# Strategic supplier selection and order allocation for sustainable development of small and medium-sized enterprises: insights from a case study



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## Abstract

**Purpose** – Efforts to implement supplier selection and order allocation (SSOA) approaches in small and medium-sized enterprises (SMEs) are quite restricted due to the lack of affordable and simple-to-use strategies. Although there is a huge amount of literature on SSOA techniques, very few studies have attempted to address the issues faced by SMEs and develop strategies from their point of view. The purpose of this study is to provide an effective, practical, and time-tested integrated SSOA framework for evaluating the performance of suppliers and allocating orders to them that can improve the efficiency and competitiveness of SMEs.

**Design/methodology/approach** – This study was conducted in two stages. First, an integrated supplier selection approach was designed, which consists of the analytic hierarchy process and newly developed measurement alternatives and ranking using compromise solution to evaluate supplier performance and rank them. Second, the Wagner-Whitin algorithm is used to determine optimal order quantities and optimize inventory carrying and ordering costs. The joint impact of quantity discounts is also evaluated at the end.

**Findings** – Insights derived from the case study proved that the proposed approach is capable of assisting purchase managers in the SSOA decision-making process. In addition, this case study resulted in 10.89% total cost savings and fewer stock-out situations.

**Research limitations/implications** – Criteria selected in this study are based on the advice of the managers in the selected manufacturing organizations. So the methods applied are limited to manufacturing SMEs. There were some aspects of the supplier selection process that this study could not explore. The development of an effective, reliable supplier selection procedure is a continuous process and it is indeed certainly possible that there are other aspects of supplier selection that are more crucial but are not considered in the proposed approach.

**Practical implications** – Purchase managers working in SMEs will be the primary beneficiaries of the developed approach. The suggested integrated approach can make a strategic difference in the working of SMEs.

**Originality/value** – A practical SSOA framework is developed for professionals working in SMEs. This approach will help SMEs to manage their operations effectively.

**Keywords** Small and medium-sized enterprises (SMEs), Supplier selection and order allocation (SSOA), Sustainable development, MARCOS, Wagner-Whitin (W-W) algorithm, Quantity discounts

**Paper type** Research paper

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## 1. Introduction

Over the past two decades, the small and medium-sized enterprises (SMEs) sector has evolved as a vibrant and dynamic sector of the Indian economy. This sector is contributing significantly to the economic growth of India by fostering entrepreneurship and creating large job opportunities at relatively lower capital costs. SMEs serve as ancillary units to large enterprises (LEs), and they play an important role in the country's inclusive industrial growth. In growing economies like India, SMEs offer quality products at cheaper prices but lag in meeting delivery timelines. It has been observed that SMEs were not able to contribute as much to gross domestic product as they could (Mukherjee, 2018). After globalization, SMEs encountered difficulties in terms of technological advancement and strengthening supply chain management (SCM) to compete with global businesses.

Every supply chain consists of LEs as well as SMEs that are engaged in either directly or indirectly fulfilling a customer request. Therefore, there is a close connection between the performance of SMEs and the success of the entire supply chain. Large companies have already been investigated experimentally and tested the rippling effects of supplier selection and order allocation (SSOA) approaches, but SMEs have undervalued the benefits of such processes due to a lack of expertise, various resources and technological constraints, and most important lack of simple, practical and cost-effective strategies (Narkhede and Rajhans, 2022; Singh and Kumar, 2020). Most SMEs purchase materials from nearby suppliers and consider cost as the sole criterion for supplier selection (Manucharyan, 2021). SMEs can only succeed if they offer high-quality products on time and can get an edge in the marketplace by being flexible in their operations. To remain flexible, SMEs require sustainable and reliable suppliers who can provide quality products at competitive prices and on time. Therefore, the SSOA strategy can play an important role for SMEs in reducing purchasing costs and product lead time and enhancing sustainability and competitiveness. Although there is a huge amount of literature on SSOA techniques, very few studies have attempted to address the issues faced by SMEs and develop strategies from SMEs' point of view.

Irrespective of the country, SMEs confront similar challenges in surviving or gaining a competitive edge. The main issues that manufacturing SMEs face are the lack of supplier selection, order allocation and inventory management strategies (Babbar and Amin, 2018; Singh and Kumar, 2020). These strategies significantly influence the productivity of manufacturing companies, and thus, purchasing can be a crucial strategic factor for manufacturing SMEs. Selecting the right suppliers can help companies save substantially because, in the manufacturing sector, the cost of raw materials and components accounts for up to 80% of the unit price (Weber *et al.*, 1991). Selecting suppliers exclusively based on price has been the conventional method of choosing suppliers for many years. SMEs have been using the same conventional methods of supplier selection and have neglected the benefits of SCM strategies. In the face of significant disruptions, shortage of capital and lack of expertise, SMEs encounter difficulties in implementing SCM approaches in their supply chains. These significant impediments persist in SMEs, especially in emerging countries like India. Therefore, it becomes necessary to explore different suppliers based on a predefined set of criteria and to develop an order allocation approach that can significantly reduce the total cost of purchase. From this perspective, this research presents a unique approach aimed to resolve the SSOA issues of SMEs by introducing a three-stage integrated SSOA approach that consists of analytic hierarchy process (AHP), measurement alternatives and ranking using compromise solution (MARCOS) and Wagner-Whitin (W-W) algorithm. In this regard, This research is focused on the following two research objectives (ROs):

*RO1.* To develop an efficient and practical SSOA approach that will assist purchase managers working in SMEs in SSOA decision-making.

*RO2.* To prepare a step-by-step framework that will help SMEs implement the proposed approach in their operations to increase their productivity and competitiveness.

The rest of this article is structured as follows: Section 2 examines the pertinent literature; Section 3 depicts the methodology adopted in this study; Section 4 discusses the findings; and Section 5 presents the conclusion, implications, limitations and future scope of the study.

## 2. Literature review

Sluggish productivity is one of the major threats to the overall growth of Indian manufacturing firms, which has serious implications for SMEs (Pasi *et al.*, 2020). The productivity gap between SMEs and LEs is 26% in France, 41% in Germany and 54% in Italy (Albaz, 2020). The sluggish productivity of SMEs is primarily caused due to their incompetent suppliers because most SMEs rely heavily on their suppliers for components and subassemblies (Aouadni *et al.*, 2019a). A significant portion of the global workforce is used by SMEs, and therefore, increasing the productivity of SMEs can be a worthwhile endeavor. An efficient SSOA can not only lower purchasing costs but also contribute to the efficient manufacturing processes of SMEs.

### *2.1 Supplier selection*

Business characteristics such as global competition, technology developments, shorter life cycles of products and strict service and high-quality product demands are the most significant driving forces for businesses to establish medium- to long-term strategic partnerships with their suppliers to enhance overall performance and achieve a competitive edge over their rivals (Rajhans and Barshikar, 2013). Additionally, managing suppliers is crucial in SCM because the cost of materials and components defines the biggest portion of the total cost. Most manufacturing businesses allocate 60%–80% of their earnings to buying raw materials or components (Kumar *et al.*, 2014). Therefore, supplier selection can be viewed as one of the most crucial SCM issues to maintain a competitive edge. But simply looking for suppliers with the cheapest price is no longer considered "efficient supplier selection" (Taherdoost and Brard, 2019). Choosing the correct suppliers is a crucial strategic aspect for the success of the firm because supplier efficiency is among the most important features of modern supply chains (Liao and Kao, 2011). However, the majority of research studies have focused on the problems of large businesses, and there are very few studies that address the limitations of SMEs (Singh, 2011). Most SMEs buy materials as and when required from local suppliers and consider cost as the sole criterion for supplier selection (Rahman *et al.*, 2020; Zavadskas *et al.*, 2018). In this context, this research aims to develop a supplier selection strategy, particularly for SMEs.

