Developing and Prioritizing Lean Supply Chain Performance Indicators in the Thai Industrial Context

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Abstract. *This research aims to systematically develop and prioritize performance indicators for Lean Supply Chain (LSC) practices that have not been widely adopted in Thai industries. The study included a comprehensive literature review of national and international industry publications. The literature review identified Lean Supply Chain (LSC) performance indicators align with the Thai industrial context. The three dimensions of the industry are (1) organizational profile, (2) finance and operations, and (3) business results. Different prioritizations and weights within each dimension are assigned to reflect their relative significance. These variations distinguish the Thai industry from industries in other countries. The research achieve its objective by applying the Fuzzy-AHP technique. This technique undertook expert evaluations from the Thai industry to assign weights to the significant indicators for LSC. This study demonstrates the development and prioritization of indicators for LSC tailored explicitly to the captivating context of the Thai industry. The indicators ranking across various dimensions can provide valuable guidance for business owners to comprehend their advantages and implement them within their organizations. Additionally, these findings can serve as a fundamental basis for future research and development, enabling the establishment of performance indicators for LSC within other countries' industries. However, further research development using techniques such as AHP, SAW, and TOPSIS is prioritized.*

Keywords: lean supply chain performance indicators, Thai industry context, developing and prioritizing, Fuzzy-AHP method

1. Introduction

Currently, Thailand places great importance on supply chain management as it presents opportunities for market expansion and enhances the country's competitive capabilities within the ASEAN region [1]. Consequently, it is essential for Thailand thoroughly examine supply chain management across various and diverse industries. This study involves understanding the entire supply chain process, from the upstream, middle stream, and downstream, to identify inefficiencies in systematic management. In this research, evaluating performance indicators using various tools and methodologies across different industries is crucial fordetermining supply chain management efficiency. Some of these measurement tools include the balanced scorecard (BSC), the supply chain operations reference (SCOR) model, the logistics scorecard (LSC), economic value added (EVA), total quality management (TQM), and activity-based costing (ABC) [2].

Additionally, measuring efficiency from both financial and non-financial perspectives is vital. Examples of non-financial performance measurement systems include economic value added (EVA), the dimension-based measurement system (DBMS), the interface-based measurement system (IBMS), and the hierarchical-based management system (HBMS) [3]. These systems are applied to measure the efficiency of manufacturing and service industries and enhance business competitiveness. Various countries in different sectors widely use the SCOR Model. Some examples include the steel industry [4], medium and small-sized ready-to-wear clothing industry [5], the Lithium Battery Factory [6], and service businesses [7]. However, when measuring supply chain efficiency, the balanced scorecard, by other methods like Data Envelopment Analysis (DEA), aims to find weighted scores for industry evaluation [8]. Evaluating supply chains in Industry 4.0 [9] has also involved applying the SCOR Model using Fuzzy set techniques [10] and considering sustainable business performance through a literature review [11]. In terms of measuring supply chain efficiency in Thailand, it primarily focuses on three aspects: effectiveness, emphasizing the quality of raw materials or products; efficiency, focusing on cost measurement [12]. Some research articles have classified important supply chain performance indicators into four groups: financial, productivity, quality, and timeliness [1]. Researchers have applied the SCOR Model to measure the efficiency of retail businesses [13] and construction material distribution companies [14]. Additionally, in Thailand's industrial sector, organizations have developed manuals for assessing efficiency and capabilities in logistics and supply chains using benchmarking techniques [15]. Furthermore, experts have designed three-dimensional supply chain efficiency measurements that consider Supplier, Manufacturer, and Distributor dimensions [16]. Preliminary research indicates that amid the current competitive landscape and the necessity to expand distribution channels, organizations must measure their supply chain efficiency using the SCOR Model or alternative methodologies. Relying exclusively on traditional approaches proves inadequate for organizational development, efficiency enhancement, and increased return on investment. Consequently, organizations should identify appropriate supply chain performance indicators relevant to Thailand's industrial context. Examples include efficiency indicators for warehouse management [17] and primary supply chain performance indicators for agricultural production [18].

A comprehensive review of existing research literature reveals extensive investigation into the application of Lean principles to supply chain management across various international industries, commonly referred to as "Lean Supply Chain" [19]. Scholars have examined performance indicators for Lean Supply Chain management, yielding the following findings:

Using information technology, Lean Supply Chain Management (LSCM) helps minimize waste in moving goods, services, and information. They facilitate systematic collaboration between suppliers and customers, eliminating waste throughout the supply chain [20]. Adopting Lean practices in the supply chain has been shown to enhance production efficiency, reduce costs,

and decrease lead time in both the short and long term [21]. Additionally, it contributes to improving quality and flexibility across the entire supply chain [22]. An essential strategy in Lean Supply Chain management involves engaging stakeholders throughout the supply chain, fostering collaboration from the initial to final stages [23]. It is recognized that merely implementing Lean principles within a single company is insufficient [24]. However, when Lean principles are applied to industries or businesses to address and resolve various challenges, they can yield significant benefits. For instance, a typical production challenge such as slow-moving inventory can be effectively addressed by implementing Lean processes, even in the presence of employee training programs [25]. In cases where operations are either simple or complex and involve multiple departments working together, adopting Lean practices simplifies operational management, increases speed, ensures safety, and enhances overall quality [26]. Similarly, Value Stream Mapping is a practical approach for businesses engaged in buying and selling to improve supply chain processes, reduce time, and eliminate waste within internal supply chain operations [27]. These findings underscore the importance of incorporating Lean principles into supply chain management practices, leading to positive and beneficial outcomes for companies.

Lean Supply Chain Performance Indicators (LSCPIs) are vital elements for a company's success, often demonstrated through receiving awards for quality excellence or achieving ISO certification. However, relying solely on these indicators is insufficient for superiority in the automotive industry. Identifying the specific LSCPIs that contribute to enhancing the quality and efficiency of the company's supply chain [23]. In the healthcare service sector, there is a lack of appropriate tools or indicators to measure the performance and effectiveness of businesses in meeting the needs of customers (patients) within the limitations of the environment and budget [28]. Company performance indicators serve as tools that indicate operational success, whether it involves producing high-quality products or satisfying customer needs, ultimately enhancing competitiveness [21]. Implementing Lean practices can lead to company success, necessitating the establishment of suitable indicators aligned with the company's objectives. These indicators aim to reduce production time and customer complaints and enhance production efficiency and equipment [25].

