Integrating Lean into Supplier Selection Problems in Small and Medium-Sized Enterprises

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Abstract. This study deals with lean philosophy and supplier selection problems in Small and Medium-Sized Enterprises (SMEs). Even though small businesses account for a significant amount of production in Turkey, lean applications are relatively scant in supply chains. The aims of this study are threefold: firstly, to present supplier selection criteria specifically tailored for SMEs from a lean management perspective; secondly, to propose a flexible lean supplier selection model that aligns with the unique needs and constraints of SMEs; and finally, to provide practical suggestions for implementing lean transformation initiatives within the case company to enhance operational efficiency and overall performance. The Integrated Analytical Hierarchy Process (AHP) and Technique for Order Preference by Similarity to An Ideal Solution (TOPSIS) method are proposed. The AHP method is used for the determination of the criterion weights, while the TOPSIS method is used for supplier selection evaluation among three supplier alternatives. The case study was implemented for the manufacturing company, considering 12 criteria, and involved the evaluation and selection of three different suppliers that supply the same raw material with different supplier service properties. This research found that customized production capability, the adaptation of new conditions and risk management, and on-time delivery were the most crucial criteria for the case company; although, financial condition and communication were the least important among the 12 criteria. Even though the cost is assumed to be the most essential criterion for the supplier selection process, the cost was ranked middle in the rankings.

Keywords: Lean Supply Chain Management · Lean Small and Medium-Sized Enterprises · AHP · TOPSIS · Lean Supplier Selection

1 Introduction

Lean Supply Chain Management (LSCM) is the implementation of lean management through the supply chain to optimize all activities and information, material, and financial flows from the point of view of the end customer. Enhancing operational effectiveness, cutting costs, raising satisfaction among consumers, and improving product quality are all achieved via the usage of lean supply chain management. Lean supply chain management allows businesses to increase their responsiveness, flexibility, and competitiveness

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in the supply chain by removing waste, reducing operations, and optimizing the flow of supplies and information [1]. Additionally, it fosters a culture of innovation and efficiency among supply chain partners by encouraging cooperation and ongoing development. In today's dynamic and competitive business world, adopting lean supply chain management ideas and practices ultimately helps businesses achieve sustainable development and long-term success.

There are various criteria used in the literature to evaluate supplier selection in the literature, whereas, evaluation for supplier selection from the lean perspective is relatively scant. Cost, product quality, financial condition, service level, geographical condition, communication, and ethics are the criteria that are currently used in the evaluation of their suppliers. Additionally, five essential criteria for supplier selection processes are used based on the most common lean supplier selection criterion in the lean supplier supply chain management and lean SMEs and given in the following: flexibility to adapt to new conditions and ability in risk management, reliability of the supplier, customize production capability, production and shipment capability, on-time delivery.

A CNC machining company that specializes in producing high-quality spare parts was used as a case company in the research. Since the company's business production strategy is make-to-order and keeping minimum raw material stock, the company is an eligible candidate for implementing lean supply chain management. Furthermore, the company is working with many suppliers that ensure the same product. Three suppliers that have provided the same unique raw material with different service and management properties are selected in the case study. Therefore, a systematic structure in the selection process is required to select suppliers in a lean and efficient way for the evaluation of suppliers among many alternatives. The aim of this study is the determine the criteria affecting the selection of lean supply and the supply chain by providing real case implementation. Integrated TOPSIS and AHP technique is the solution method to solve this problem. The TOPSIS approach is used to evaluate supplier selection among three supplier alternatives, while the AHP method is utilized to determine the criterion weights.

This paper is organized as a literature review, methodology, implementation and results, and discussion and conclusion, respectively.