*2.1.1 Criteria for supplier selection.* For the previous few decades, selecting suppliers simply based on cost has been the conventional method of selecting suppliers (Khoshfetrat *et al.*, 2020). However, LEs have realized that using cost as the only factor for the selection of suppliers is not effective and have switched to a more thorough multicriteria decision-making (MCDM) process. The selection criterion for suppliers varies depending on the size of the purchasing organization (Rajhans and Barshikar, 2013). Academics have been working on the supplier selection process since it was identified as an MCDM problem and have looked at it from different perspectives. Both qualitative and quantitative factors are included in the supplier selection process, and therefore, making a trade-off between them becomes important (Mendoza and Ventura, 2012). Mostly, supplier selection is done using a typical set of established criteria such as price, quality, delivery and technical expertise. (Büyüközkan and Çifçi, 2011; Nourmohamadi Shalke *et al.*, 2018; Zhu *et al.*, 2012). Table 1 shows an overview of supplier selection criteria used in the literature.

Most SMEs do not follow any specific supplier selection criteria, and they purchase materials in smaller quantities as and when required from nearby suppliers (Albaz *et al.*, 2020; Higgs and Hill, 2019). As a result, SMEs are unable to take benefit of mass quantity buying and related discounts (Narkhede and Rajhans, 2022). Therefore, order allocation with economical lot sizes must also be considered in supplier selection decision-making.

*2.1.2 MCDM techniques for supplier selection.* The AHP, analytic network process (ANP), the technique for order performance by similarity to ideal solution (TOPSIS), data envelopment analysis (DEA), genetic algorithm, fuzzy set theory, case-based reasoning, mathematical programming, simple multiattribute rating technique and their hybrids are few examples MCDM techniques that have been presented in recent years for supplier selection.

One of the most popular linear weighting methods in the supplier selection method is referred to as AHP. AHP offers a structure to capture the criteria, subcriteria and alternative suppliers (Triantaphyllou and Mann, 1995). AHP is capable of handling both quantitative and qualitative criteria. Kull and Talluri (2008), Kurniawan *et al.* (2018), Rajhans and Barshikar (2013) and Triantaphyllou and Mann (1995) used the AHP method in supplier selection. Govindan *et al.* (2015) conducted a survey of the literature on green purchasing and green supplier selection that was published between 1997 and 2011, and they concluded that AHP is the most widely used MCDM approach for evaluating green suppliers. Aouadni *et al.* (2019a) examined 270 publications on SSOA, published between 2000 and 2017 and concluded that 17%, 9% and 7% of the examined studies, respectively, took into account AHP, TOPSIS and ANP techniques. They also emphasized fuzzy multiple-objective programming as a prominent strategy.

Bohner and Minner (2017) proposed a mixed-integer linear programming approach for addressing the complex problem of SSOA by having a noncost-effective backup supplier. Çebi and Otay (2016) presented a two-stage fuzzy approach consisting of fuzzy MULTIMOORA and fuzzy goal programming for green SSOA problems in the beverage firm. Babbar and Amin (2018) proposed a novel two-stage quality function deployment (QFD) technique to deal with the vagueness and uncertainty in SSOA. They used general algebraic modeling system (GAMS) software to solve the optimization model, which took into account both qualitative and quantitative criteria.

Stević *et al.* (2020) invented the MARCOS approach, which is based on the TOPSIS principle. The MARCOS method has the following advantages: it can take into account a large number of criteria and alternatives without compromising stability; it can take into account both ideal and anti-ideal solutions before forming an initial matrix; it can determine utility degree more precisely concerning both solutions. Table 2 presents an overview of various optimization techniques.

*2.1.3 Order allocation with economical lot sizes with quantity discounts.* Lot-sizing approaches can significantly reduce system nervousness and total costs in a material requirement planning system (Pooya *et al.*, 2020). Without a lot-sizing policy, all efforts to reduce costs are ineffective (Sobhanallahi *et al.*, 2016). Armagan Tarim and Kingsman (2004) discussed a method for determining the intervals at which potential future replenishments can be made and the appropriate order quantities using a mixed-integer programming method. Dye and Hsieh (2012) considered a time-varying rate of deterioration and partial backlogs to create the optimal ordering policy. Gilding (2014) looked into the optimal replenishment strategies with finite time planning horizons and time-varying demands and deterioration. Samak-Kulkarni and Rajhans (2013) explored various lot-sizing models and demonstrated that, in each situation, the W-W algorithm yields the lowest costs. Purchasing

**Table 1.** Summary of supplier selection criteria

| Criteria | (Dickson, 1966) | (Ellram, 1990) | (Birgün Barla, 2003) | (Çebi and Bayraktar, 2003) | (Tan, 2006) | (Chan and Kumar, 2007) | (Gencer and Gürpinar, 2007) | (Lee, 2009) | (Hudymáčová *et al.*, 2010) | (Jamil *et al.*, 2013) | (Kilic, 2013) | (Hruška *et al.*, 2014) | (P. Kumar *et al.*, 2014) | (Nourmohamadi Shalke *et al.*, 2018) | (Zeydan, 2020) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Price | ✓ | | ✓ | | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Quality | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ |
| Delivery time | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | | ✓ |
| Financial stability | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ | |
| Payment method | | | | | | | | | ✓ | | | ✓ | | | |
| Transportation cost | | | | | | ✓ | | ✓ | ✓ | ✓ | | ✓ | | | ✓ |
| Quantity discounts | | | | | | | | | | ✓ | | | | ✓ | |
| Reliability | | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | | |
| Flexibility | | | | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ | | |
| Logistic capacity | ✓ | ✓ | | | ✓ | | | ✓ | | ✓ | | | | | ✓ |
| Warranty | ✓ | | | | | | | | | | | | | | |
| Certification of products | | | ✓ | | | | | | | ✓ | | | | | |
| Reputation | ✓ | ✓ | | ✓ | | ✓ | | | | | | | ✓ | | |
| Communication system | ✓ | | | ✓ | | ✓ | | ✓ | | ✓ | | | | | |
| Responsiveness | | | | | | | | | | ✓ | | | ✓ | ✓ | ✓ |
| Information technology | | | | | | | | | | ✓ | | | | ✓ | ✓ |

**Source:** Authors' own work

| Optimization techniques | References |
|---|---|
| Analytic hierarchy process (AHP) | Hamdan and Cheaitou (2015, 2017b, 2017a), Khoshfetrat *et al.* (2020), Mohamed (2018), Rajhans and Barshikar (2013), Razak *et al.* (2018) |
| AHP-QFD, chance constrained programming, chance-constrained optimization | Moheb-Alizadeh and Handfield (2018), Scott *et al.* (2015) |
| Analytic network process-integer programming (ANP-IP) | Wang *et al.* (2020) |
| Analytical Model-heuristics | Meena and Sarmah (2016) |
| Best worst method | Cheraghalipour and Farsad (2018), Shafique *et al.* (2017) |
| Branch and cut algorithm | Hamdan and Cheaitou (2017b) |
| Cuckoo optimization algorithm (COA), discrete event simulation (DES) | Shadkam and Bijari (2017) |
| Grey system and uncertainty theory | Memon *et al.* (2015), Rajak *et al.* (2021) |
| Correlated AHP, linear physical programming | Kumar *et al.* (2018) |
| DEA, fuzzy sets theory | Arabzad *et al.* (2015), Moheb-Alizadeh and Handfield (2018) |
| Fuzzy AHP, fuzzy TOPSIS | Azadnia *et al.* (2015), Kaur and Prakash Singh (2021) |
| Fuzzy ANP | Bodaghi *et al.* (2018) |
| Fuzzy DEMATEL | Gören (2018), Govindan *et al.* (2020) |
| Fuzzy MOORA + failure mode and effect analysis (FMEA), fuzzy MULTIMOORA | Arabsheybani *et al.* (2018), Çebi and Otay (2016) |
| Hybrid Monte Carlo simulation | Wong (2020) |
| Hybrid SWOT-QFD | PrasannaVenkatesan and Goh (2016) |
| Linguistic entropy weight method (LEWM) | Shao *et al.* (2022) |
| Minimum deviation approach | Moheb-Alizadeh and Handfield (2019) |
| Mixed-integer programming (MIP), Mixed-integer nonlinear programming (MINLP) | Kaur and Prakash Singh (2021), Moheb-Alizadeh and Handfield (2019) |
| Fuzzy TOPSIS and SWOT analysis | Govindan and Sivakumar (2016), Hamdan and Cheaitou (2015), Memon *et al.* (2015) |
| Fuzzy-PROMETHEE | Bektur (2020) |
| Weighted comprehensive criterion (WCM) | Hamdan and Cheaitou (2015, 2017b) |