Scholars have engaged in extensive discourse regarding Lean concepts; however, the majority of investigations have been narrow and context-specific. For example, researchers have examined Lean production methodologies [29], Lean practices within the industrial sector [30], and performance measurement frameworks in specialized domains such as Plastering supply chains [31] and small to medium manufacturing enterprises. Despite these contributions, a significant research gap persists concerning the development of Lean Supply Chain performance indicators applicable across diverse industrial contexts, particularly those addressing waste reduction [32] and enhancing operational efficiency [21] in response to economic fluctuations.

In Thailand, Lean concepts have been applied in various industries to eliminate process waste. Examples include plastic bag factories [33], the hard disk drive industry [34], polo shirt production [35], improving product receiving processes in companies [36], managing perishable raw materials in made-to-order food production systems [37], rubber glove factories [38] reducing lead time in company operations [39], managing medical materials [40], eliminating waste in procurement processes [41], and improving procurement processes in the construction industry [42]. Moreover, Lean concepts have also been implemented in supply chain management to eliminate waste throughout the supply chain [43].

Considering Lean studies from various perspectives, such as Lean production, Lean management, Lean practices, and Lean supply chain management, they all highlight the same significance. This includes assessing companies' efficiency in terms of quality and achieving predetermined success goals, such as increasing productivity, reducing overall costs, minimizing lead time, satisfying customer needs, and maximizing returns from increased market share.

Observation of the current literature reveals a paucity of research regarding Lean Supply Chain performance indicators within the Thai industrial context, with existing frameworks remaining insufficiently developed. This research deficiency has prompted scholars to conduct comprehensive reviews of international literature on "Lean Supply Chain" methodologies. The primary objective of these investigative efforts is to formulate and establish priority hierarchies for appropriate Lean Supply Chain performance indicators specifically calibrated to the unique characteristics of Thai industrial operations.

This study represents one of Thailand's pioneering efforts focusing on Lean Supply Chain performance indicators. The main objectives of this study are as follows:

1. Developing Lean Supply Chain performance indicators relevant to the Thai industry.
2. Determining the weights and relationships of Lean Supply Chain performance indicators within the Thai industry context.
3. Prioritizing the importance of Lean Supply Chain performance indicators in the Thai industry.

This investigation endeavors to develop and establish priority hierarchies for Lean Supply Chain Performance Indicators (LSCPIs) specifically tailored to the Thai industrial context, an unexplored domain in the extant literature. Prior scholarly investigations have predominantly concentrated on industry-specific implementations or geographically constrained applications, resulting in heterogeneous lean assessment frameworks. Consequently, this research seeks to formulate LSCPIs with cross-sectoral applicability, transcending variations in industrial classification, organizational scale, and operational environments.

To accomplish the research objectives, the investigators conducted a comprehensive literature review and utilized the collective expertise of academic scholars and industry practitioners in the selection of appropriate Lean Supply Chain Performance Indicators (LSCPIs) [31-32]. For effective weighting and prioritization of these indicators, the researchers implemented the Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) methodology, which facilitates uncertainty reduction in decision-making processes and minimizes expert disagreement. This methodological approach incorporates a Triangular Fuzzy Number (TFN) scale comprising nine distinct levels [44]. A significant advantage of this technique lies in its nine-scale evaluation system, which mitigates ambiguity in assessments that might otherwise lack precision. Furthermore, Fuzzy-AHP demonstrates superior efficacy in structuring complex decision hierarchies compared to conventional AHP methodologies. Various scholarly investigations have demonstrated the versatility of this approach across multiple domains, including D. Adebanjo et al. [28] in healthcare service operations optimization, S. Kaganski et al. [44] in performance indicator prioritization frameworks, G. Peng et al. [45] in risk evaluation modeling, and S. Butdee [46] in supply chain risk assessment for manufacturing operations.

Moreover, alternative analytical frameworks including Analytic Hierarchy Process (AHP), Simple Additive Weighting (SAW), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) warrant consideration for subsequent

developmental iterations and prioritization schema refinement.

In this article, the researchers aim to develop and prioritize Lean Supply Chain Performance Indicators (LSCPIs) that are suitable for the context of the Thai industry. They utilize literature review and draw upon academic scholars' and industry practitioners' expertise and experiences to select the LSCPIs [31-32]. To ensure effective weighting and prioritization of the indicators, they employ the Fuzzy-AHP method, which helps mitigate decision-making uncertainties and reduce conflicts among experts. The technique utilizes the triangle fuzzy number (TFN) scale with nine levels [44].

2. Literature reviews

2.1 Lean Supply Chain

The Lean Supply Chain (LSC) encompasses eight key components: (1) Information technology management, (2) Supplier management, (3) Waste elimination, (4) Just-in-Time (JIT) production, (5) Customer relationship management, (6) Logistics management, (7) Top management commitment, and (8) Continuous improvement [29]. This operational paradigm is extensively acknowledged as a systematic methodology that fulfills customer requirements through the provision of appropriate products or services with optimal placement, timing, and quantity accuracy, while simultaneously minimizing resource utilization within constrained operational parameters. Lean incorporates many tools such as Total Quality Management (TQM), JIT, and Business Process Re-engineering (BPR) to enhance competitiveness in the global market [28]. These tools include poka-yoke, setup time reduction (SMED), kanban/pull system, production levelling, standardized work, 5S/housekeeping, small lot size, total productive maintenance (TPM), supplier involvement, employee involvement, root cause analysis (5 Whys), customer involvement, value stream mapping (VSM), cellular manufacturing, kaizen/continuous improvement, and statistical quality control [33]. This approach's strengths are reducing lead time and production costs and increasing flexibility. At the same time, its limitations lie in effectively responding to customer needs from external sources. Collaboration among stakeholders is essential, ranging from the supply chain's upstream, middle stream, and downstream [23]. In addition to the perspectives of other researchers, other noteworthy issues include the application of Lean principles in supplier selection, focusing on effectiveness rather than cost. The perspective can measure the researcher's common and high-risk problems through rigorous processes and evaluations [19]. Previous studies on Lean systems demonstrate the need for a comprehensive analysis that encompasses manufacturing and service industries such as construction, healthcare, and food [22]. The diverse nature of LSC's business models facilitates seamless communication and collaboration among supply chain partners [47].