2 Literature Review: Lean Supplier Selection Criteria

Lean Supply Chain Management (LSCM) is a tactical strategy that places a strong emphasis on reducing waste and streamlining supply chain operations to increase productivity and customer value. It includes a variety of ideas and methods drawn from lean manufacturing, which started in the car industry and eventually spread to other industries. Given its potential to promote operational excellence and competitiveness, there has been an increase in interest in applying Lean concepts to the management of supply chains in recent years. Both LSCM and lean SME literature are covered to find eligible evaluation criteria in the assessment of the suppliers. These criteria are cost, product quality, financial condition, service level, flexibility to adapt to new conditions and ability in risk management, reliability of the supplier, customized production capability, production and shipment capability, geographical condition, communication, on-time delivery, and ethics and explained respectively in the following.

Cost refers to the product price, logistics cost, and the conditions that determine the payouts for which the supplier is responsible. It refers to a supplier that can be negotiated at a reasonable price [2–8]. Product Quality refers to product performance, warranties, claim procedures, maintenance and return rates, and quality awards are all included in the quality system. Lean Six Sigma (LSS) combines lean and Six Sigma principles to maximize their benefit, thus using LSS tools and methods is beneficial for companies by reducing waste and improving quality [2, 3, 4, 6, 7, 9–13]. Financial Condition adverts the financial situation, economic stability, and pricing strategy of the supplier [3, 5, 6, 8, 9]. According to [2], low cost and good quality are important supplier qualities in the lean supplier selection process, and a higher service level is expected from the supplier [3, 4, 5, 7, 8, 10]. [4] defined cost, quality, and service level as lean-related properties in the lean supplier selection process.

Flexibility to adapt to new conditions and ability to address the supplier's risk management in the face of unexpected orders or changes [14–17]. Risk management whether it is in lean or agile perspectives has attracted practitioners as new notions such as resilience emerged in the literature [2]. Reliability of the Supplier mentions that there are standards regarding product availability as well as product quality [5, 7, 9]. Only reliable and consistent suppliers can meet these demands. Suppliers must show that they can not only deliver goods of a certain quality but that they can do so on an ongoing basis under the lean philosophy [3] Customize Production Capability is the supplier's ability to respond to customizations requested by the company. In this case, if differentiation is desired in a product, the supplier's ability to make this customization by the company [5–8, 13, 18–20]. [8] claimed that implementing a lean approach enables SMEs to manufacture high variety and low volume products. Therefore, the capability of product customized level is directly related to the degree of the lean implementation in the business. Production and Shipment Capability refers to the maximum amount of production the supplier can produce at any given time how the supplier mixes the product when shipping the product and what it can do when physically processing orders [7, 10, 13]. Geographical Condition is geographic proximity, geographical location is reachable. It affects delivery time and transportation costs which cause unnecessary waste in the supply chain [3, 7].

Communication is the other criterion in the literature review. In a lean supply chain; effective and efficient communication, open and honest communication, a good communication system, good relations with SMEs, responsiveness, and supplier need to be proactive to the SMEs [5, 7, 21]. One of the main characteristics that makers use to set their product offerings apart from those of rivals is on-time delivery (OTD). It is the measurement that encourages continuous development which is the main objective of Kaizen and aids in figuring out preferred lead times. The primary indicator of how effective supply chain procedures are working is OTD. Finding the underlying reason for OTD delays is essential to resolving the problem and creating standards of manufacturing excellence. This can include systems issues, supplier management issues, and execution issues. OTD ensures that production is completed on time without delay. Therefore, the damages arising from the delay in production are prevented [22, 23]. Ethics refers to

business ethics. Business ethics is concerned with the moral guidelines, codes of conduct, values, and standards that direct ethical behavior in particular circumstances [6, 18, 19].

3 Methodology

To solve this problem, research has been conducted primarily on the lean philosophy and lean practices of small businesses. In the literature review, different sectors are compared regarding adjusting lean implementation. In addition, the position of small businesses in Turkey was taken in the macro system, reviews were made about the machining sector in the microsystem, and the company's process flow chart was drawn and explained. Later, research was conducted on the company's problem. In this article, a literature review has been conducted on lean SCM and lean SMEs. According to the literature review, 16 criteria were revealed. Following the discussion with the firm, these criteria were whittled down to 12. The criteria that the company also uses are shown with '*'. The criteria are Cost* (C1), Product Quality* (C2), Financial Condition* (C3), Service Level* (C4), Flexibility to Adapt to New Conditions and Ability in Risk Management (C5), Reliability of the Supplier (C6), Customize Production Capability (C7), Production and Shipment Capability (C8), Geographical Condition* (C9), Communication * (C10), On-Time Delivery (C11), Ethics* (C12). The supplier chain selection process included two methods.

