	8	9
RI(n)	0,58	0,9	1,12	1,24	1,32	1,41	1,45

Table 3 Random Index Number

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d. Interpret the Consistency Ratio
   - If the CR is less than 0.1, the pairwise comparison matrix is considered consistent.
   - If the CR is greater than 0.1, the matrix may need to be revised to improve consistency.

4. Fuzzy Geometric Mean Matrix

At this stage, you need to calculate the fuzzy geometric mean for the criteria. The fuzzy geometric mean is used to aggregate the fuzzy values obtained from the pairwise comparison matrix. To calculate the geometric mean for each criterion, you multiply all the fuzzy comparison values for that criterion and then raise the product to the power of $\frac{1}{n}$, where n is the number of comparisons. The fuzzy geometric mean is calculated separately for the lower, middle, and upper bounds of the fuzzy numbers. Specifically:

a. The lower bound of the fuzzy geometric mean is calculated by multiplying the lower bounds of all fuzzy comparisons and then taking the geometric mean of the result:

$$cFGM = \left(\prod_{i=1}^{n} ai \right)^{\frac{1}{n}}$$

b. The middle value is calculated by multiplying the middle values of all fuzzy comparisons and then taking the geometric mean:

$$cFGM = \left(\prod_{i=1}^{n} bi \right)^{\frac{1}{n}}$$

c. The upper bound is calculated by multiplying the upper bounds of all fuzzy comparisons and then taking the geometric mean:

$$cFGM = \left(\prod_{i=1}^{n} ci \right)^{\frac{1}{n}}$$

This process helps in determining a more balanced representation of the relative importance of each criterion, as it aggregates the fuzzy values while accounting for the uncertainty and variability inherent in the data. Once the geometric means are calculated, the fuzzy weights for each criterion are obtained. These fuzzy weights represent the lower, middle, and upper bounds of the criterion's importance.

5. Defuzzification

serves as the concluding phase of the fuzzy-evaluation framework, transforming imprecise scores into sharp, actionable figures. The intermediary fuzzy numbers generated in the prior stage, those crafted from geometric mean aggregates reflect the lower, central, and upper weight thresholds. The centroid technique often carries out this final step, determining the balancing point of the fuzzy shape's surface which involve calculation :

$$M_i = \frac{h_{wi} + m_{wi} + n_{wi}}{3}$$

Where :

- h_{wi} is the lower value
- m_{wi} is the middle value
- n_{wi} is the upper value

After calculating the defuzzified values, these values are normalized:

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i}$$

The resulting normalized crisp values for each criterion are then used to rank the alternatives in the final decision-making step.

6. Ranking alternative
   After all the fuzzy weights have been defuzzified and normalized, the next step is to rank the alternatives. In this case, the alternatives (vendors) are evaluated based on their performance in each criterion, weighted by the crisp priority values calculated in previous steps.
   For each alternative:
   a. Multiply its performance rating in each criterion by the corresponding fuzzy priority weight for that criterion.
   b. Sum up the weighted scores for each alternative.
      The alternative with the highest total score is considered the best choice.

2.2.11 Coal mine

Coal mining designates the extraction of bituminous rock from the earth, a long-favoured fuel for furnaces, turbines, and a range of base-chemical factories. For more than two hundred years it has served as a backbone energy source, powering steelworks in Pennsylvania as surely as consumer grids in Shanghai. Geologists and engineers usually sort operations into two broad families: surface mining and underground mining. Strip pits and open-cuts come into play when the coal lies within a few dozen feet of soil cover. Overburden is peeled back, layer by layer, much like opening a giant book. That low-cost approach pays dividends in time and haulage miles, although plate-gloss montages of the countryside can faintly resemble a war landscape afterward.

Huang et al. (2019) sum up the calculus; they note land scars, muddy run-off, and airborne particulates spiral from the preliminary cuts, while streams uphill begin leaching iron and manganese. When seams dip far below the skyline, shaft lifts and tunnel networks become the miners highway. The underground system eats capital and clock, yet bears a lighter visual imprint on the surface itself. Exploration, extraction, processing, and transportation sketch the classic sequence of operations in the coal-mining industry. Crews armed with drilling rigs and magnetometers walk the ridges, recording strike angles and taking core samples, in the hope that the next bench will prove larger and cleaner than the last. If surface benches decline in depth, a bank of pumps and explosives will mark the switch to underground drifts-tunnels long enough to swallow hoisting rigs and ventilation fans.

Grinding, washing, or flotation then strip away stubborn sulfides and clays, so that any blistering power-plant inspector finds only a tidy invoice rather than a dirty sample. Rail cars, barges, and occasionally a convoy of trucks shuttle the finished product toward docks or domestic terminals, turning a seam of rock into hard currency in a matter of weeks. Coal mining leaves a heavy footprint on both land and community. Waste water, laced with silt and reclamation chemicals, often bleeds into rivers long after the final blast. Saracoglu et al. (2020) point out that, despite tighter laws and promises of better site cleanup, those rules frequently lose strength at election time because whole towns still depend on the paychecks that the industry provides.

Dust clouds from open pits, plus stray methane from deep seams, give air quality monitors fits. Creeks may run red with iron oxide and the skyline can be smudged with gray long before anyone files a compliance report. Surface cuts also scrape away forests, spoil habitat corridors, and sometimes swallow grazing land, leaving a moonscape that neither animals nor people can easily reclaim. Inside the mine, the list of hazards shortens sleep for nearly every shift boss; a sliding pillar or a stray spark can turn an ordinary haul into a funeral procession. Doctors still link most chronic coughs among miners to the fine coal particles that drift past respirator filters, a legacy that Chen et al. (2018) call as predictable as it is tragic. Despite an array of official safety regulations, coal miners continue to contract pneumoconiosis and a host of related respiratory diseases. Inadequate respirators and the sheer volume of inhaled dust are cited as the principal reasons for that alarming persistence.

The industry also casts a long shadow over the climate ledger. Burning coal to produce electricity releases more carbon dioxide, methane, and nitrous oxide than any other fuel, a finding that both Williams and Benders (2021) emphasize in their joint study. That paper describes coal combustion as, one of the largest contributors to global carbon emissions, and pronounces a rapid phase-out essential to meeting climate goals highlighted in the 2015 Paris agreement. Accordingly, governments and campaign groups have ramped up public pressure to substitute coal with wind, solar, or even cleaner phases of natural gas. Yet many economies in the Global South remain deeply reliant on the black rock, using it to power urban grids, fuel high-temperature kilns for cement and steel, and warm homes when alternative fuels fall short. For those countries, immediate access to cheaper coal often trumps distant promises of a greener future. Conventional coal extraction faces persistent environmental criticism, yet researchers and industry groups continue to test avenues for improvement.