2.2 Measurement of Lean Supply Chain Performance

Key Performance Indicators (KPIs) are established in alignment with the company's specific context and strategic objectives [48]. Lean indicators reflect operational efficiency within limitations and guide appropriate process improvements [31]. Critical Lean indicators are also established during the selection and tracking process to facilitate practical problem-solving assessments within the company [49]. Implementing KPIs efficiently in a company leads to increased reliability and standardization in operations, and Lean indicators are designed to evaluate all systems based on Lean principles [50]. The process is conducted monthly and categorized clearly to enhance accountability [51]. To ensure the model remains practical and user-friendly for medium-sized and small enterprises, only a minimal set of indicators is employed. The indicators should emphasize quantitative rather than qualitative aspects for ease of understanding and implementation [52].

2.3 Lean Supply Chain Performance Indicators

Based on the literature review, a total of 109 supply chain performance indicators were identified, as presented in previous studies such as those by B. Argiyantari [19], G. L. Tortorella [29], S. Saetung [34], and M. Rossini [47]. To refine and contextualize these indicators for the Thai industrial setting, the researchers conducted a focus group interview with 10 experts. As a result, 12 indicators were selected and categorized into three key dimensions.

According to expert opinions, all three dimensions are considered equally important, as the core industrial processes—from importation through operations to exportation—must be comprehensively addressed to achieve the desired performance outcomes. The three dimensions are outlined as follows:"

Stage 1: Organizational Profile -This refers to the input processes suitable for the organization's operations.

Stage 2: Finances and Operations—This refers to the organization's processes that can be measured for efficiency.

Stage 3: Business Results—This refers to the output results from the organization's operations or the assessment of its performance.

Each stage considers data received from various dimensions of the organization. Table 1 presents the summarized and explained results.

Table no. 1. Literature review of different lean supply chain management indicators

References		International														National		
		L. G. Tortorella et al. [29]	D.C.A. Oliveira et al. [31]	J. Bhadu et al. [32]	F. Behrouzi et al. [53]	G. Ante et al. [54]	I. Rakhmanhuda and D.P. Karningsih [55]	M. Todorov et al.[56]	D. De et al. [57]	H. Afonso and M. do R Cabrita [58]	Fauzi Khair et al. [59]	L. Catellani and E. Rotteni [60]	A. Sukkar and M. Mc G. Mugla [61]	B. Dahinine et al. [62]	D. Adebanjo et al. [28]	S. Saetung et al. [34]	A. Vanichchinchai [63]
Organizational profile	Assurance														*		
	Image		*								*				*		
	Reliability				*						*				*		*
Finances and Operations	Investment			*											*		
	Operating cost		*					*							*		*
	Inventory cost		*				*						*				
	Operational performance	*	*		*	*	*	*				*	*				*
Business results	Financial success	*	*		*	*			*	*	*			*		*	
	Time	*	*	*	*		*	*		*	*	*	*			*	*
	Quality	*		*	*	*	*		*	*	*	*				*	*
	Effectiveness							*			*						
	Efficiency							*			*			*			

According to Table No. 1, the researchers selected and grouped 12 indicators into three dimensions based on the experts' opinions through a focus-group interview technique. These indicators align with the context of the Thai industry.

2.3.1 Organizational Profile Dimension

The organizational profile refers to the organization's overall image or the general impression it creates for business partners and customer perception. Customer satisfaction and stakeholders' perceptions serve as key measures for evaluating this dimension. such as employees, customers, and business partners. Implementing appropriate strategic practices can help the company gain a good reputation and broad acceptance [64]. This includes the organization's importation process, both in terms of work standards and credibility.

(a) Assurance

Quality assurance involves establishing quality standards and evaluating quality, focusing not only on personnel but also on the knowledge and skills of employees. It also includes products and services, considering the appropriateness of employees based on regulations that align with the business size [65-66]. This objective can be achieved through compliance with various certification standards, such as ISO9000 and TQM, and by receiving certificates and awards from reputable national-level organizations.

(b) Image

Image refers to the brand or product logo that needs to be consistently remembered by customers and business partners. Therefore, the key dimensions in building a product brand are:

1. Creating the influence and identity of the brand.
2. Establishing a distinctive personality for the product logo.
3. Creating continuous brand recognition through marketing activities.
4. Developing interactions between the product brand and customers.
5. Demonstrating the benefits and advantages of the product brand [67]. They also include the company's history and the duration of its operations.

(c) Reliability

Reliability, or the trustworthiness of the organization, focuses primarily on customers and suppliers. It involves evaluating performance based on past achievements and improving strategies to address risks or conflicts. Examples include the accuracy of purchase order documents, timely delivery, accuracy of invoicing, and maintaining mutual benefits [68].

2.3.2 Finances and Operation Dimension

The financial status of a company is crucial for the efficiency indicators in Lean Six Sigma and may also include the company's revenue [32]. However, the operations process or systematic work procedures can contribute to sustainable efficiency and acceptance.

(a) Investment

In terms of financial investment and return on investment, indicators such as the break-even point and expected profit reflect the organization's current economic condition and highlight areas requiring improvement [32]. The allocation of budget for business operations plays a critical role in illustrating how resources are invested across various activities and whether such allocations are appropriate. Moreover, operational activities should be aligned with the planned objectives and remain consistent with the organization's overall strategic goals.

(b) Operating Cost

Operating costs encompass expenses directly associated with operations, including labor, raw materials, transportation, and management-related costs. A thorough and clear evaluation of these operating costs is essential for effectively controlling and minimizing non-value-added expenses [69]. It is important to note that the costs outlined here do not include inventory-related expenses.