AHP and TOPSIS methods are used respectively in the paper. Since the company does not know the importance of criteria, AHP was used to find the criterion weights. TOPSIS methodology is selected to determine how the alternative is closest or furthest to the ideal solution. Instead of ranking solutions, the position of the alternative solutions gives more valuable insight to the company in the decision-making process in the selection of the suppliers in different scenarios such as receiving urgent orders, etc.

3.1 AHP

AHP is an effective and straightforward method that combines both subjective and objective variables in decision-making. AHP is a fundamental decision-making strategy that is used to address problems containing multiple criteria. AHP has become one of the most popular decision-making methodologies due to its simplicity [24, 25]. Setting a goal is the beginning of the AHP. Under the specified goal, a progressive model consisting of criteria, sub-criteria, and options is being constructed. The definition of the problem is the first step in AHP. The comparison of the criteria and the building of the matrix, respectively, conclude with a comparison of the available alternatives based on the criteria and the conclusion of the best alternative.

Normalized Decision Matrix: Each cell of the decision matrix is divided by the sum of the corresponding column. This gives the normalized decision matrix.

$$NDM_{ij} = \frac{DM}{\sum(DM_{ij})}$$

Weighted Normalized Decision Matrix: The weighted normalized decision matrix is obtained by multiplying the normalized decision matrix by the weights of the criteria.

$$WNDM_{ij} = NDM_{ij} * W_i$$

3.2 TOPSIS

TOPSIS is a sophisticated sequencing approach that can be used in a variety of information technology applications. The TOPSIS approach involves selecting the alternative that is closest to the ideal solution on the positive side and the alternative that is farthest away from the negative side. The TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) technique computes and orders the distances of the decisions (points) from the ideal solution (positive and negative).

Normalized Decision Matrix: Each cell of the decision matrix is divided by the square root of the sum of the squares of the corresponding column. This gives the normalized decision matrix.

$$NDM_{ij} = \frac{DM_{ij}}{sqrt\left(\sum\left(DM_{ij}^2\right)\right)}$$

Weighted Normalized Decision Matrix: The weighted normalized decision matrix is obtained by multiplying the normalized decision matrix by the weights of the criteria.

$$WMDM_{ij} = NDM_{ij} * W_i$$

Ideal and Negative-Ideal Solutions: The ideal solution is the maximum value of each criterion, and the negative-ideal solution is the minimum value of each criterion.

$$IS_j = \max\left(WNDM_{ij}\right), NIS_i = \min\left(wndm_{ij}\right)$$

Distance from Ideal Solution and Negative-Ideal Solution: The distance of each option from the ideal solution and negative ideal is calculated using the Euclidean distance formula.

$$D_i+ = sqrt\left(\sum\left(WNDM_{ij} - IS_j\right)^2\right), D_i- = sqrt\left(\sum\left(WNDM_{ij} - nis_{\mathrm{I}}^2\right)\right)$$

Similarity to Ideal Solution: The similarity of each option to the ideal solution is calculated using the formula: $S_i = D_i/(D_i + +D_i)$

4 Implementation and Results

Three suppliers that are not manufacturers are provided by the case company and supplier properties are as follows:

Supplier A, which is the first supplier, is a non-importer that typically sources materials from Istanbul importers. It can provide the organization with a customized product

without extra cost or quantity constraints. Because of these advantages, it outperforms competitors.

Despite the higher price, the company prefers Supplier B, which is the second import supplier, for its quality and service. Company B, which does not like flexible ordering opportunities very much, cannot meet the demand at a low rate. The price difference is high for low-rate orders. It does not produce.