**Source:** Authors' own work

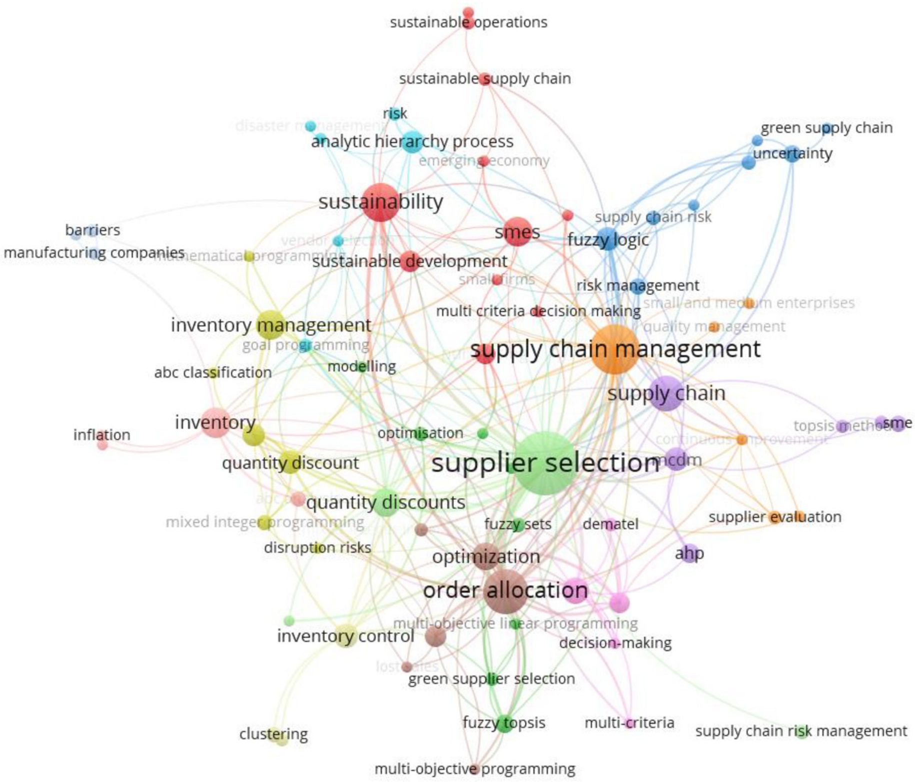
**Table 2.**
Overview of various optimization techniques

in large quantities has the potential to cut expenditures and increase profits (Raj, 2012). The unit cost can be reduced if a substantial order is placed by the buyer in line with the supplier's predefined quantity discount schedules (Cha and Moon, 2005). Burke *et al.* (2008) examined the effect of quantity discounts on the optimum resource allocation strategy. They included linear discounts in their strategy in combination with incremental and all-unit quantity discounts.

### *2.2 Research gap and motivation of the study*

Effective SSOA with quantity discounts can have a significant impact on a firm's ability to minimize costs and, consequently, increase profits (Rezaei *et al.*, 2020). To the best of our knowledge, there is no evidence that such an integrated solution exists for manufacturing SMEs. Moreover, a bibliographic analysis was performed to thoroughly explore the current state of literature and gain insights into the SSOA approaches, particularly within the context of SMEs. Figure 1 illustrates the findings of the bibliographic analysis conducted by using the VOS viewer tool.

The thorough examination of existing literature and the bibliographic analysis revealed that very few efforts have been taken to address the challenges encountered by




**Source:** Authors' own work

**Figure 1.** Most researched keywords in the context of SSOA

SMEs. This realization sparked the search for an efficient and easy-to-implement SSOA approach for SMEs.

## 3. Methodology

In the current study, a case study approach is used to draw quantitative facts. The proposed approach consists of three steps. First, supplier selection criteria were prioritized using AHP; a recently developed MARCOS method is used next to rank the suppliers based on selected criteria; the W-W algorithm is applied to determine economical lot sizes for order allocation and to get the benefit of quantity discounts. Figure 2 depicts the procedure of the proposed methodology.

With the realization that focusing solely on pricing as a single criterion for supplier selection is not sufficient, it becomes essential to formulate the problem and explicitly evaluate all significant criteria before making a decision. The selection of appropriate criteria is also influenced by the size of the organization. The selection criteria used by LEs may not be suitable for SMEs. Therefore, based on the inputs taken from purchase managers working in manufacturing SMEs and available literature on SMEs, 19 criteria were selected for further study. Figure 3 shows various criteria considered for supplier selection decision-making in SMEs.