(c) Inventory Cost

This refers to costs specifically associated with inventory, including the cost of raw materials, work-in-progress inventory, and finished goods inventory held at service points such as warehouses, production lines, or storage facilities. Additionally, it encompasses inventory awaiting delivery based on purchase orders [70] and inventory carrying costs [71]. These costs may also include expenses related to inventory obsolescence, damaged goods, and product returns.

(d) Operational Performance

Enhancing operational efficiency to achieve organizational excellence in various operational aspects according to set goals or objectives. The measurement of such performance should be clearly defined [72], whether it pertains to IT or digital elements in the supply chain, the development of personnel capabilities, or the benefits derived from maximizing the use of tools and equipment.

2.3.3 Business Results Dimension

This dimension includes indicators that showcase the company's operations results and the use of Lean to improve future performance [31]. The company can view the results from multiple perspectives, such as financial, quality, time, efficiency, and effectiveness, as well as achieving planned objectives. Specific and measurable targets are established for each indicator.

(a) Financial Success

This refers to the organization's profitability [65], with indicators set according to the company's goals or plans. It relates to financial status or various operational expenses.

(b) Time

These indicators relate to the time or duration of work processes and the fundamental practices of Lean. They encompass the total time from receiving purchase orders to product delivery and service [68]. The resulting outcomes should align with the operational goals or success indicators.

(c) Quality

Quality refers to meeting appropriate specifications for usability, supplier quality management, internal company systems, and customer expectations. Quality indicators may include product and service quality, continuous process improvement, and a commitment to providing products that meet customer objectives [69]. Quality encompasses not only the product itself but also after-sales service and communication with customers. Utilizing satisfaction assessment methods can help the organization better understand the context of customers and business partners.

(d) Effectiveness

The effectiveness focuses on achieving the goals set in the operational plan, including short-term, medium-term, and long-term objectives, aligning with the organization's strategies [32]. The most critical aspect lies in the execution of operations to effectively achieve the desired objectives, fully addressing the needs of customers and business partners across all dimensions. For example, it includes implementing effectiveness in areas such as green supply chain, supply chain 4.0, utilizing tools or platform-generated results.

(e) Efficiency

Efficiency involves prioritizing and carrying out operations quickly, utilizing existing resources to maximize efficiency. It is crucial for an organization to maintain competitiveness and business status and continuously improve efficiency throughout the supply chain. Additionally, the organization must support good operational practices, enhance speed, efficiently respond to customer needs [71], and align with the set objectives.

To address these challenges, the organization can employ the Multi-criteria Decision Making (MCDM) tool to solve problems. Previous research has found that prioritizing the importance of Lean supply chain management and initiating healthcare service operations using the Fuzzy-AHP technique [28] is necessary. This technique relies on expert evaluation to obtain results for LSCPIs (Lean Supply Chain Performance Indicators). The research proposes using the Fuzzy-AHP method to evaluate the outcomes of LSCPIs and minimize potential disagreements arising from experts in various fields' perspectives. This study focuses on developing LSCPIs with three dimensions and 12 indicators, ranking their importance using the Fuzzy-AHP technique within the Thai industrial context.

3. Research Methodology

In this research, a quantitative research methodology was employed. It consisted of three steps, namely:

Step 1: Literature review concerning the performance indicators of lean supply chains.

Step 2: Designing questionnaires and sending them to experts for evaluation using the Fuzzy-AHP method.

Step 3: Assign weight scores to each indicator to prioritize their importance in each dimension.

The details are as follows:

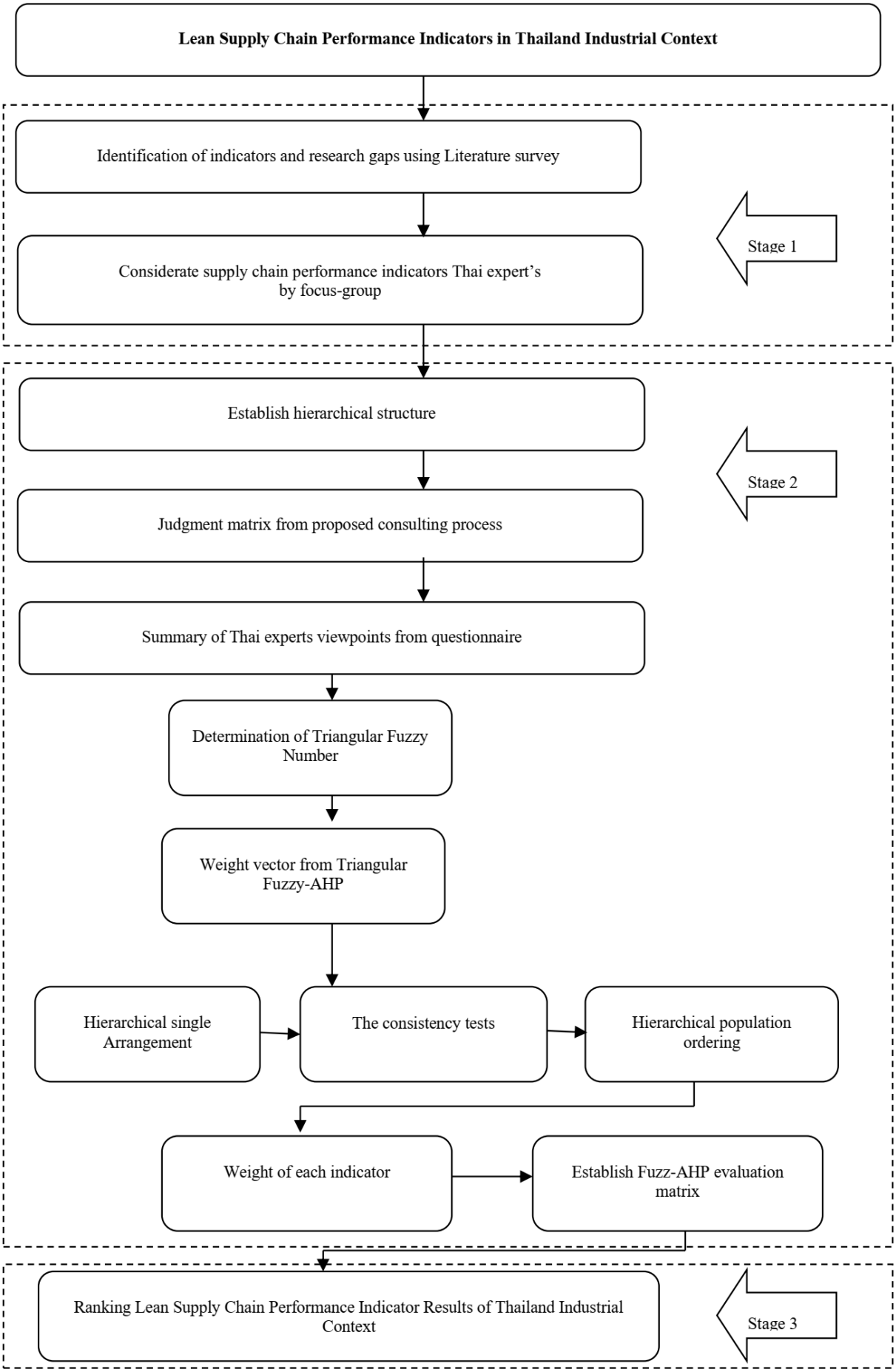

Figure 1. Flow research framework of Lean Supply Chain Performance indicator using Fuzzy-AHP Source: Improvement from [64]

Step 1 is crucial, considering a diverse set of performance indicators applicable to lean supply chains in the industrial context. This step includes (1) Reviewing the literature on lean supply chain performance indicators (as shown in Table 1) and (2) Assessing the scope or limitations derived from the literature review based on keywords such as "Lean management," "Lean supply chain," "Lean performance," "Lean indicators," "Supply chain performance," and "Supply chain performance indicators."

The reviewer used these keywords to search databases in Thai and international supply chain, management, and engineering journals, including Scopus and Google Scholar. Table 2 presents the results of the finding keyword.

Table 2 Results of finding keywords.

Keyword / Articles	National	General
Lean management	3	16
Lean manufacturing	8	22
Lean supply chain management	2	9
Lean performance	10	17
Lean indicators	1	8
Total	27	83

Subsequently, experts were invited to participate in focus-group interviews to provide their insights and contribute to the decision-making process regarding the selection of lean supply chain performance indicators. These indicators were then grouped in a manner that aligns with the specific context of the Thai industry. Once the consideration process was completed, the selected lean supply chain performance indicators were used to create a design by applying selection criteria and assigning values on a 9-point scale. In the next step, these indicators were sent to experts for evaluation.

Step 2: After officially distributing the questionnaires to the relevant participants in the study, which consisted of (1) five academic experts in the field of lean supply chain and manufacturing from educational institutions [73] and (2) five representatives from industrial businesses, including Supply Chain Managers, Heads of Operation Planning departments, or Co-managers [69], in total of 10 completed questionnaires were collected.

The criteria for participant selection were as follows: Academic experts from educational institutions were required to have at least 5 years of knowledge and expertise in the supply chain field [44].

On the other hand, industry experts were professionals actively involved in businesses related to various industries such as automotive component manufacturing, wood processing, cosmetics production, fuel and petroleum distribution, and cement and construction material industries.

Each expert evaluated the performance indicators using a questionnaire [74] through the Fuzzy-AHP method [75]. This approach allowed the experts to express their opinions independently and provide diverse perspectives. Once the research team received the completed questionnaires, all 10 completed questionnaire were returned.

The number of experts involved in this study was deemed sufficient to provide relevant insights, in line with the study conducted by D. Adebanjo et al. [28], which included seven experts, and the research by G. Peng et al. [45], which involved six experts. During the expert panel discussion to select the 12 key indicators, the experts observed that, within the context of the Thai industry, some indicators could not be effectively measured in either quantitative or qualitative terms. Consequently, the selected indicators were primarily chosen to align with organizational strategies and objectives aimed at capability development and management improvement. As a result, a final set of 12 lean indicators was established. This consensus was reached by both academic and industry experts, and the selected indicators were considered adequate and appropriate for the contexts of both manufacturing and service industries.

However, academic experts emphasized the significance of the 'Assurance' indicator in shaping the corporate image, as well as the critical cost factors, such as Operating Cost and Inventory Cost, which effectively reflect an organization's management performance. In contrast, industry professionals placed greater emphasis on Operational Performance. This perspective aligns with the Business Results dimension, where both academic and industry experts prioritized Financial Success over Time and Quality. Moreover, these 12 indicators offer a robust foundation for new businesses that may lack knowledge and understanding of lean performance measurement.

The objectives and definitions of the selected indicators are clearly outlined in Section 2.3, providing interested organizations with the opportunity to adopt them as Key Performance Indicators (KPIs). However, certain indicators received minimal emphasis from the experts. For example, the Market Growth indicator [28] was deprioritized, likely due to differing viewpoints on marketing management and its impact on organizational outcomes. Rather than treating marketing management as a separate entity, the experts viewed Market Growth as an integral aspect of overall organizational performance, particularly in relation to Financial Success. Similarly, while L. Catellani and E. Bottani [60] assigned high importance (93.9%) to the Customer Satisfaction indicator, the experts in this study suggested that customer satisfaction should be assessed specifically within the context of the service industry or analyzed in conjunction with Operational Performance from a lean perspective.

The data obtained from this step were then processed using a spreadsheet application to calculate the weight scores based on the Fuzzy-AHP method. Therefore, this research utilized the Fuzzy Analytical Hierarchy Process (fuzzy-AHP) method, developed by Zadeh. This widely popular technique helps mitigate issues of unreliable decision-making among experts [44]. However, the fuzzy-AHP method can assess the following three levels: goal level, criterion level, and factor level [73], using triangular fuzzy numbers (TFN) with a 1-9 scale, as shown in Table 3. The geometric mean method was employed to calculate the best solution [51]. Furthermore, the consistency of the index values, as shown in Table 4, was examined. If the Consistency Ratio (CR) is less than or equal to 0.1, it indicates that the assessment results for the indicators are acceptable. In case the CR exceeds 0.1, further

scrutiny and decision-making by the evaluators are required to ensure appropriate results for the indicators and the process of finding solutions using the Fuzzy-AHP method. The findings from this analysis will be presented in the next section [77].