Supplier C, which is the last supplier as an importer. Despite its proximity to the company in terms of geographical location, it is a supplier with poor service. For these reasons, it is a supplier who does not offer any flexibility and it claims that there is no product but still does not offer any alternatives.

12 lean supplier criteria are evaluated by two company experts. Then each criterion is normalized by dividing the square root of the summation of the corresponding criterion and results are shown in Table 1.

The customized production capability criterion with the highest score of 0.199 was highlighted in the related Table 1. Because the company works on an order basis, a customized product is required. Understanding new-generation production requires a thorough understanding of customization. The company's priority highlights the importance of its suppliers having a flexible structure and being able to satisfy the company's various needs by doing JIT production as necessary. The second criterion with the highest score of 0.117 is adaptability to new conditions and risk management abilities. Risk management has become a highly significant factor for SMEs in today's complicated and dynamic market, especially in Turkey, according to the results risk management is one of the most significant considerations in terms of supplier selection. Lean implementations stand for eliminating waste and minimizing errors as much as possible; thus, using proper risk management tools and techniques is critical for organizations and this company's suppliers to adapt to new unexpected conditions and apply risk management techniques properly. The third highest value criterion is On-Time Delivery with a score of 0.113. To have a successful supply chain we need to consider all the stakeholders in the system. The service level of the company and customer satisfaction are dependent on their suppliers' on-time deliveries because their production relies on their suppliers, hence stakeholder relationships throughout the supply chain are crucial for this company.

The majority of the articles claimed that cost is a key factor in supplier selection for SMEs, however, it ranked seventh in terms of importance according to AHP results shown in Table 1. As a result, the customized production capability criterion was found the most important, and financial condition was found to be least important among the 12 criteria at the end of AHP implementation.

Table 1. The criteria weights

	Cost	Product Quality	Financial Condition	Service Level	Adapt to New Conditions and Risk Management	Reliability of the Supplier	Customize Production Capability	Production and Shipment Capability	Geographical Condition	Communication	On-Time Delivery	Ethics
Weights	0,067	0,083	0,023	0,054	0,117	0,106	0,199	0,056	0,068	0,052	0,113	0,061

Three suppliers are evaluated by two experts on a scale of 1 to 7, and Table 2 indicates the supplier evaluation results according to 12 criteria. 1 indicates that the criteria do not important for the supplier; whereas, 7 indicates that that criterion is very critical for the supplier. Normalized scores for each supplier criterion pair are shown in Table 2 are shown in Table 3. Each criterion divided by the square root of the sum of each criterion values in the calculation normalization process.

Table 2. The firm's criterioncriterion-scoringon

	Cost	Product Quality	Financial Condition	Service Level	Adapt to New Conditions and Risk Management	Reliability of the Supplier	Customize Production Capability	Production and Shipment Capability	Geographical Condition	Communication	On-Time Delivery	Ethics
S1	4	3	3	6	6	5	6	5	2	7	5	5
S2	2	6	7	6	4	6	5	2	2	5	6	6
S3	5	4	6	3	2	5	4	4	6	1	3	4

Table 3. The Normalized Rating Scores

	Cost	Product Quality	Financial Condition	Service Level	Adapt to New Conditions and Risk Management	Reliability of the Supplier	Customize Production Capability	Production and Shipment Capability	Geographical Condition	Communication	On-Time Delivery	Ethics
S1	0,5963	0,3841	0,3094	0,6667	0,8018	0,5392	0,6838	0,7454	0,3015	0,8083	0,5976	0,5698
S2	0,2981	0,7682	0,7220	0,6667	0,5345	0,6470	0,5698	0,2981	0,3015	0,5774	0,7171	0,6838
S3	0,7454	0,5121	0,6189	0,3333	0,2673	0,5392	0,4558	0,5963	0,9045	0,1155	0,3586	0,4558