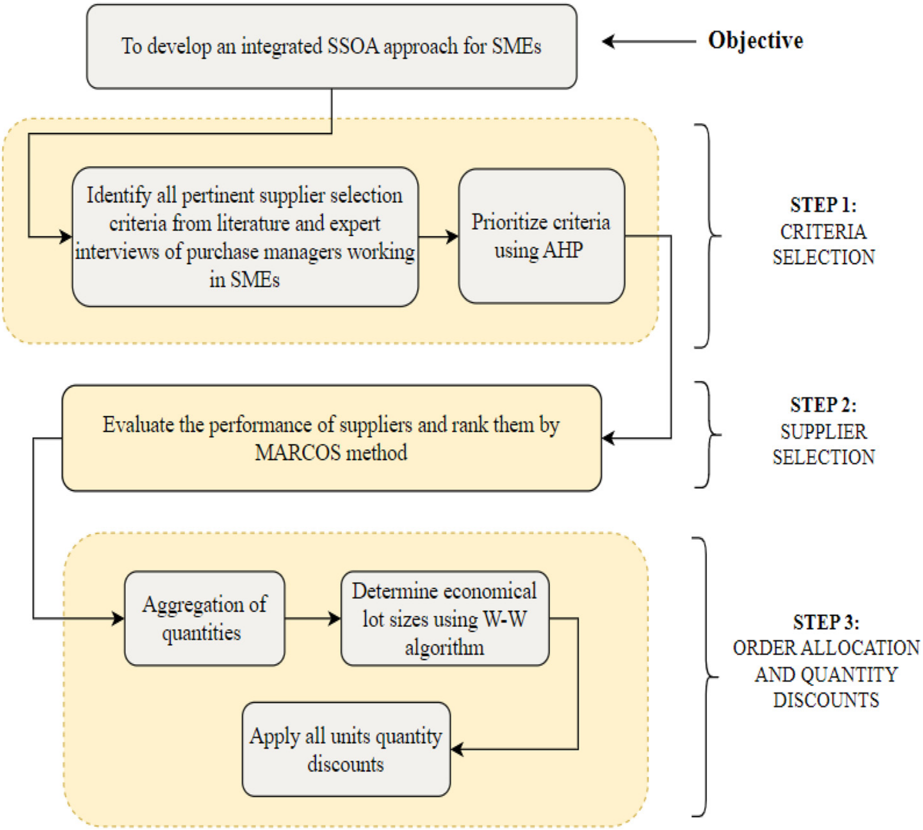
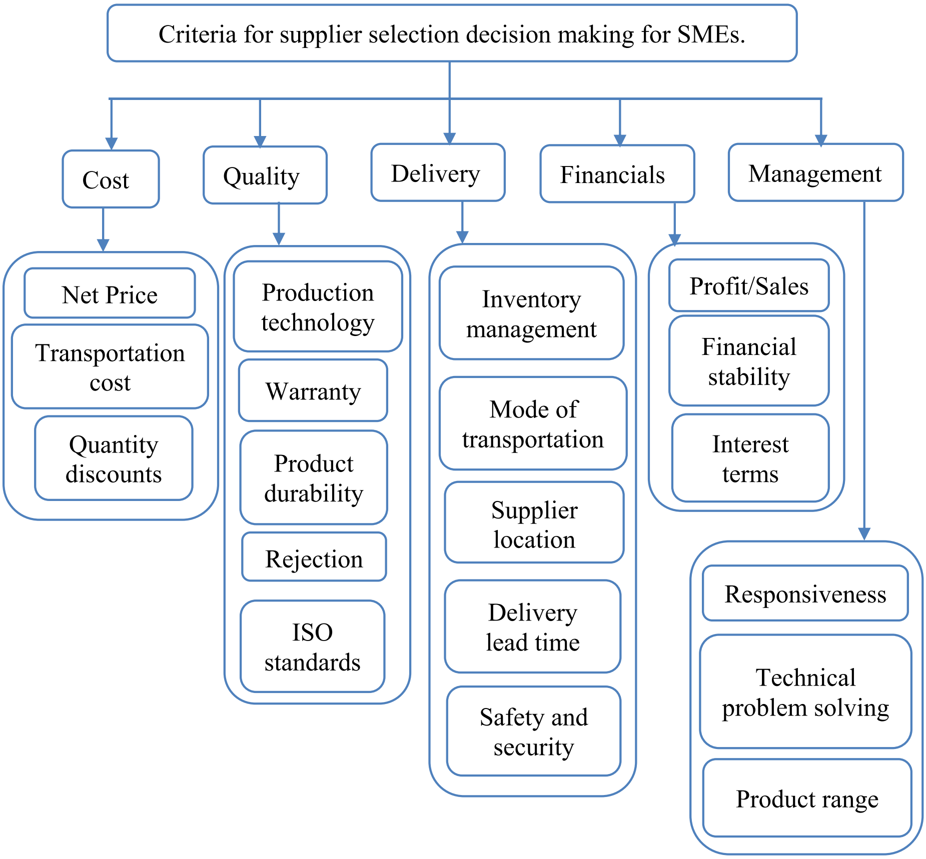



**Figure 2.**
Proposed methodology

**Source:** Authors' own work

AHP is used next to prioritize the above-mentioned criteria and identify the most critical criteria as per the priorities of any particular firm. A newly developed MARCOS is used next to evaluate suppliers' performance and rank them. The MARCOS method works by creating a link between alternatives and reference values (ideal and anti-ideal alternatives). The utility functions of alternatives are determined using the established relationships, and a compromise ranking between ideal and anti-ideal solutions is produced. Decision preferences are defined using utility functions. Utility functions are used to position alternatives with respect to an ideal and an anti-ideal solution. The alternative that is closest to the ideal while also being the farthest from the anti-ideal reference point is the best option.

An integrated SSOA with an economical order batch sizes approach has significant potential to improve the performance of SMEs. The proposed integrated approach can enable SMEs to get the benefits of sustainable supplier selection, economical order batch sizes and quantity discounts. In addition, SMEs can manage their inventory levels very effectively and avoid stock-out situations. Therefore, the joint impact of optimal order batch sizes with quantity discounts was studied to evaluate further cost savings. The W-W algorithm is used next to determine economical order sizes and their timings and then quantity discounts are applied to further lower the unit price.




**Source:** Authors' own work

**Figure 3.**
Criteria for supplier selection of SMEs

The following assumptions are taken into consideration when developing the proposed technique:

- A single-item, multiperiod problem.
- Independent and fluctuating demand for every product.
- In the first period, the initial inventory is assumed to be zero.
- Order quantity is assumed to be delivered at the start of the period, and the lead time for every replenishment is the same and known.
- Irrespective of quantities, the ordering cost is fixed per order.
- Inventory carrying cost is dependent on the price per unit.
- All unit quantity discounts are taken into account.

## 4. Case study

A suitable case selection will significantly impact the quality of the research. As this research is intended to alleviate SSOA problems of manufacturing SMEs, a medium-sized manufacturing firm located in Pune, Maharashtra, was selected for the case study. This company manufactures transmission parts for planetary gearboxes, bevel planetary drives, worm planetary drives, hoist drives and slew drives. The aforementioned company manufactures 40 gearboxes, and each gearbox assembly is made up of between 15 and 54 components. Table 3 shows the number of components required per gearbox assembly.

The firm under consideration relies heavily on suppliers, and it was found that purchase managers usually bought smaller quantities of material from different suppliers and at different prices, which led to higher ordering costs despite decreasing inventory costs. Furthermore, due to smaller order quantities, quantity discounts could not be availed of. Stock-out situations were also observed in a few instances, which resulted in a missed

**Table 3.** Number of parts required per assembly

| Sr. no. | Gearbox no. | Parts required |
|---|---|---|
| 1 | 1,130 | 24 |
| 2 | 4,095 | 13 |
| 3 | 1,190 | 20 |
| 4 | 3,095 | 20 |
| 5 | 1,240 | 23 |
| 6 | 1,160 | 21 |
| 7 | 1,280 | 20 |
| 8 | 1,095 | 15 |
| 9 | 1,340 | 16 |
| 10 | 2,095 | 18 |
| 11 | 3,130 | 28 |
| 12 | 1,260 | 20 |
| 13 | 3,160 | 31 |
| 14 | 3,190 | 31 |
| 15 | 3,240 | 43 |
| 16 | 3,260 | 34 |
| 17 | 3,280 | 38 |
| 18 | 3,300 | 41 |
| 19 | 3,340 | 54 |
| 20 | 3,380 | 52 |
| 21 | 4,130 | 25 |
| 22 | 2,130 | 26 |
| 23 | 2,160 | 25 |
| 24 | 2,240 | 32 |
| 25 | 2,190 | 25 |
| 26 | 2,280 | 39 |
| 27 | 2,260 | 40 |
| 28 | 2,340 | 28 |
| 29 | 2,300 | 29 |
| 30 | 2,380 | 37 |
| 31 | 1,300 | 14 |
| 32 | 4,160 | 30 |
| 33 | 2,230 | 25 |
| 34 | 4,260 | 26 |
| 35 | 4,190 | 27 |
| 36 | 4,280 | 29 |
| 37 | 4,240 | 27 |
| 38 | 4,300 | 34 |
| 39 | 4,380 | 41 |
| 40 | 4,340 | 43 |

**Source:** Authors' own work

opportunity at few instances. Additionally, poor quality, late deliveries and a lack of service support were the most frequent problems.

*4.1 Prioritization of criteria*

In the initial phase, industry experts conduct pairwise comparisons to prioritize criteria and subcriteria. For pairwise comparison of criterion and subcriteria, a normal scale rating from 1 to 10 is used. Numerical scale ratings can differ from organization to organization depending on their priorities. The experts contributing to the pairwise comparisons are experienced purchase managers from SMEs. Their expertise lies in procurement, supplier evaluation and strategic decision-making within the context of SMEs, providing valuable insights for the research, as shown in Table 4.