Table 3 The scale of fuzzy-AHP pair-wise comparison [44]

The relative importance of the two sub-elements	Fuzzy triangular	Reciprocal fuzzy
Equally Important	1 1 1	1, 1, 1
intermediate value between 1 and 3	1 2 3	1/3, 1/2, 1
Slightly important	2 3 4	1/4, 1/3, 1/2
intermediate value between 3 and 5	3 4 5	1/5, 1/4, 1/3
Important	4 5 6	1/6, 1/5, 1/4
intermediate value between 5 and 7	5 6 7	1/7, 1/6, 1/5
Strongly important	6 7 8	1/8, 1/7, 1/6
intermediate value between 7and 9	7 8 9	1/9, 1/8, 1/7
Extremely important	9 9 9	1/9, 1/9, 1/9

Table 4 Random Index values for different values of n [73]

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Step 3: After obtaining the weight scores for each lean supply chain performance indicator, They are ranked in descending order, from the highest to the lowest. This ranking process allows for further discussion and conclusion. Subsequently, a deliberation and a summary of the results follow.

4. Results

4.1 The Development of Lean Supply Chain Performance Indicators

As essential framework for Lean supply chain performance indicators has been developed through a literature review and the evaluation of indicators, utilizing the focus-group method with experts. It consists of measurement criteria encompassing three dimensions: Organizational profile (L1) with three indicators, Finances and Operations (L2) with four indicators, and Business results (L3) with five indicators. The consideration of these indicators involved a questionnaire administered to academic experts in the field of Lean supply chain and business practitioners from Thailand's manufacturing and service sectors. The decision-making process involved 10 participants, with five individuals from each group, as shown in Fig. 2.

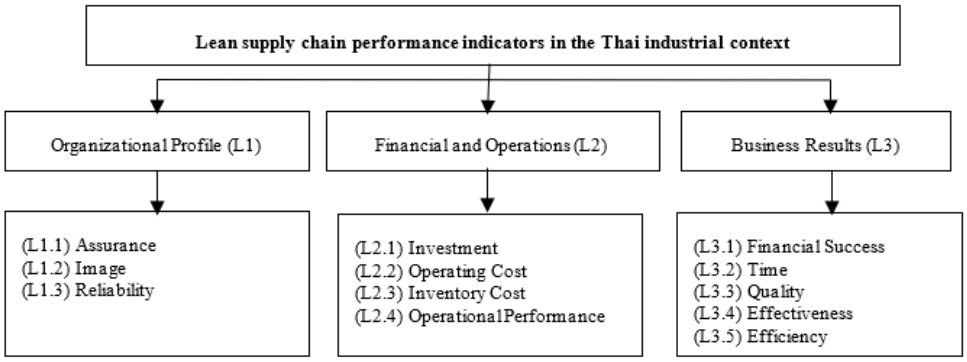

Figure 2. The structure of lean supply chain management in the Thai industrial context

Fig. 2 shows the structure of prioritizing Lean supply chain performance indicators, which is crucial in this study. It comprises three dimensions and 12 indicators: organizational profile (Assurance, Image, Reliability), Financial and Operations (Investment, Operating cost, Inventory cost, Operational performance), and Business Results (Financial success, Time, Quality, Effectiveness, Efficiency).

4.2 Ranking by Fuzzy-AHP methods

Evaluations conducted using the Fuzzy-AHP method by academic experts and business demonstrated similar opinions, yielding statistically significant results.

The Fuzzy-AHP algorithm applied in this study can be described as follows:

1. Let $\tilde{A}$ be the pair-wise comparison matrix with fuzzy number, $\tilde{A} = [\tilde{a}_{ij}]$where is a fuzzy number (l_{ij}, m_{ij}, u_{ij}) for a comparison between criterion i and j. For a reciprocal fuzzy value $\tilde{a}_{ij}^{-1} = \tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})^{-1} = \left(\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}}\right)$and $\tilde{a}_{ij} =$

$1 \forall i = j$ where l_{ij}, m_{ij}, u_{ij} represents the lowest possible, most likely and highest possible value of the fuzzy number of the comparison and respectively.

2. Starting with A, we determine the fuzzy geometric mean for each criterion i using the formula $\tilde{r}_i = (\prod_{i=1}^{n} \tilde{a}_{ij})^{\frac{1}{n}}$, where n represents the total number of number.

3. to find the fuzzy weights for each criterion, we compute the vector sum for each $\tilde{r}_i$.

$$\sum_{i=1}^{n} \tilde{r}_i = \tilde{r}_{i1} \oplus \tilde{r}_{i2} \oplus \ldots \quad (1)$$

This vector sum is then inverted and arranged is ascending order, denoted as $(\sum_{i=1}^{n} \tilde{r}_i)^{-1}$

4. the relative fuzzy weights for each criterion are calculated by multiplying the fuzzy geometric mean value, $\tilde{r}_i$ with its inverted vector sum.

$$\widetilde{w}_i = \tilde{r}_i \otimes (\sum_{i=1}^{n} \tilde{r}_i)^{-1} \quad (2)$$

Where $\widetilde{w}_i$ represents the relative fuzzy weight for criterion i and

$$\widetilde{w}_i = l\widetilde{w}_i, m\widetilde{w}_i, u\widetilde{w}_i \quad (3)$$

5. the defuzzification of $\widetilde{w}_i$ is achieved using the center of area method, resulting in the relative non-fuzzy weight M_i.

$$M_i = \frac{l\widetilde{w}_i + m\widetilde{w}_i + u\widetilde{w}_i}{3} \quad (4)$$

The non-fuzzy weight is then normalized.

$$w_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \quad (5)$$

Where w_i is the normalized non-fuzzy weight for criterion i.

6. The Consistency Index (CI) and Consistency Ratio (CR) are subsequently calculated to verify the consistency of the comparison.

$$\lambda_{max} = \frac{\sum_{j=1}^{n} Aw_i}{n} \quad (6)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (7)$$

$$CR = \frac{CI}{RI} \quad (8)$$

Where RI stands for the Random Consistency Index.