Table 4. The weighted normalized ratings

	Cost	Product Quality	Financial Condition	Service Level	Adapt to New Conditions and Risk Management	Reliability of the Supplier	Customize Production Capability	Production and Shipment Capability	Geographical Condition	Communication	On-Time Delivery	**Ethics**
S1	0,0398	0,0320	0,0072	0,0361	0,0936	0,0570	0,1362	0,0417	0,0205	0,0420	0,0678	0,0348
S2	0,0199	0,0641	0,0169	0,0361	0,0624	0,0684	0,1135	0,0167	0,0205	0,0300	0,0813	0,0417
S3	0,0498	0,0427	0,0145	0,0181	0,0312	0,0570	0,0908	0,0334	0,0615	0,0060	0,0407	0,0278
a*	**0,0199**	**0,0641**	**0,0169**	**0,0361**	**0,0936**	**0,0684**	**0,1362**	**0,0417**	**0,0615**	**0,0420**	**0,0813**	**0,0417**
a¯	**0,0498**	**0,0320**	**0,0072**	**0,0181**	**0,0312**	**0,0570**	**0,0908**	**0,0167**	**0,0205**	**0,0060**	**0,0407**	**0,0278**

The weighted normalized ratings are calculated and shown in Table 4. It indicates the results that are obtained by the multiplication of criteria weights and the normalized rating scores. The a* and a- values are calculated for each criterion and they indicate cost and benefit, respectively. While the cost criterion took the* value at the minimum value for 3 suppliers, the other criterion took the maximum value. In addition, while the cost criterion took the a-value as the maximum, the other criterion took the minimum value for the 3 suppliers. This is because the cost is desired to be reduced rather than increased. Each a* and a- values are calculated by following this procedure.

Table 5. The separation measures and similarities to positive ideal solution

	S*	S-	C*
Supplier1	0,0597	0,0883	0,5967
Supplier2	0,1027	0,0762	0,4258
Supplier3	0,1048	0,0461	0,3056

The S* value gives the positive ideal solution, while the S- value indicates the negative ideal solution. C* indicates the score reached by the supplier. Since the aim is to find the highest score among alternative suppliers, the supplier with the highest C* is selected. According to the Table 5, supplier 1 is selected.

5 Discussion and Conclusion

The real-life complex supplier selection problem of a production company is examined in this study. The company has been given a supplier selection model that they can utilize in future activities. The current supplier selection process used by the company is based on the company's instant accessibility and does not always result in a suitable supplier. As a result, the process is extremely vulnerable to human error, resulting in waste and severe time and capacity loss. The model presented for supplier selection, on the other hand, aims to improve the company's efficiency through lean practices, select the correct supplier, make a profit, and minimize waste.

The problem solution methodology consists of a combination of two different applications. The AHP application, which is used to determine criterion weights, is the first of them. The goal of AHP is to determine which criteria are significant to the company. The TOPSIS application was then used to choose suppliers. The TOPSIS evaluates suppliers based on these defined criteria, which are utilized to identify the best supplier. Thus, with this approach, the company will be able to manage the supplier selection process easier and decide on the appropriate supplier.

Implementing the case study for the manufacturing firm involves evaluating and choosing three distinct suppliers who provide the same raw material but with varying supplier service characteristics based on 12 criteria. The research discovered that the example company's most vital factors were customized production capacity, the ability to respond to changing circumstances and manage risk, and on-time delivery, while the least critical criteria were financial condition and communication. The cost was rated third in the rankings, even though it is widely believed to be the most important factor in the supplier selection process. In addition to these, some recommendations are proposed to the company. Firstly, the value stream mapping method is proposed to distinguish value-added and non-value-added activities in the company. Secondly, the Enterprise Resource Planning system is proposed as a better information system. Thirdly, a standardized supplier selection process together with a standardized process design and workplace should be applied to sustain standardization in the whole supply chain. Fourthly, for better product quality, Lean Six Sigma (LSS) should be applied to ensure

quality at each level. Furthermore, a Just-In-Time (JIT) inventory system should be implemented as a management strategy to minimize waste. Principle should be applied to waste management. Lastly, for inventory control and management improvement, the spaghetti diagram and the Kanban system are proposed for a better and more efficient layout design.

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