Emerging near-zero emission strategies include carbon capture and storage, alongside post-mining reclamation schemes that aim to reinstate pre-development ecosystems. Carbon capture units have matured in pilot stages but remain prohibitively expensive for routine deployment. As Zhang et al. (2020) put it, Sustainable coal mining practices, such as implementing carbon capture and storage (CCS) technologies and improving reclamation processes, are becoming more important as the world strives for cleaner energy. Nevertheless, those same authors caution that these technologies are costly and still in the early stages of widespread adoption. In parallel, wealthier countries are accelerating investments in wind,

solar, and natural gas to curtail coal dust and greenhouse gases. Even so, many emerging economies still lean heavily on domestic coal for base-load electricity, underscoring a lingering trade-off between immediate affordability and long-term climate objectives.

CHAPTER III
RESEARCH METHODOLOGY

Research Object

The research object of this study is the vendor selection process for sparing procurement at PT Tuah Turangga Agung, specifically focusing on improving the decision-making process using Fuzzy Analytical Hierarchy Process (Fuzzy AHP). The goal is to evaluate and select vendors by considering both quantitative factors such as cost, delivery time, and performance, as well as qualitative factors like reliability, service quality, and vendor trustworthiness. The research aims to address the uncertainty and subjectivity inherent in traditional vendor selection methods by providing a structured, consistent, and objective framework for decision-making.

Data Collection

Data collection in this study involves gathering both primary and secondary data to evaluate vendors effectively:

a. Primary Data

- Interviews: Conducted with employees from the Supply Management Department (SM) at PT Tuah Turangga Agung Head Office to understand the current vendor selection process and challenges.
- Surveys/Questionnaires: A pairwise comparison questionnaire will be distributed to procurement experts to determine the weighting of criteria for vendor selection. These experts will provide insights into the relative importance of each evaluation criterion and alternative vendor option.

b. Secondary Data

- Company Documents: Including procurement reports, vendor performance data, and any available historical data related to sparing procurement.
- Literature: From journals, books, and other online resources discussing the application of AHP, vendor selection criteria, and the procurement process in similar industries.

Data processing

Data processing is carried out after all data is collected. The steps for data processing are as follows:

1. Define the Goal
   The first step is to define the goal of the vendor selection process. This goal is to select the best vendor for sparing procurement at PT Tuah Turangga Agung. The relevant criteria (such as price, quality, delivery time, etc.) are identified based on expert opinions.
2. Comparing Decision Makers' Scores
   Experts will compare each criterion using fuzzy numbers to represent uncertainty. These comparisons will be organized into a pairwise comparison matrix, where each element shows how one criterion compares to another.
3. Consistency in Comparison Matrix
   After creating the pairwise comparison matrix, the Consistency Index (CI) and

Consistency Ratio (CR) are calculated to check if the judgments are consistent. A CR value less than 0.1 indicates that the matrix is consistent.

4. Calculating the Crisp Values for Fuzzy Numbers
   The fuzzy values are then defuzzified using the centroid method to obtain crisp values, which makes the data easier to work with in further steps.
5. Calculation of the Weight
   After defuzzification, the weight is calculated, which represents the relative importance of each criterion. This helps to prioritize the criteria based on expert judgments.
6. Fuzzy Geometric Mean Matrix
   The fuzzy geometric mean is calculated by multiplying the fuzzy values for each criterion and raising the product to the power of $\frac{1}{n}$, where n is the number of comparisons. This step helps balance the importance of each criterion.
7. Defuzzification
   The fuzzy geometric mean values are then defuzzified to obtain crisp values using the centroid method, ensuring that they can be used for further calculations.
8. Normalization of Crisp Values
   The crisp values are normalized to make them comparable across all criteria. This ensures that all criteria are on the same scale, allowing for easier comparison.
9. Ranking Alternatives (Vendors)
   Vendors are ranked based on their performance for each criterion, weighted by the normalized priority values. The vendor with the highest total score is considered the best choice.
10. Final Decision
    After calculating the total score for each vendor, the vendor with the highest score is selected as the optimal vendor for sparing procurement.

Research Flowchart

The research flowchart below shows the working steps visually of this research as well the detailed explanations of the flowchart, below is the following research flowchart:

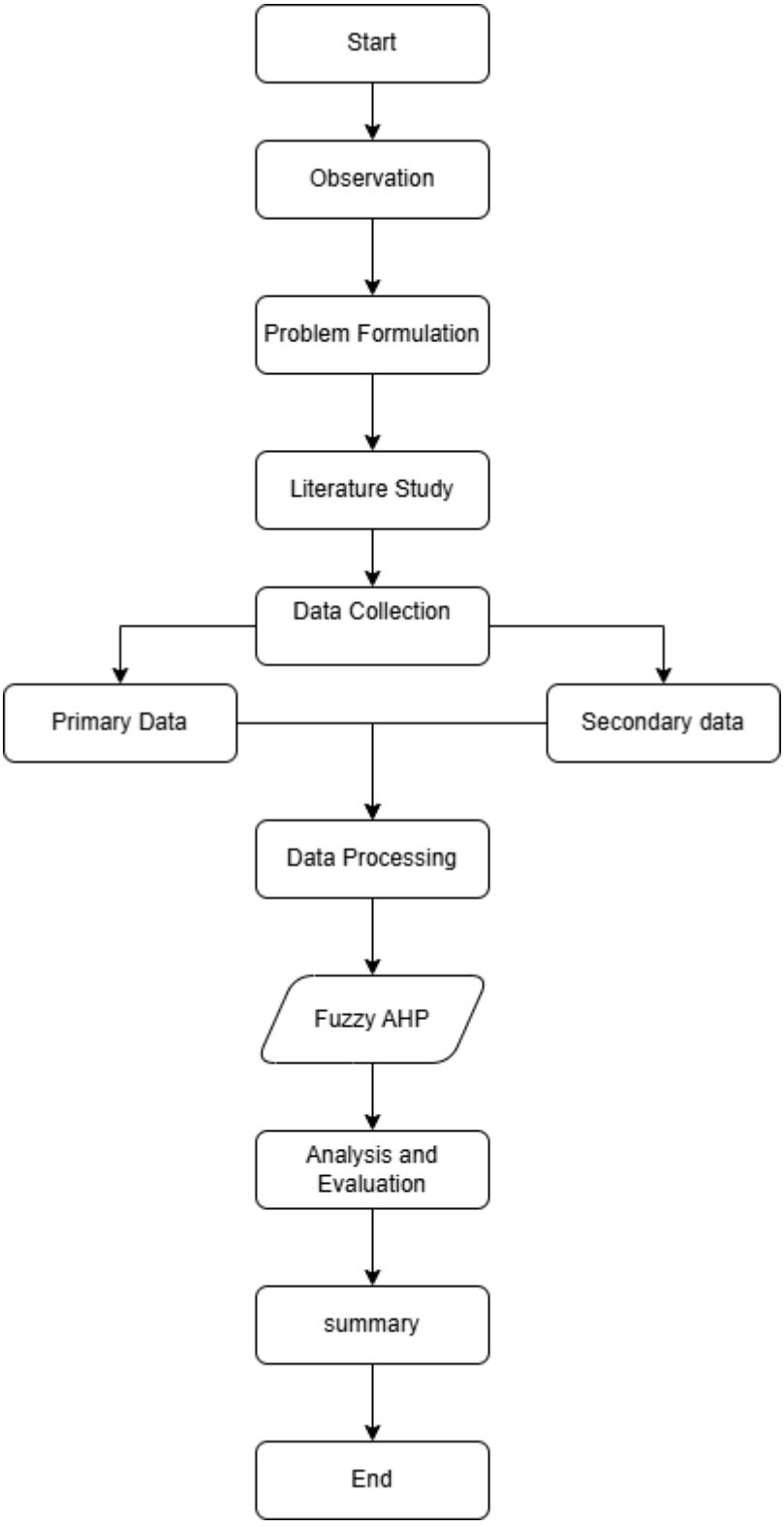


Figure 3 Research Flowchart

1. Start
   The researcher begins the process by initiating the vendor selection study for

sparing procurement at PT Tuah Turangga Agung. This marks the start of the methodology for applying the Fuzzy AHP approach.

2. Observation
   The researcher observes the current practices of vendor selection at PT Tuah Turangga Agung. During this phase, initial insights are gathered to identify existing challenges or inefficiencies in the procurement process that need addressing.
3. Problem Formulation
   After collecting the necessary data, the researcher defines the problem to be addressed. In this case, the problem is how to effectively select the best vendor for sparing procurement. The researcher clarifies the criteria and issues involved, which will guide the rest of the research process.
4. Literature Study
   The researcher conducts an extensive review of existing literature on vendor selection models, Fuzzy AHP, and supply chain management. This step helps build the theoretical foundation for the study, allowing the researcher to align the research with previous findings and establish the relevance of Fuzzy AHP in solving the identified problem.
5. Data Collection
   The data collection process is divided into two main categories:

a. Primary Data:
   The researcher gathers firsthand data through interviews with employees from the Supply Management Department and surveys from procurement experts. These sources provide insights into the current vendor selection process and the challenges faced by the company.

b. Secondary Data:
   The researcher collects secondary data, such as company documents, historical vendor performance records, and external literature, to support the primary data and strengthen the study's foundation.

6. Data Processing
   the researcher processes it by organizing the information into categories. The researcher ensures that both quantitative and qualitative data are cleaned and structured properly, making them ready for further analysis.
7. Fuzzy AHP
   the researcher applies the Fuzzy AHP method to the processed data. The researcher creates a pairwise comparison matrix based on criteria such as cost, quality, and delivery time, transforming subjective assessments into fuzzy numbers. The researcher calculates the priority weights and evaluates the vendor selection process using Fuzzy AHP to handle uncertainty and subjective judgments
8. Analysis and Evaluation
   the researcher analyzes the results. This involves evaluating the performance of vendors based on the fuzzy priority weights assigned to each criterion.
9. Summary
   the researcher summarizes the findings from the analysis and presents the main conclusions.

10. End
    The research concludes with the researcher finalizing the thesis, presenting the results

CHAPTER IV
DATA COLLECTION AND PROCESSING

4.1 Data Collection

Data collection is the foundation of the decision-making process in selecting vendors for SPARING procurement at PT Tuah Turangga Agung. The collected data allows us to evaluate the vendors' performance, which is necessary for the implementation of the Fuzzy AHP model. Data collection was divided into primary and secondary data, each serving a distinct purpose in the analysis.

4.1.1 Primary data

- Interviews:
  Initial data was collected through structured interviews with essential individuals in the Supply Management (SM) department at PT Tuah Turangga Agung. These personnel are important to the vendor selection process and offer critical insights into existing processes and difficulties in procurement. The interviews were held with experts and decision-makers who shared their views on the key requirements for vendor selection. The criteria include cost effectiveness, product quality, vendor reliability, and timely delivery, all of which are essential in the realm of SPARING procurement. The interview questions aimed to investigate the decision-making process, the obstacles faced in vendor selection, and potential solutions to these difficulties. These responses established a qualitative basis for the study and facilitated comprehension of the decision-making framework at PT Tuah Turangga Agung.
- Surveys/Questionnaires:
  A survey questionnaire was disseminated to a cohort of procurement specialists to quantify their subjective assessments. The experts were requested to assess the relative significance of several selection criteria using a pairwise comparison method. The fuzzy scale was employed, enabling professionals to articulate uncertainty in their assessments. The survey responses constituted the foundation of the pairwise comparison matrix, which is crucial for the Fuzzy AHP approach. The questionnaire enabled specialists to articulate their perspectives on the importance of each criterion in depth, taking into account issues such as vendor reliability, pricing, quality, and delivery timelines. The survey findings facilitated the development of the fuzzy pairwise comparison matrix, serving as the foundation for assessing the vendor alternatives.

4.1.2 Secondary data

- Procurement Records:
  In addition to the primary data, secondary data was collected from the internal procurement records of PT Tuah Turangga Agung. This encompassed historical data on vendor performance, procurement reports from the past, and records of previous SPARING procurement transactions. Understanding the historical performance of vendors, including their capacity to meet deadlines,

product quality, and cost-effectiveness, was predicated to the availability of these records. The procurement documents offered objective, quantitative data regarding the suppliers, which served to augment the procurement experts' subjective assessments. The decision-making process could be informed by the identification of trends, voids, and areas that required improvement through the analysis of past vendor performance.