As for the cost and quality, both criteria were given 9 ratings, in the comparison matrix corresponding value will be 9/9 = 1. This corresponding value is highlighted in Table 5. The same logic is extended to prepare the entire comparison matrix.

Table 6 shows the normalized matrix. A sample calculation is shown below to depict how the normalized matrix has been prepared:

$$1/3.67 = 0.27$$

The same logic is extended to prepare the comparison matrices and normalized matrices for subcriteria. Tables 7–9 show sample calculations of cost subcriteria.

The comparison matrices and normalized matrices for the other subcriteria are created using the same approach. The criteria weights were multiplied by the weights of the

| Criteria | Scale | Criteria | Scale |
|---|---|---|---|
| Cost | 9 | Quality | 9 |
| Cost | 7 | Delivery | 7 |
| Cost | 9 | Financials | 3 |
| Cost | 9 | Management | 3 |
| Quality | 9 | Delivery | 7 |
| Quality | 9 | Financials | 5 |
| Quality | 9 | Management | 3 |
| Delivery | 7 | Financials | 5 |
| Delivery | 7 | Management | 5 |
| Financials | 5 | Management | 5 |

**Source:** Authors' own work

**Table 4.** Pairwise comparison of criteria

| Parameter | Cost | Quality | Delivery | Financials | Management |
|---|---|---|---|---|---|
| Cost | 1.00 | 1.00 | 1.00 | 3.00 | 3.00 |
| Quality | 1.00 | 1.00 | 1.29 | 1.80 | 3.00 |
| Delivery | 1.00 | 0.78 | 1.00 | 1.40 | 1.40 |
| Financials | 0.33 | 0.56 | 0.71 | 1.00 | 1.00 |
| Management | 0.33 | 0.33 | 0.71 | 1.00 | 1.00 |
| Sum | 3.67 | 3.67 | 4.71 | 8.20 | 9.40 |

**Source:** Authors' own work

**Table 5.** Comparison matrix for criteria

subparameters, and their final weights were calculated. Table 10 shows the weights of the subcriteria and their ranking.

Subsequently, the weights were arranged in descending order. Ultimately, five parameters with the highest weights were selected for further analysis, as they collectively contributed nearly 47% to the overall weight of the parameters. Accordingly, final weights were calculated, as shown in Table 11.

### *4.2 Supplier ranking using measurement alternatives and ranking using compromise solution*

A newly developed MARCOS is carried out next in the following manner to evaluate suppliers' performance and rank them.

| Parameter | Cost | Quality | Delivery | Financials | Management | Sum | Normalized weight |
|---|---|---|---|---|---|---|---|
| Cost | 0.27 | 0.27 | 0.21 | 0.37 | 0.32 | 1.44 | 0.29 |
| Quality | 0.27 | 0.27 | 0.27 | 0.22 | 0.32 | 1.36 | 0.27 |
| Delivery | 0.27 | 0.21 | 0.21 | 0.17 | 0.15 | 1.02 | 0.20 |
| Financials | 0.09 | 0.15 | 0.15 | 0.12 | 0.11 | 0.62 | 0.12 |
| Management | 0.09 | 0.09 | 0.15 | 0.12 | 0.11 | 0.56 | 0.11 |
| Sum | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 5.00 | 1.00 |

**Source:** Authors' own work

**Table 6.** Normalized matrix for criteria

| Subcriteria | Scale |
|---|---|
| Net price | 9 |
| Net price | 9 |
| Transportation cost | 5 |
| Transportation cost | 3 |
| Quantity discount | 7 |
| Quantity discount | 7 |

**Source:** Authors' own work

**Table 7.** Pairwise comparison of subcriteria (cost)

| Parameter | Net price | Transportation cost | Quantity discount |
|---|---|---|---|
| Net price | 1.00 | 3.00 | 1.29 |
| Transportation cost | 0.33 | 1.00 | 0.71 |
| Quantity discount | 0.78 | 1.40 | 1.00 |
| Sum | 2.11 | 5.40 | 3.00 |

**Source:** Authors' own work

**Table 8.** Comparison matrix for cost subcriteria

| Parameter | Net price | Transportation cost | Quantity discount | Sum | Normalized |
|---|---|---|---|---|---|
| Net price | 0.47 | 0.56 | 0.43 | 1.46 | 0.49 |
| Transportation cost | 0.16 | 0.19 | 0.24 | 0.58 | 0.19 |
| Quantity discount | 0.37 | 0.26 | 0.33 | 0.96 | 0.32 |
| Sum | 1.00 | 1.00 | 1.00 | 3 | 1.00 |

**Source:** Authors' own work

**Table 9.** Normalized matrix for cost subcriteria

| Criteria | Subcriteria | Weights of criteria | Weights of subcriteria | Final weights | Rank |
|---|---|---|---|---|---|
| Cost | Net price | 0.29 | 0.49 | 0.140 | 1.00 |
| Cost | Transportation cost | 0.29 | 0.19 | 0.056 | 9.00 |
| Cost | Quantity discount | 0.29 | 0.32 | 0.092 | 3.00 |
| Quality | Production technology | 0.27 | 0.39 | 0.105 | 2.00 |
| Quality | Warranty | 0.27 | 0.21 | 0.058 | 7.00 |
| Quality | Product durability | 0.27 | 0.17 | 0.045 | 10.00 |
| Quality | Rejection | 0.27 | 0.14 | 0.037 | 11.00 |
| Quality | ISO standards | 0.27 | 0.10 | 0.027 | 16.00 |
| Delivery | Inventory management | 0.20 | 0.28 | 0.057 | 8.00 |
| Delivery | Supplier location | 0.20 | 0.31 | 0.063 | 5.00 |
| Delivery | Mode of transportation | 0.20 | 0.16 | 0.033 | 14.00 |
| Delivery | Delivery lead time | 0.20 | 0.14 | 0.029 | 15.00 |
| Delivery | Safety and security | 0.20 | 0.11 | 0.023 | 18.00 |
| Financial | Financial stability | 0.12 | 0.53 | 0.066 | 4.00 |
| Financial | Profit/sales | 0.12 | 0.27 | 0.034 | 13.00 |
| Financial | Interest terms | 0.12 | 0.19 | 0.024 | 17.00 |
| Management | Responsiveness | 0.11 | 0.52 | 0.058 | 6.00 |
| Management | Technical problem solving | 0.11 | 0.32 | 0.036 | 12.00 |
| Management | Product range | 0.11 | 0.16 | 0.017 | 19.00 |

**Source:** Authors' own work

**Table 10.** Final weights and their ranking

| Rank | Subcriteria | Weights | Final weight |
|---|---|---|---|
| 1 | Net price | 0.140 | 0.30 |
| 2 | Production technology | 0.105 | 0.23 |
| 3 | Quantity discount | 0.092 | 0.20 |
| 4 | Financial stability | 0.066 | 0.14 |
| 5 | Supplier location | 0.063 | 0.13 |
| | Sum | *0.47* | *1* |

**Source:** Authors' own work

**Table 11.** Final weights

*Step 1:* Create a preliminary decision-making matrix.

Multicriteria models consist of a set of "*n*" criteria and "m" alternatives. When making a decision, a group of "*r*" specialists is formed to examine alternatives using the criteria. Expert evaluation matrices are aggregated into an initial group decision-making matrix in the event of group decision-making.

*Step 2:* Formation of extended initial matrix.

At the next stage, the starting matrix is extended, and the ideal (*AI*) and anti-ideal (*AAI*) solutions are defined, as shown in Table 12.