To illustrate how the algorithm operates, we shall consider expert 1 and the assurance criterion L1.1. Let criteria L1.1, L1.2, and L1.3 be represented by $i = 1,2,3$ respectively.The $\tilde{r}_i$values for the criterion were calculated as follows:

$$\tilde{r}_1 = \left((1\text{x}6\text{x}4)^{1/3}, (1\text{x}7\text{x}5)^{1/3}, (1\text{x}8\text{x}6)^{1/3}\right) = (2.8845, 3.2711, 3.6342)$$

Similar computations were performed for the other criterion, resulting in $\tilde{r}_2 = (0.5, 0.5228, 0.5503)$ and $\tilde{r}_3 = (0.5503, 0.5848, 0.6300)$ The vector sum was then calculated, inverted, and sorted in ascending order.

$$\left(\sum_{i=1}^{3} \tilde{r}_1\right)^{-1} = (0.2077, 0.2284, 0.2541)$$

For the first criterion, the relative fuzzy weight, $\widetilde{w}_i$, was determined as (2.8845 x 0.2077, 3.2711 x 0.2284, 3.6342 x 0.2541) = (0.5991, 0.7471, 0.9236). this fuzzy weight was then defuzzified to M_1 = (0.5991+0.7471+0.9236)/3 = 0.7566. Subsequently, the non-fuzzy weight was normalized to w_1 = 0.7566/(0.7566+0.1210 + 0.1360) = 0.7464. Note that M_2 and M_3 were 0.1210 and 0.1360 respectively. This value is reflected in Table 1 for indicator L1.1 and expert1. For consistency verification, CI and CR were computed. CI = $\frac{3.0270-3}{3-1} = 0.0135$. It is Note that λ_{max} = 3. 0270. Therefore, CR was calculated as $\frac{0.0135}{0.5800} = 0.0233$, which is acceptable since CR ≤ 0.10 This procedure is then repeated for all indicators and experts.

Table 5 Results data analysis and weights from 10 experts

Indicators	Ex-1	Ex-2	Ex-3	Ex-4	Ex-5	Ex-6	Ex-7	Ex-8	Ex-9	Ex-10	Weights
Organizational profile											
L1.1	0.7464	0.0547	0.3333	0.3333	0.7221	0.3333	0.3333	0.8059	0.7919	0.8059	0.5260
L1.2	0.1194	0.4727	0.3333	0.3333	0.1618	0.3333	0.3333	0.1160	0.1244	0.1160	0.2444
L1.3	0.1342	0.4727	0.3333	0.3333	0.1162	0.3333	0.3333	0.0781	0.0837	0.0781	0.2296
Financial and Operations											
L2.1	0.6773	0.2500	0.6209	0.2500	0.4622	0.7428	0.6451	0.6498	0.6789	0.0753	0.5052
L2.2	0.1448	0.2500	0.2002	0.2500	0.3866	0.0857	0.1912	0.1533	0.0489	0.5500	0.2261
L2.3	0.1272	0.2500	0.1065	0.2500	0.0913	0.0857	0.1030	0.1282	0.1361	0.2476	0.1526
L2.4	0.0507	0.2500	0.0723	0.2500	0.0599	0.0857	0.0607	0.0687	0.1361	0.1271	0.1161
Business results											
L3.1	0.5800	0.2495	0.2000	0.2499	0.3904	0.4622	0.6333	0.6422	0.6305	0.3227	0.4361
L3.2	0.1747	0.0328	0.2000	0.0696	0.0625	0.1133	0.0904	0.1360	0.0653	0.0352	0.0980
L3.3	0.0739	0.2494	0.2000	0.2495	0.2343	0.1369	0.1124	0.0697	0.1024	0.4200	0.1849
L3.4	0.0944	0.2229	0.2000	0.1814	0.1543	0.1369	0.0736	0.0750	0.0903	0.1174	0.1346
L3.5	0.0770	0.2453	0.2000	0.2495	0.1585	0.1508	0.0904	0.0771	0.1116	0.1047	0.1465

Regarding the evaluation of the indicators in Dimension 1: Organizational profile, the Assurance indicator has the highest weight of 0.5260. Meanwhile, the Image and Reliability indicators have weights of 0.2444 and 0.2272, respectively. However, this dimension emphasizes measuring Quality and assurance more than Image and Reliability. Both of the last two indicators reflect the same direction of results.

In the evaluation of the indicators in Dimension 2: Finances and Operations, the Investment indicator has the highest weight of 0.5052. Following that, the Operating Cost indicator weighs 0.2261, indicating that many experts consider Investment more critical than other indicators. The Inventory Cost and Operational Performance indicators have weights of 0.1526 and 0.1161. Respectively, the importance of these two indicators is close, which implies that inventory cost is one of the indicators that may affect the organization's operational performance positively or negatively.

Lastly, regarding the evaluation of the indicators in Dimension 3: Business Results, it is found that the financial success indicator has the highest weight of 0.4482 and 0.4361. Efficiency, Effectiveness, and Time indicators have weights that are close to each other, namely 0.1388, 0.1465, 0.1283, 0.1346, and 0.1061, 0.0980, respectively. In this dimension, importance is clearly given to the success of the set goals. Each indicator contributes to achieving the results efficiently. The results are shown in Table 6

Table 6 Results ranking of Fuzzy-AHP method

Dimensions/ Indicators	Fuzzy-AHP method	Rank
Organizational profile		
Assurances	0.5260	1
Image	0.2444	2
Reliability	0.2296	3
Finance and Operations		
Investment	0.5052	1
Operation cost	0.2261	2
Inventory cost	0.1526	3
Operational performance	0.1161	4
Business results		
Financial success	0.4361	1
Quality	0.1849	2
Efficiency	0.1465	3
Effectiveness	0.1346	4
Time	0.0980	5

5. Discussion

5.1 Lean supply chain performance indicators outcomes

The prioritization of Lean supply chain performance indicators within the Thai industry is a study that provides guidelines for industrial practitioners to apply them appropriately and efficiently. These indicators also consider their alignment with improving operational efficiency and business competitiveness. The Analytic Hierarchy Process (AHP) method, which employs a structured grouping design [32], may not always be fully endorsed due to uncertainties or inaccuracies in assessing specific indicators [28]. Therefore, Fuzzy-AHP has been developed from AHP to enhance decision-making comprehensiveness and address multi-criteria considerations, including ranking various indicators [80]. This technique assists evaluators in assigning relative importance to multiple criteria based on the same foundation as AHP [75]. It can be observed that the application of the Fuzzy-AHP method, based on evaluations by experts, yields more reliable results in prioritizing the importance of Lean supply chain performance indicators.