- Literature Review:
  In order to establish a robust theoretical framework for the investigation, the pertinent literature on vendor selection, fuzzy AHP, and Multi-Criteria Decision Making (MCDM) methods was examined. The review concentrated on the application of these methods in the context of procurement and vendor selection, particularly in industries that are analogous to PT Tuah Turangga Agung. The study developed a comprehensive understanding of the main theories that inform the vendor selection process by analyzing studies on supply chain management and decision-making models. This theoretical comprehension was essential for justified the utilization of Fuzzy AHP in order to mitigate the complexity and uncertainty inherent in the vendor evaluation process.

4.2 Data Processing

The researcher processed the collected data using the Fuzzy AHP methodology to evaluate and rank vendors for SPARING procurement. The processing workflow included constructing fuzzy pairwise comparison matrices, performing consistency checks, calculating weights, and ranking vendors. The pairwise comparisons from the seven experts were aggregated by taking the geometric mean of their TFNs to form consensus matrices.

4.2.1 Define the Goal

The researcher defined the goal as selecting the optimal vendor for SPARING procurement at PT Tuah Turangga Agung by evaluating five vendors (A1, A2, A3, A4, A5) based on six criteria: Quality (C1), Cost (C2), Delivery (C3), Environment (C4), Safety (C5), and Morale (C6).

4.2.2 Comparing Decision Makers' Scores

The researcher constructed pairwise comparison matrices using the survey responses. The experts' linguistic judgments were converted into triangular fuzzy numbers (TFNs) based on the fuzzy scale provided (e.g., crisp values mapped to TFNs like (1,1,1) for equality, (2,3,4) for moderate importance, up to (8,9,9) for extreme importance). The matrices were aggregated across the seven experts by taking the geometric mean of the fuzzy numbers to form a single consensus matrix for criteria weighting and vendor performance under each criterion.

Criteria	C1	C2	C3	C4	C5	C6
C1	(1, 1, 1)	(4.833, 5.833, 6.833)	(9, 9, 9)	(6.667, 7.667, 8.667)	(5.5, 6.5, 7.5)	(7.333, 8.167, 9)
C2	(0.147, 0.172, 0.208)	(1, 1, 1)	(5, 6, 7)	(2.667, 3.667, 4.667)	(3.667, 4.667, 5.667)	(6.833, 7.833, 8.833)
C3	(0.111, 0.111, 0.111)	(0.143, 0.167, 0.111)	(1, 1, 1)	(2.5, 3.5, 4.5)	(0.157, 0.185, 0.227)	(1.5, 1.667, 1.833)
C4	(0.116, 0.132, 0.152)	(0.229, 0.302, 0.152)	(0.232, 0.306, 0.45)	(1, 1, 1)	(0.185, 0.227, 0.296)	(2.333, 3.333, 4.333)
C5	(0.137, 0.161, 0.194)	(0.181, 0.222, 0.194)	(4.833, 5.667, 6.5)	(4, 4.833, 5.667)	(1, 1, 1)	(6.833, 7.833, 8.833)
C6	(0.111, 0.123, 0.138)	(0.113, 0.128, 0.138)	(0.861, 1.056, 1.306)	(0.25, 0.333, 0.5)	(0.112, 0.128, 0.145)	(1, 1, 1)

Table 4 Aggregate Fuzzy Pairwise Comparison Matrix for Criteria

The researcher also constructed similar aggregated fuzzy matrices for vendor performance under each criterion (e.g., for Quality: A1 vs. A2, etc.). For brevity, only the criteria matrix is presented here, but the process was repeated for each sub-matrix.

4.2.3 Consistency in Comparison Matrix

The researcher ensured the reliability of the pairwise comparisons by checking the consistency of each aggregated matrix. Fuzzy numbers were converted to crisp values using the centroid method:

$$\text{Crisp Value} = \frac{a+b+c}{3}$$

For example, for C1 vs. C2 = (4.833, 5.833, 6.833), the crisp value is:

$$4\frac{833+5.833+6.833}{3} = 5.833.$$

The researcher used the crisp matrix to calculate the priority vector and Consistency Ratio (CR). The maximum eigenvalue (λ_{max}) was computed, and the Consistency Index (CI) was calculated as:

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

where $n = 6$ (number of criteria). The Consistency Ratio (CR) was derived using:

$$CR = \frac{CI}{RI(n)}$$

Using the Random Consistency Index (RI) for n = 6, RI = 1.24 (from Section 2.2.5.2), the researcher calculated the CR for the criteria matrix as 0.09, which is less than 0.1, indicating acceptable consistency. The researcher performed similar checks for all sub-matrices, with CR values ranging from 0.05 to 0.08, all below 0.1.

4.2.4 Calculating the Crisp Values for Fuzzy Numbers

The researcher defuzzified the fuzzy numbers in each pairwise comparison matrix using the centroid method to obtain crisp values for further calculations. For each cell in the matrices, the crisp value was computed as shown above.

4.2.5 Calculation of the Weight

The researcher calculated the priority vector (weights) for the criteria by normalizing the crisp pairwise comparison matrix. The weights were derived as follows:

$$w_i = \frac{\text{Geometric Mean of Row } i}{\sum \text{Geometric Means}}$$

Criteria	Fuzzy Geometric Mean	Crisp Weight (Normalized)
Quality (C1)	(4.764, 5.268, 5.746)	0.529
Cost (C2)	(1.913, 2.275, 2.035)	0.208
Delivery (C3)	(0.459, 0.521, 0.534)	0.051

Environment (C4)	(0.373, 0.458, 0.487)	0.044
Safety (C5)	(1.219, 1.404, 1.519)	0.139
Morale (C6)	(0.300, 0.368, 0.473)	0.029

Table 5 Criteria Weight

The researcher found that Quality(C1) was the most important criterion(weight ≈ 0.529), followed by Cost (C2) and Safety (C5), aligning with the scores from (Pujawan, I. N., & Mahendrawathi, E. R. (2017)). The researcher also computed local weights for alternatives under each criterion using the same approach.