The least desired choice is the anti-ideal solution (*AAI*), whereas the most desirable one is the ideal solution (*AI*). Depending upon the type of criterion, *AAI* and *AI* are specified using equations:

$$AAI = \min x_{ij} \quad if\ i \in B\ and \max x_{ij}\ if\ i \in\ C \tag{1}$$

$$AAI = \max xij \quad if\ i \in B\ and\ min\ x_{ij}\ if\ i \in C \tag{2}$$

where $B$ denotes a set of benefit criteria and C denotes a set of cost criteria. With this concept, an initial decision matrix was prepared, as shown in Table 13.

*Step 3:* Normalization of the extended initial matrix ($X$).

The following equations are used to obtain the elements of the normalized matrix:

$$N = [nij]mxn$$

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \quad if\ j\ \in C \tag{3}$$

$$n_{ij} = \frac{X_{ij}}{x_{aj}} \quad if\ j\ \in B \tag{4}$$

| Anti ideal solutions | $C_1$ | $C_2$ | …. | $Cn$ |
|---|---|---|---|---|
| AAI | $X_{aa1}$ | $X_{aa2}$ | …. | $X_{aan}$ |
| $A_1$ | $X_{11}$ | $X_{12}$ | …. | $X_{1n}$ |
| $A_2$ | $X_{21}$ | $X_{22}$ | …. | $X_{2n}$ |
| …. | …. | …. | …... | …. |
| $A_m$ | $X_{m1}$ | $X_{m2}$ | …... | xmn |
| AI | $X_{ai1}$ | $X_{ai2}$ | …... | xain |

**Source:** Authors' own work

**Table 12.** Extended initial matrix

| Supplier parameters | Net price | Production technology | Quantity discount | Financial stability | Supplier location |
|---|---|---|---|---|---|
| Weight | 0.30 | 0.23 | 0.20 | 0.14 | 0.13 |
| AAI | 9 | 6 | 9 | 6 | 6 |
| Supplier A | 9 | 7 | 8 | 6 | 8 |
| Supplier B | 8 | 9 | 9 | 6 | 7 |
| Supplier C | 9 | 6 | 7 | 7 | 8 |
| Supplier D | 7 | 7 | 8 | 8 | 6 |
| Supplier E | 6 | 6 | 6 | 8 | 9 |
| AI | 6 | 9 | 6 | 8 | 9 |

**Source:** Authors' own work

**Table 13.** Initial decision matrix

| Anti ideal solutions | Net price | Production technology | Quantity discount | Financial stability | Supplier location |
|---|---|---|---|---|---|
| AAI | 0.667 | 0.667 | 0.667 | 0.750 | 0.667 |
| Supplier A | 0.667 | 0.778 | 0.750 | 0.750 | 0.889 |
| Supplier B | 0.750 | 1.000 | 0.667 | 0.750 | 0.778 |
| Supplier C | 0.667 | 0.667 | 0.857 | 0.875 | 0.889 |
| Supplier D | 0.857 | 0.778 | 0.750 | 1.000 | 0.667 |
| Supplier E | 1.000 | 0.667 | 1.000 | 1.000 | 1.000 |
| AI | 1 | 1 | 1 | 1 | 1 |

**Source:** Authors' own work

**Table 14.** Normalized decision matrix

where elements $x_{ij}$ and $x_{ai}$ represent the elements of matrix $X$. Table 14 shows the normalized decision matrix.

*Step 4:* Determination of the weighted matrix.

The weighted matrix $V = [v_{ij}]m \times n$ is obtained by multiplying the normalized matrix $N$ with the weight coefficients of the criterion $w_j$:

$$v_{ij} = n_{ij} \quad * w_j \tag{5}$$

Table 15 shows the weighted normalized decision matrix.

*Step 5:* Calculation of the utility degree of alternatives $K_i$.

The utility degrees of an alternative in relation to the anti-ideal and perfect solution can be determined using the formulae below:

$$V_i^- = \frac{S_i}{S_{aai}} \tag{6}$$

$$V_i^+ = \frac{S_i}{S_{ai}} \tag{7}$$

where $S_i$ (i = 1, 2 . . .$m$) is the sum of the weighted matrix V's members:

$$S_i = \sum_{i=1}^{n} V_{ij} \tag{8}$$

Table 16 shows:

| | Net price | Production technology | Quantity discount | Financial stability | Supplier location |
|---|---|---|---|---|---|
| AAI | 0.20 | 0.15 | 0.13 | 0.11 | 0.09 |
| Supplier A | 0.20 | 0.18 | 0.15 | 0.11 | 0.12 |
| Supplier B | 0.23 | 0.23 | 0.13 | 0.11 | 0.10 |
| Supplier C | 0.20 | 0.15 | 0.17 | 0.12 | 0.12 |
| Supplier D | 0.26 | 0.18 | 0.15 | 0.14 | 0.09 |
| Supplier E | 0.30 | 0.15 | 0.20 | 0.14 | 0.13 |
| AI | 0.30 | 0.23 | 0.20 | 0.14 | 0.13 |

**Source:** Authors' own work

**Table 15.** Weighted normalized decision matrix

| | $S_i$ | $K_-$ | $K_+$ |
|---|---|---|---|
| AAI | 0.68 | | |
| Supplier A | 0.75 | 1.11 | 0.75 |
| Supplier B | 0.79 | 1.16 | 0.79 |
| Supplier C | 0.77 | 1.13 | 0.77 |
| Supplier D | 0.81 | 1.2 | 0.81 |
| Supplier E | 0.93 | 1.37 | 0.93 |
| AI | 1 | | |

**Source:** Authors' own work

**Table 16.** Utility degree

For supplier A:

$$Si_{AAI} = 0.20 + 0.15 + 0.13 + 0.11 + 0.09 = 0.68$$

$$S_i = 0.20 + 0.18 + 0.15 + 0.11 + 0.12 = 0.75$$

$$K_- = \frac{0.75}{0.68} = 1.11$$

$$K_+ = \frac{0.75}{1} = 0.75$$

Similarly, the sum of the weighted matrix, K– and K+, has been calculated for suppliers B, C, D and E.

*Step 6:* Determination of the utility function of alternatives $f(K_i)$ and ranking of alternatives.

The utility function represents the trade-off between the observable alternative and the ideal and anti-ideal solutions. The utility function in regard to the anti-ideal solution is represented by ($K_i$), while ($K^+$) represents the utility function in relation to the ideal solution. The following equations are used to derive utility functions in regard to the ideal and anti-ideal solutions:

$$f\left(K_i^-\right) = \frac{K_i^+}{K_i^+ + K_i^-} \tag{9}$$

$$f\left(K_i^+\right) = \frac{K_i^-}{K_i^+ + K_i^-} \tag{10}$$

For supplier A:

$$f\left(K_i^-\right) = \frac{0.75}{0.75 + 1.11} = 0.40$$

and:

$$f\left(K_i^+\right) = \frac{1.11}{1.11 + 0.75} = 0.60$$

The utility function of alternatives is given by the equation below:

$$f(K_i) = \frac{k_i^+ + k_i^-}{1 + \frac{1 - f\left(K_i^+\right)}{f\left(K_I^+\right)} + \frac{1 - f\left(K_i^-\right)}{f\left(K_i^-\right)}} \tag{11}$$

$$\therefore\ f(K_1) = \frac{0.75 + 1.11}{1 + \frac{1 - 0.60}{0.60} + \frac{1 - 0.40}{0.40}} = 1.43$$

Similarly, utility function values for suppliers B, C, D and E have been calculated, resulting values are 1.47, 1.44, 1.49 and 1.60, respectively. A higher utility function value represents a higher rank. Therefore, the suppliers are ranked in the order of 5, 3, 4, 2 and 1, as shown in Table 17.

The conclusion drawn is that supplier E excels across criteria such as cost, production technology, quantity discounts, financial stability and location among suppliers.