Due to the differing contexts of industries, lean supply chain performance indicators are mostly presented from industry-specific perspectives. As a result, comprehensive presentations of Lean supply chain performance indicators for overall industries have not yet emerged, like the case of Thai industries, where the context differs from other countries.

Regarding the organizational profile dimension, when considering Lean supply chain indicators in Thailand, The researcher found that assurance, image, and reliability had the same ranking outcomes as those of Thailand's healthcare service operations industry [28]. Additionally, the evaluation only considered the Image indicator, which ranked third.

When considering the overall picture of Thailand's Finance and Operation dimension. The researcher found that the Investment and Operation cost indicators had the same ranking, occupying the first and second positions, respectively. However, in other countries, there were differing opinions. For example, the operation cost indicator ranked first compared to Operational performance [31]. Additionally, when evaluating based on weighting criteria or averages, the Operational performance indicator received scores of 0.719 and an average of 3.32 according to Tortorella [29] and Rakhmanhuda and Karningsih [55] while ranked last. The Operating cost and Inventory cost indicators, which reflect operational practices aligned with company strategies and goals, contribute to profitability within Plastering supply chains for SMEs [31].

Regarding procurement, which is part of the Operating cost, it improves efficiency and reduces non-value-added time [80]. It is relevant to manufacturing, where Investment is ranked second. Finances and Operations are indicators of the company's operations [71]. The apparent result indicator is Assurance, while in contrast, Time is more important than Quality, such as reducing lead time in the work process [39][43]. The method can understand that applying appropriate Lean concepts to various activities' timeframes enhances the efficiency of industries and businesses, making Investment a weighted indicator. At the same time, Investment or Cost-Time profiles rank fourth [32].

In the Business results dimension in Thailand, it was found that the Time indicator had a weighting of 0.1849, whereas, in the research work of Adebanjo et al. (2016), it had a weighting of 0.019. Conversely, when considering research from different countries, The Quality indicator was found to be more significant than financial success and time [29]. However, Rakhmanhuda and Karningsih (2018) assigned a score of 0.998 to Quality. Upon examination, it was found that the Time and Quality indicators were ranked equally in importance [32].

Regarding Business results, Quality was observed to contribute to overall company quality [34]. The continuous development of successful companies is evident from Business results related to available resources such as Cost, Efficiency, and Effectiveness [81].

5.2 Implications for research and practice

This study has significant implications for prioritizing the importance of lean supply chain performance indicators. In the past, there has been considerable variation in performance indicators, and in some cases, similar indicators were employed, necessitating industries to carefully consider indicators that are appropriate for their specific context [47]. From an academic perspective, the proposed perspective on Lean Supply Chain Performance Indicators in Thai industries includes Organizational Profile, Finance and Operations, and Business Results. These dimensions provide a reliable and straightforward means of measuring supply chain performance, with each dimension contributing to a fundamental aspect of performance measurement [22]. However, there is a clear focus on specific objectives or goals, with Investment being a key indicator for assessing financial status, costs, and service capabilities. The Finances and Operations dimension reflects the company's image and credibility in supplier relationships and building trust. Lastly, the Business results dimension measures performance in various aspects of company management, including financial, time, quality, efficiency, and effectiveness, demonstrating an efficient organizational operation [82].

Regarding the implementation guidelines, it can be observed that the Financial and Operations dimensions are the most critical, with Investment being the most important, followed by Operation cost. Companies should apply lean principles to improve efficiency in their management systematically, aiming to reduce costs and increase profits consistently. In the context of the organizational profile, it is evident that the performance indicators mentioned will undoubtedly enhance the company's image, including reliability, and help the supply chain become more flexible by improving its operational efficiency [71]. As for Business Results, the most prominent indicator is Financial Success. Thus, these indicators represent the results of management efficiency in the company that can be quantitatively measured, although other indicators' importance should not be overlooked.

Nevertheless, this research emphasizes the importance of disseminating Lean Supply Chain Performance Indicators to Thai industrial companies. This dissemination is essential for companies to become aware, understand, and pay attention to enhancing their capabilities to gain a competitive edge [28]. Given the uncertain economic conditions and unpredictable factors, measuring company efficiency using these indicators requires careful policy considerations. It relies on a well-trained team or management to correctly apply the lean supply chain performance indicators.

6. Conclusions

This research provides insights into the prioritization of lean supply chain performance indicators within the context of the Thai industry. Through input from academic experts and practitioners, The Fuzzy-AHP technique was utilized, which is a recognized and accepted method for multi-criteria decision-making. The analysis revealed that within the Organizational Profile dimension, 'Assurances' received the highest weighting at 0.5260, followed by Image at 0.2444, and Reliability, which holds the lowest value at 0.2296. The Finance and Operations dimension includes Investment at 0.5052, Operation Cost at 0.2261, Inventory Cost at 0.1526, and Operational Performance at 0.1161, in that order. Lastly, the Business Results dimension consists of Financial Success at 0.4361, Quality at 0.1849, Efficiency at 0.1465, Effectiveness at 0.1346, and Time at 0.0980.These findings represent an initial exploration within the context of the Thai industry, serving as a driving force to help companies achieve success and assess their financial capabilities, image, and outcomes through the implementation of lean supply chain processes. Companies can utilize these indicators to appropriately improve their operational processes.

This research is limited by the fact that it does not specify or target any particular type or size of industry and exclusively employs the Fuzzy-AHP technique. Future studies could extend this research to encompass a broader range of industrial sectors, while also incorporating suitable performance measurement approaches. Additionally, alternative techniques such as AHP, SAW, the Best-Worst Method, and TOPSIS could be employed to develop criteria and weights that better reflect the specific context of various types and sizes of industries. This may result in findings that differ from those derived using the original approach.

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