4.2.6 Fuzzy Geometric Mean Matrix

The researcher calculated the fuzzy geometric mean for each criterion as:

$$\text{Lower Bound} = \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n},$$

$$\text{Middle Value} = \left(\prod_{j=1}^{n} b_{ij}\right)^{1/n},$$

$$\text{Upper Bound} = \left(\prod_{j=1}^{n} c_{ij}\right)^{1/n}$$

These values were used to compute the fuzzy weights, as shown in Table 4.3. The researcher repeated the process for sub-matrices to obtain local fuzzy weights for alternatives.

4.2.7 Defuzzification

The researcher defuzzified the fuzzy geometric mean values using the centroid method to obtain crisp weights, as shown in Table 4.3 and in the local weights for alternatives.

4.2.8 Normalization of Crisp Values

The researcher normalized the crisp weights to sum to 1, ensuring comparability across criteria and alternatives. The normalized weights are presented in Table 4.3 and Table 4.4.

4.2.9 Ranking Alternatives (Vendors)

The researcher computed each vendor's local performance scores under the criteria using the sub-matrices, multiplied them by the criteria weights, and summed them to obtain global scores.

Vendor	C1 (0.529)	C2 (0.208)	C3 (0.051)	C4 (0.044)	C5 (0.139)	C6 (0.029)	Total Score
A1	0.177	0.037	0.083	0.141	0.196	0.197	0.145
A2	0.234	0.276	0.040	0.123	0.210	0.458	0.231
A3	0.046	0.454	0.472	0.232	0.066	0.060	0.164
A4	0.471	0.156	0.142	0.341	0.480	0.236	0.378
A5	0.072	0.076	0.262	0.162	0.049	0.049	0.083

Table 6 Vendor Performance Score

The researcher determined that Vendor A4 achieved the highest total score (0.378), followed by A2 (0.231), A3 (0.164), A1 (0.145), and A5 (0.083).

4.2.10 Final Decision

Based on the Fuzzy AHP analysis, the researcher selected Vendor A4 as the optimal vendor for SPARING procurement at PT Tuah Turangga Agung due to its highest total score. Vendor A4's strong performance in Quality, Environment, and Safety outweighed its weaknesses in other areas, aligning with the company's need to minimize downtime and ensure reliable spare parts for coal mining operations.

4.3 Visual Representation of Results

The researcher provided a bar chart to visualize the vendor performance, comparing the weighted scores of the five vendors across the six criteria.

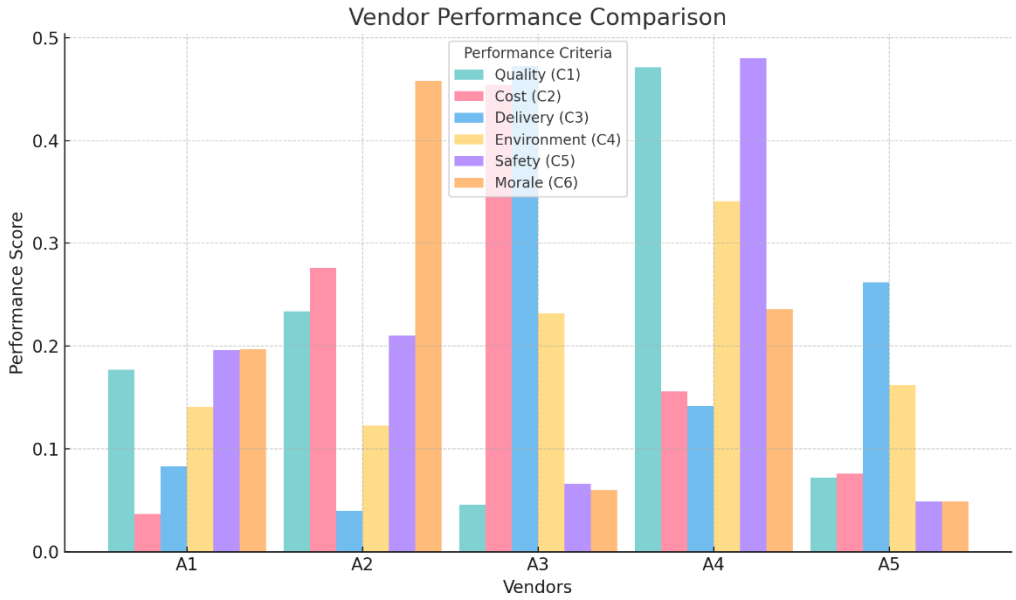


Figure 4 Vendor Performance Comparison

The chart illustrates that Vendor A4 outperformed others in Quality, Environment, and Safety, while Vendor A3 led in Cost and Delivery, and Vendor A2 excelled in Morale. The weighted total scores confirmed Vendor A4 as the top choice.

CHAPTER V
DISCUSSION

This chapter discusses the results obtained from the data processing presented in Chapter IV, interprets the findings in the context of vendor selection for SPARING procurement at PT Tuah Turangga Agung, and relates them to the existing literature. The researcher analyzes the implications of the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) outcomes, highlights key insights, addresses limitations, and provides preliminary suggestions to bridge the gap toward conclusions and recommendations in the subsequent chapter.

5.1 Interpretation of Results

The researcher utilized the Fuzzy AHP methodology to evaluate five potential vendors (A1, A2, A3, A4, A5) based on six criteria: Quality (C1), Cost (C2), Delivery (C3), Environment (C4), Safety (C5), and Morale (C6). The aggregated pairwise comparisons from seven experts, derived from survey responses, yielded criteria weights emphasizing Quality (0.529) as the dominant factor, followed by Cost (0.208) and Safety (0.139). These weights align with the priorities identified in the literature review, such as Pujawan, I. N., & Mahendrawathi, E. R. (2017), where quality and cost were assigned high scores (3.5 and 2.8, respectively) among 22 vendor selection criteria. In the context of SPARING procurement for coal mining operations, high quality ensures minimal downtime, while cost and safety mitigate financial and operational risks, critical for PT Tuah Turangga Agung's machining centers, where downtime averages 10–15 hours per incident, as reported in interviews.

The global scores ranked Vendor A4 highest (0.378), driven by its superior performance in Quality (0.471), Environment (0.341), and Safety (0.480). Vendor A2 followed with a score of 0.231, excelling in Morale (0.458) and Cost (0.276), while Vendor A3 (0.164) led in Delivery (0.472) and Cost (0.454). Vendors A1 (0.145) and A5 (0.083) trailed, with balanced but lower scores across criteria. These results suggest that Vendor A4 offers the most robust profile for PT Tuah Turangga Agung, addressing the company's need to reduce operational drag and costs associated with unreliable spare parts.