*4.3 Order allocation*

An example of External Circlip A20 is used to illustrate the current purchase policy and proposed solution. External circlip A20 was being used in three different assemblies, 1290, 1310 and 2095, but separate orders were being placed to different suppliers to fulfill the demand of that particular period. Table 18 shows the quantity required per period for each assembly.

An illustration of a cost calculation of External Circlip A20 for assembly 1290 is shown in Table 19.

*Similarly, purchasing the required quantities of external circlip A20 for assemblies 1310 and 2095 costs Rs 3,150 and Rs 2,877 yearly, respectively. As a result, the total price paid to buy the entire quantity over the period of a year is Rs 10,289.*

The proposed approach consists of three steps. First, an initial matrix of parts versus assembly was prepared to identify assemblies consisting of similar components and aggregate the demand. Aggregating the demand can lower the ordering cost, but simultaneously holding cost is likely to increase. Therefore, the W-W lot-sizing technique is applied next to optimize holding cost and ordering costs and to take the maximum possible benefit of all unit quantity discounts:

- Step I. Component versus assembly matrix.

| Anti ideal solutions | $S_i$ | $K_-$ | $K_+$ | $fk_-$ | $fk_+$ | $fk_i$ | Rank |
|---|---|---|---|---|---|---|---|
| AAI | 0.68 | | | | | | |
| Supplier A | 0.75 | 1.11 | 0.75 | 0.40 | 0.60 | 1.43 | 5 |
| Supplier B | 0.79 | 1.17 | 0.79 | 0.40 | 0.60 | 1.47 | Y3 |
| Supplier C | 0.76 | 1.13 | 0.76 | 0.40 | 0.60 | 1.44 | 4 |
| Supplier D | 0.81 | 1.20 | 0.81 | 0.40 | 0.60 | 1.49 | 2 |
| Supplier E | 0.92 | 1.36 | 0.92 | 0.40 | 0.60 | 1.60 | 1 |
| AI | 1 | | | | | | |

**Source:** Authors' own work

**Table 17.** Suppliers rank

| Period | 1,290 | 1,310 | 2,095 |
|---|---|---|---|
| Apr | 27 | 23 | 39 |
| May | 81 | 69 | 14 |
| Jun | 18 | 0 | 8 |
| Jul | 0 | 0 | 0 |
| Aug | 27 | 23 | 0 |
| Sep | 0 | 0 | 0 |
| Oct | 54 | 46 | 15 |
| Nov | 54 | 23 | 53 |
| Dec | 0 | 0 | 0 |
| Jan | 0 | 46 | 29 |
| Feb | 81 | 23 | 24 |
| Mar | 27 | 0 | 20 |

**Source:** Authors' own work

**Table 18.** Quantity required per assembly per period

| Period | Order quantity | Ordering cost | Procurement cost |
|---|---|---|---|
| Apr | 27 | 150 | 224.1 |
| May | 81 | 150 | 672.3 |
| Jun | 18 | 150 | 149.4 |
| Jul | 0 | 0 | 0 |
| Aug | 27 | 150 | 224.1 |
| Sep | 0 | 0 | 0 |
| Oct | 54 | 150 | 448.2 |
| Nov | 54 | 150 | 448.2 |
| Dec | 0 | 0 | 0 |
| Jan | 0 | 0 | 0 |
| Feb | 81 | 150 | 672.3 |
| Mar | 27 | 150 | 224.1 |
| | Sum = | 1,200 | 3,062.7 |
| | Total cost | | 4,262.7 |

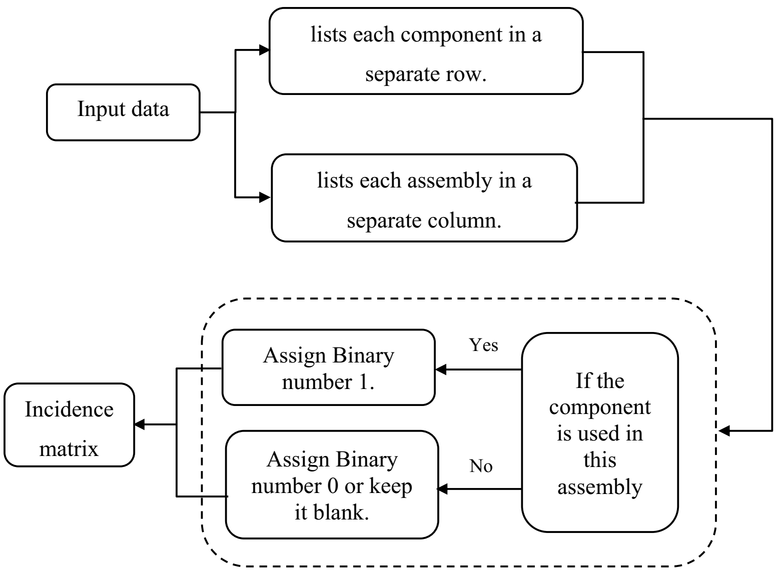
**Source:** Authors' own work

**Table 19.**
Cost calculation as per existing policy

The process of aggregation is described in the flowchart as shown in Figure 4.

The quantity aggregation matrix is prepared and illustrated in Figure 5.

This approach endows identifying assemblies made up of the same components. This enables purchase managers to aggregate their demands and to place sizable large orders all at once instead of more frequently. Hence, after quantity aggregation, the quantity needed for component External circlip A20 for each of the twelve periods is 89, 164, 26, 0, 50, 0, 115, 130, 0, 75, 128 and 47.




**Source:** Authors' own work

**Figure 4.**
Flowchart for quantity aggregation

| Assembly No. ⇩ | Allen bolt 10 x 30 | Allen bolt 10 x 60 | Allen bolt 10 x 70 | Allen bolt 10 x 80 | Ball brg 6212 | Ball brg 6214 | Ball brg. 6216 | Ball brg 6217 | Ball brg 6218 | Barrel nipple 1/4" | Breather plug 1/2" | Breather plug 1/4" | M8 copper washer | Drain Plug 1/2" | External circlip A20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1095 | | | | 1 | | | 1 | | | 1 | | | 1 | | |
| 1130 | | | | | | | | 1 | | 1 | 1 | 1 | | 1 | |
| 1160 | | | | | | | | | | 1 | | | | | |
| 1190 | | | | | | 1 | | | | | | | | 1 | |
| 1240 | | 1 | 1 | | | | | | 1 | | | | 1 | | |
| 1260 | | 1 | 1 | | | | | | | | 1 | 1 | | | |
| 1290 | 1 | | | | | | | | | | | | | | 1 |
| 1310 | 1 | | | | | | | | | 1 | | | | | 1 |
| 1340 | | | | | 1 | | | | | | | | | | |
| 2095 | | | | | | | | | | 1 | | | | | 1 |
| 2130 | | 1 | | | | 1 | | | | | | | 1 | | |
| 2160 | | | | 1 | | | | | | | | | | | |
| 2190 | | | | | | | | | 1 | | | | | | |
| 2230 | | 1 | 1 | | | | | | | | 1 | | | 1 | |
| 2380 | 1 | | 1 | | | 1 | | | | | | | 1 | | |

**Source:** Authors' own work

**Figure 5.**
Incidence matrix

*4.4 Step II. Determine economic lot sizes using the Wagner-Whitin algorithm*

Ordering costs can be reduced by aggregating quantities and buying large purchases, but the inventory cost is likely to go up at the same time. Therefore, the second step was intended to identify the best suitable lot-sizing technique that leads to the least possible total cost using the W-W algorithm.

Parameters:

$T$ = time period ($t$: 1 to 12);
$Dt$ = demand of period t;
$Ct$ = unit price;
$Ot$ = cost of ordering per order;
$h_t$ = inventory holding cost (from period $t$ to period $t+1$);
$Qt$ = lot-size of period $t$;
$Cij$ = sum of the inventory holding and ordering costs incurred in period $i$ to satisfy the demand through period $j$–1; and
$f_i$ = lowest of total inventory costs for each period with different time periods.