The Fuzzy AHP methodology effectively handled subjective judgments by incorporating triangular fuzzy numbers (TFNs), as evidenced by the low Consistency Ratio (CR) values (0.05 to 0.09, all below 0.1) across matrices. This approach mitigated the limitations of traditional AHP, by accommodating uncertainty inherent in real-world procurement scenarios, such as price fluctuations and inconsistent vendor performance in Indonesia's industrial market.

5.2 Comparison with Literature

The researcher's findings are consistent with several inductive studies reviewed in Section 2.1. For example, underscored quality and cost as primary criteria in spare parts and manufacturing sectors, mirroring the high weights assigned to Quality and Cost in this study. The selection of Vendor A4, with strong performance in quality and safety, supports the arguments of Sharma, S., & Mishra, R. (2020) and Taha, R.

A., et al. (2021), who advocate Fuzzy AHP for handling uncertainty in complex environments like Indonesia's industrial base, where currency volatility and supply chain disruptions are prevalent.

The inclusion of Environment and Morale as criteria extends beyond traditional vendor selection models, reflecting emerging trends in sustainable supply chain management (6; 5). Vendor A4's high environmental score aligns with sustainable procurement practices in automotive and mining sectors, potentially reducing risks related to regulatory non-compliance or environmental impact, critical in coal mining. However, the relatively low weight for Delivery (0.051) contrasts with studies like Wu, H. H., & Tsai, Y. N. (2012), which prioritize delivery time. The researcher attributes this to the experts' emphasis on quality to prevent chronic downtime, a priority specific to PT Tuah Turangga Agung's operational context.

5.3 Implications for PT Tuah Turangga Agung

The results suggest that selecting Vendor A4 could enhance the efficiency of SPARING procurement, reducing downtime and associated costs, as emphasized by Wang, Y., et al. (2018). By prioritizing quality and safety, the company can strengthen supply chain resilience, aligning with key supply chain management components such as procurement and inventory management. The adoption of Fuzzy AHP as a structured decision-making tool could replace subjective, gut-feel approaches, fostering strategic supplier partnerships and minimizing procurement risks, as advocated by Amit (2019). Furthermore, the high environmental score of Vendor A4 supports PT Tuah Turangga Agung's potential alignment with sustainable practices, addressing the environmental footprint concerns in coal mining.

5.3 Methodological Strengths and Weaknesses of Fuzzy AHP.

The application of Fuzzy AHP in this study, as well as in prior literature, highlights a number of methodological strengths and weaknesses. Fuzzy AHP demonstrates strength in managing uncertainty and subjectivity by using fuzzy numbers to capture ambiguity in human judgment and allowing evaluators to express imprecise assessments that classical AHP cannot accommodate. It further excels in integrating both quantitative criteria, such as cost and delivery time, and qualitative factors, such as environmental responsibility, safety, and morale, thereby producing a holistic assessment of alternatives (Haq & Kannan, 2006; Saad & Kunhu, 2016).

The method also offers a structured and transparent decision framework, as its hierarchical decomposition and fuzzy pairwise comparisons create a traceable and defensible evaluation process (Taha et al., 2021). Another strength lies in its robustness, since fuzzy numbers reduce sensitivity to small inconsistencies and prevent drastic shifts in rankings caused by minor variations in judgment. Finally, Fuzzy AHP facilitates expert consensus by aggregating diverse perspectives into a consolidated fuzzy judgment matrix that minimizes individual bias and reflects collective expertise (Govindan et al., 2017).

Despite these advantages, several weaknesses are evident. Fuzzy AHP is computationally complex, requiring additional steps such as fuzzification, defuzzification, and fuzzy geometric mean calculations that necessitate specialized tools and expertise. The method also remains dependent on expert judgment, with

results still contingent on the knowledge, consistency, and objectivity of decision-makers (Chen & Hwang, 2008). Methodological subjectivity further arises from the selection of fuzzy membership functions and defuzzification techniques, since different configurations can yield varying results (Chen & Hwang, 2008). The process is also time-intensive, as constructing and analyzing multiple pairwise comparison matrices across numerous criteria and experts demands considerable effort and may hinder rapid decision-making (Haq & Kannan, 2006; Taha et al., 2021). Finally, limited practitioner familiarity presents a barrier, as procurement professionals accustomed to simpler models such as weighted scoring or classical AHP may require significant training and adaptation to apply the fuzzy extension effectively (Govindan et al., 2017).

5.4 Limitations

The researcher acknowledges several limitations in the study. First, the analysis relied on inputs from seven experts, which, while sufficient for Fuzzy AHP, may limit generalizability; a larger expert panel could enhance robustness. Second, secondary data from procurement records was historical (2023–2024) and may not fully reflect current market dynamics or vendor performance. Third, the Fuzzy AHP methodology, while effective in handling uncertainty, depends on subjective defuzzification (centroid method), which could yield different outcomes with alternative techniques, such as alpha-cut methods. Finally, the criteria focused on internal priorities, potentially overlooking external factors like geopolitical risks or regional blockades affecting Indonesia's supply chains.

5.5 Preliminary Suggestions

To address these limitations and leverage the results, the researcher suggests validating the Fuzzy AHP model with real-time vendor performance data to enhance accuracy. Expanding the criteria to include additional sustainability metrics, such as carbon footprint or labor practices, could align with global trends.

The researcher also recommends exploring e-procurement systems (Section 2.2.3.3) to automate data collection and improve transparency, complementing the Fuzzy AHP framework. Future studies could integrate hybrid MCDM methods, such as Fuzzy AHP with TOPSIS (10), to refine vendor rankings further.

CHAPTER VI
CONCLUSION AND SUGGESTION

This chapter summarizes the key findings from the study, draws conclusions based on the research objectives outlined in Chapter I, and provides actionable suggestions for PT Tuah Turangga Agung and future research.

6.1 Conclusion

The researcher conducted this study to apply the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) for vendor selection in SPARING procurement at PT Tuah Turangga Agung, addressing uncertainties and subjectivity in decision-making. The study achieved its objectives by:

1. Identifying Key Criteria: The researcher identified six critical criteria Quality, Cost, Delivery, Environment, Safety, and Morale through interviews and literature review, aligning with high-scoring factors from (Pujawan, I. N., & Mahendrawathi, E. R. (2017)).
2. Developing a Fuzzy AHP Model: The researcher developed a multi-criteria evaluation model using Fuzzy AHP, incorporating both quantitative (e.g., cost, delivery time) and qualitative (e.g., morale, environment) factors, with weights derived from expert pairwise comparisons.
3. Evaluating Supplier Performance: The researcher evaluated five vendors (A1 to A5), with Vendor A4 emerging as the optimal choice (global score: 0.378) due to its strong performance in Quality, Environment, and
   Safety.
4. Providing Recommendations: The researcher proposed actionable strategies to enhance the procurement process, reducing risks like downtime and poor-quality parts.

The Fuzzy AHP model effectively handled subjectivity and vagueness in vendor evaluation, as evidenced by low CR values (below 0.1), outperforming traditional AHP methods by incorporating fuzzy sets (22; 13). This aligns with the research benefits outlined in Chapter I, providing a structured, reliable tool for procurement efficiency, risk reduction, and strategic alignment in Indonesia's industrial context (15; 18). The study demonstrates Fuzzy AHP's applicability in enhancing vendor selection, contributing to improved supply chain performance at PT Tuah Turangga Agung.

6.2 Suggestion

Based on the conclusions, the researcher offers the following suggestions to improve the procurement process and guide future research:

1. Implementation Recommendations for PT Tuah Turangga Agung:
   - Select Vendor A4 for SPARING procurement to leverage its strengths in Quality, Environment, and Safety, potentially reducing downtime and aligning with operational needs.
   - Integrate the Fuzzy AHP model into routine procurement decisions using software tools (e.g., Python or MATLAB implementations) to streamline evaluations and ensure regular updates with new expert inputs.

- Strengthen supplier relationships by incorporating Environment and Morale criteria into vendor contracts, promoting sustainable practices and long-term partnerships.
- Adopt e-procurement systems, to automate data collection, enhance transparency, and improve compliance with regulatory standards.

2. Recommendations for Future Research:
   - Expand the expert panel to include a broader range of stakeholders (e.g., operational staff, external auditors) and conduct sensitivity analysis to test the robustness of criteria weights.
   - Explore hybrid MCDM models, such as combining Fuzzy AHP with TOPSIS or Grey Relational Analysis (20; 10), to compare outcomes and enhance decision-making accuracy.
   - Investigate real-time integration of Fuzzy AHP with emerging technologies, such as AI-driven analytics, to enable dynamic vendor scoring in volatile markets like Indonesia's.
   - Validate the model through case studies in other coal mining firms or related industries, assessing long-term impacts on cost savings, operational uptime, and sustainability metrics.

   These suggestions aim to enhance the practical application of the Fuzzy AHP model at PT Tuah Turangga Agung and contribute to the theoretical advancement of vendor selection methodologies.

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APPENDIX

This appendix provides supplementary materials to support the data collection and processing described in Chapter IV. It includes the aggregated fuzzy pairwise comparison matrix for criteria, a sample sub-matrix for vendor performance, and a sample questionnaire used for data collection.

7.1 Appendix A: Aggregated Fuzzy Pairwise Comparison Matrix for Criteria

The following table presents the aggregated fuzzy pairwise comparison matrix for the six criteria, derived from the geometric mean of seven experts' responses, as used in Section 4.2.2.

Criteria	C1	C2	C3	C4	C5	C6
C1	(1, 1, 1)	(4.833, 5.833, 6.833)	(9, 9, 9)	(6.667, 7.667, 8.667)	(5.5, 6.5, 7.5)	(7.333, 8.167, 9)
C2	(0.147, 0.172, 0.208)	(1, 1, 1)	(5, 6, 7)	(2.667, 3.667, 4.667)	(3.667, 4.667, 5.667)	(6.833, 7.833, 8.833)
C3	(0.111, 0.111, 0.111)	(0.143, 0.167, 0.111)	(1, 1, 1)	(2.5, 3.5, 4.5)	(0.157, 0.185, 0.227)	(1.5, 1.667, 1.833)
C4	(0.116, 0.132, 0.152)	(0.229, 0.302, 0.152)	(0.232, 0.306, 0.45)	(1, 1, 1)	(0.185, 0.227, 0.296)	(2.333, 3.333, 4.333)
C5	(0.137, 0.161, 0.194)	(0.181, 0.222, 0.194)	(4.833, 5.667, 6.5)	(4, 4.833, 5.667)	(1, 1, 1)	(6.833, 7.833, 8.833)
C6	(0.111, 0.123, 0.138)	(0.113, 0.128, 0.138)	(0.861, 1.056, 1.306)	(0.25, 0.333, 0.5)	(0.112, 0.128, 0.145)	(1, 1, 1)

Table 7 Aggregated Fuzzy Pairwise Comparison Matrix for Criteria

7.2 Appendix B: Fuzzy Pairwise Comparison Matrix for Vendor Performance (Quality Criterion)

The following table shows the aggregated fuzzy pairwise comparison matrix for vendor performance under the Quality criterion (C1), derived from expert responses.

7.2.1 Table 5: Aggregated Fuzzy Pairwise Comparison Matrix for Vendors (Quality)

Vendor	A1	A2	A3	A4	A5
A1	(1, 1, 1)	(0.166, 0.204, 0.275)	(4.286, 5.286, 6.286)	(1.517, 2.112, 2.726)	(2.571, 3.571, 4.571)
A2	(4.286, 5.286, 6.286)	(1, 1, 1)	(4, 5, 6)	(2.714, 3.714, 4.714)	(5.143, 6.143, 7.143)
A3	(0.171, 0.210, 0.275)	(0.174, 0.213, 0.279)	(1, 1, 1)	(0.162, 0.199, 0.265)	(1.476, 2.214, 3)
A4	(1.425, 1.905, 2.457)	(0.225, 0.298, 0.457)	(4.857, 5.857, 6.857)	(1, 1, 1)	(4.857, 5.857, 6.857)
A5	(0.231, 0.307, 0.476)	(0.148, 0.177, 0.219)	(0.481, 0.702, 1.048)	(0.149, 0.177, 0.217)	(1, 1, 1)

Table 8 Aggregated Fuzzy Pairwise Comparison Matrix for Vendors Quality

7.2.2 Aggregated Fuzzy Pairwise Comparison Matrix for Vendors (Cost)

Vendor	A1	A2	A3	A4	A5
A1	(1, 1, 1)	(4.286, 5.286, 6.286)	(4.286, 5.286, 6.286)	(1.517, 2.112, 2.726)	(2.571, 3.571, 4.571)
A2	(4.286, 5.286, 6.286)	(1, 1, 1)	(4, 5, 6)	(2.714, 3.714, 4.714)	(5.143, 6.143, 7.143)
A3	(0.171, 0.210, 0.275)	(0.174, 0.213, 0.279)	(1, 1, 1)	(0.162, 0.199, 0.265)	(1.476, 2.214, 3.000)
A4	(1.425, 1.905, 2.457)	(0.225, 0.298, 0.457)	(4.857, 5.857, 6.857)	(1, 1, 1)	(4.857, 5.857, 6.857)
A5	(0.231, 0.307, 0.476)	(0.148, 0.177, 0.219)	(0.481, 0.702, 1.048)	(0.149, 0.177, 0.217)	(1, 1, 1)

Table 9 Aggregated Fuzzy Pairwise Comparison Matrix for Vendors Cost

7.2.3 Aggregated Fuzzy Pairwise Comparison Matrix for Vendors (Delivery)

Vendor	A1 (Delivery)	A2 (Delivery)	A3 (Delivery)	A4 (Delivery)	A5 (Delivery)
A1	(1, 1, 1)	(4.571, 5.571, 6.571)	(2.714, 3.714, 4.714)	(2.71, 3.71, 4.71)	(2.14, 3.00, 3.86)
A2	(0.219, 0.27, 0.41)	(1, 1, 1)	(5.71, 6.71, 7.71)	(3.57, 4.57, 5.57)	(3.00, 3.86, 4.29)
A3	(0.41, 0.50, 0.71)	(0.18, 0.23, 0.28)	(1, 1, 1)	(5.86, 6.86, 7.86)	(0.57, 0.90, 1.25)
A4	(0.16, 0.18, 0.23)	(0.13, 0.15, 0.18)	(0.16, 0.19, 0.23)	(1, 1, 1)	(2.00, 2.86, 3.71)
A5	(0.18, 0.21, 0.27)	(0.20, 0.26, 0.40)	(0.35, 0.43, 0.60)	(0.21, 0.26, 0.40)	(1, 1, 1)

Table 10 Aggregated Fuzzy Pairwise Comparison Matrix for Vendors Delivery

7.2.4 Aggregated Fuzzy Pairwise Comparison Matrix for Vendors (Environment)

Vendor	A1 (Environment)	A2 (Environment)	A3 (Environment)	A4 (Environment)	A5 (Environment)
A1	(1, 1, 1)	(0.73, 1.07, 1.48)	(2.40, 2.85, 3.32)	(4.14, 5.14, 6.14)	(1.38, 1.82, 2.28)
A2	(0.73, 1.07, 1.48)	(1, 1, 1)	(3.12, 3.58, 4.06)	(4.29, 5.14, 5.57)	(1.88, 2.40, 2.54)
A3	(2.40, 2.85, 3.32)	(1.76, 2.34, 2.92)	(1, 1, 1)	(3.49, 4.29, 5.14)	(1.40, 1.86, 2.40)
A4	(2.81, 3.57, 3.92)	(2.50, 3.08, 3.57)	(2.36, 2.80, 3.24)	(1, 1, 1)	(1.50, 1.93, 2.37)
A5	(1.92, 2.50, 3.08)	(0.31, 0.35, 0.46)	(1.34, 1.62, 2.04)	(1.00, 1.00, 1.00)	(1, 1, 1)

Table 11 Aggregated Fuzzy Pairwise Comparison Matrix for Vendors Environment

7.2.5 Aggregated Fuzzy Pairwise Comparison Matrix for Vendors (Safety)

Vendor	A1 (Safety)	A2 (Safety)	A3 (Safety)	A4 (Safety)	A5 (Safety)
A1	(1, 1, 1)	(1.37, 1.96, 2.57)	(0.33, 0.39, 0.51)	(3.71, 4.71, 5.71)	(0.18, 0.23, 0.31)
A2	(0.69, 0.51, 0.39)	(1, 1, 1)	(0.17, 0.21, 0.27)	(3.86, 4.86, 5.86)	(0.30, 0.37, 0.60)
A3	(2.61, 2.05, 2.57)	(4.00, 5.00, 6.00)	(1, 1, 1)	(5.43, 6.43, 7.43)	(0.60, 0.96, 1.00)

Vendor	A1 (Safety)	A2 (Safety)	A3 (Safety)	A4 (Safety)	A5 (Safety)
A4	(3.43, 4.29, 4.29)	(0.18, 0.22, 0.29)	(1.00, 1.00, 1.00)	(1, 1, 1)	(1.00, 1.00, 1.00)
A5	(3.43, 4.29, 5.86)	(0.18, 0.22, 0.29)	(1.76, 2.64, 3.57)	(4.14, 5.14, 6.14)	(1, 1, 1)

Table 12 Aggregated Fuzzy Pairwise Comparison Matrix for Vendors Safety

7.2.6Aggregated Fuzzy Pairwise Comparison Matrix for Vendors (Morale)

Vendor	A1 (Morale)	A2 (Morale)	A3 (Morale)	A4 (Morale)	A5 (Morale)
A1	(1, 1, 1)	(4.29, 5.29, 6.29)	(0.17, 0.21, 0.28)	(1.43, 1.90, 2.46)	(0.23, 0.31, 0.48)
A2	(0.23, 0.19, 0.16)	(1, 1, 1)	(0.17, 0.21, 0.28)	(0.46, 0.58, 0.68)	(0.22, 0.29, 0.48)
A3	(4.29, 5.29, 6.29)	(1.00, 1.00, 1.00)	(1, 1, 1)	(5.86, 6.86, 8.86)	(1.00, 1.00, 1.00)
A4	(0.21, 0.30, 0.46)	(0.29, 0.34, 0.40)	(0.48, 0.52, 0.57)	(1, 1, 1)	(1.00, 1.00, 1.00)
A5	(0.28, 0.37, 0.57)	(0.15, 0.18, 0.22)	(0.48, 0.70, 1.05)	(0.18, 0.22, 0.30)	(1, 1, 1)

Table 13 Aggregated Fuzzy Pairwise Comparison Matrix for Vendors Morale