The following are the steps in the W-W algorithm.

*Step 1.* Fulfill the first period's requirement:

$$f_1^* = O_1 \tag{12}$$

As the requirement of the first period is fulfilled at the beginning of the same period and consumed in the same period, the inventory holding cost is zero:

Therefore, $f_1^* = O_1$.

Therefore, the total cost amounts to Rs 150.

*Step 2.* There are two options: either combine the first and second-period requirements and place an order at the start of the first period or satisfy the first and second-period demands separately:

$$f_2^* = \ min\begin{cases} O_1 + h_1 D_2 \\ f_1^* + O_2 \end{cases} \tag{13}$$

- If the requirement of the 2nd period is aggregated with the requirement of the 1st period and purchased in the 1st period itself, only one order of 253 units is needed. Therefore, the cost of ordering will be Rs. 150; however, an inventory of 164 parts is to be carried in the 1st period.

Hence, the cost of carrying inventory is equal to:

$$h_1 D_2 = 164\text{x}((20/100*8.3)/12) = \text{Rs}.22.69$$

The cumulative inventory cost of the first and second period:

$$O_1 + h_1 D_2 = 150 + 22.69 = \text{Rs}.172.69$$

- If the 1st and 2nd periods' requirements are placed independently during the same time periods:

$$f_1^* + \ O_2 = 150 + 150 = \text{Rs}\ 300.$$

*Step 3.* Similarly, total inventory costs for subsequent time periods (t3, t4,. . .. t12) can be determined:

$$f_3^* = \min\begin{cases} O_1 + h_1 D_2 + (h_1 + h_2) D_3 \\ f_1^* + O_2 + h_2 D_3 \\ f_2^* + O_3 \end{cases} \tag{14}$$

In the third period, $O_1 + h_1 D_2 + (h_1 + h_2)\, D_3 = \text{Rs}\ 179.88$:

$$f_1^* + O_2 + h_2 D_3 = \text{Rs}\ 303.60$$

$$f_2^* + O_3 = \text{Rs}\ 322.69$$

To calculate $f_4^*, f_5^*$ and so forth up to $f_{12}^*$, the same technique is extended.

The same concept is applied to determine inventory costs for the remaining periods, and the findings are displayed in Figure 6.

This aforementioned matrix is created to determine the optimal period order quantities based on ordering and inventory cost optimization. The minimum costs for different periods are highlighted in red color. The matrix shows that the first and seventh periods have the lowest costs. As a result, the requirements of the first six periods are combined and purchased all at once at the start of the first period itself.

As a result, the requirements of the first six periods (89, 164, 26, 0, 50, 0 and 115, respectively) were combined and purchased just once in a quantity of 329 at the start of the

| Demand/ Period (Dt) | 89 | 164 | 26 | 0 | 50 | 0 | 115 | 130 | 0 | 75 | 128 | 47 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period (t)** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| 1→ | 150.00 | 172.69 | 179.88 | 179.88 | 207.55 | 207.55 | 303.00 | 428.88 | 428.88 | 522.26 | 699.32 | 770.84 |
| 2 | | 300.00 | 303.60 | 303.60 | 324.35 | 324.35 | 403.89 | 511.79 | 511.79 | 594.79 | 754.15 | 819.17 |
| 3 | | | 322.69 | 322.69 | 336.52 | 336.52 | 400.15 | 490.07 | 490.07 | 562.70 | 704.35 | 762.86 |
| 4 | | | | 329.88 | 336.80 | 336.80 | 384.52 | 456.46 | 456.46 | 518.71 | 642.65 | 694.67 |
| 5 | | | | | 329.88 | 329.88 | 361.70 | 415.65 | 415.65 | 467.52 | 573.76 | 619.27 |
| 6 | | | | | | 357.55 | 373.46 | 409.42 | 409.42 | 450.92 | 539.46 | 578.47 |
| 7→ | | | | | | | 357.55 | 375.53 | 375.53 | 406.66 | 477.48 | 509.99 |
| 8 | | | | | | | | 453.00 | 453.00 | 473.75 | 526.87 | 552.87 |
| 9 | | | | | | | | | 525.53 | 535.91 | 571.32 | 590.82 |
| 10 | | | | | | | | | | 525.53 | 543.24 | 556.24 |
| 11 | | | | | | | | | | | 556.66 | 563.16 |
| 12 | | | | | | | | | | | | 627.48 |
| **Min costs** | **150.00** | **172.69** | **179.88** | **179.88** | **207.55** | **207.55** | **303.00** | **375.53** | **375.53** | **406.66** | **477.48** | **509.99** |

**Source:** Authors' own work

**Figure 6.** W-W algorithm matrix

first period. Similar to this, at the start of the seventh period, the requirements for the seventh through the twelfth periods (115, 130, 0, 75, 128 and 47) are combined and ordered in 495 quantities.

Table 20 illustrates how the aforementioned matrix helped in preparing the replenishment cycle of External Circlip A20.

As shown in Table 20, orders were placed twice in the first and seventh period: Ordering cost = 150 × 2= Rs 300.

Inventory carrying cost will be the sum of inventory costs for each period.

Inventory carrying cost = Rs 209.99.

Procurement cost = Rs 6,839.20.

Total cost: 300 + 209.99 + 6,839.20 = Rs 7,349.19.

It proved that the total annual cost can be reduced from Rs 10,289 to Rs 7,349, yielding a 28.57% cost savings. In addition, the joint influence of quantity discount is studied in the next section.

### *4.5 Step III: quantity discounts*

Suppliers give discounts on large-quantity purchases, and the discount goes up as quantity rises. All unit quantity discount schedules are taken into account in the current study to achieve economies of scale by lowering the purchase price. In this subsection, consider suppliers offering quantity discounts, as shown in Table 21.

With the aforesaid consideration, an enterprise receives 2% discount on the first order of lot size 329 quantities and 4% discount on the second order of 495 quantities, respectively. Table 22 examines the impact of the discount policy on the total annual cost.

The total yearly cost is then further reduced to Rs 7,130.24 after considering quantity discounts. As shown in the numerical analysis, this approach reduces total cost from Rs 10,289 to Rs 7,130, which is 30.7% of the total cost.

Table 20.
Resulted replenishment cycle for external circlip A20

| Period | Demand | Orders | Qty to be ordered | Inventory at the end of the month | Procurement cost | Ordering cost | Inventory cost |
|---|---|---|---|---|---|---|---|
| 1 | 89 | 1 | 329 | 240 | 2,730.70 | 150 | 33.20 |
| 2 | 164 | | | 76 | 0.00 | 0 | 10.51 |
| 3 | 26 | | | 50 | 0.00 | 0 | 6.92 |
| 4 | 0 | | | 50 | 0.00 | 0 | 6.92 |
| 5 | 50 | | | 0 | 0.00 | 0 | 0.00 |
| 6 | 0 | | | 0 | 0.00 | 0 | 0.00 |
| 7 | 115 | 1 | 495 | 380 | 4,108.50 | 150 | 52.57 |
| 8 | 130 | | | 250 | 0.00 | 0 | 34.58 |
| 9 | 0 | | | 250 | 0.00 | 0 | 34.58 |
| 10 | 75 | | | 175 | 0.00 | 0 | 24.21 |
| 11 | 128 | | | 47 | 0.00 | 0 | 6.50 |
| 12 | 47 | | | 0 | 0.00 | 0 | 0.00 |
| | | | | Sum: | 6,839.20 | 300 | 209.99 |
| | | | | Total cost: | | 7,349.19 | |

**Source:** Authors' own work

Table 21.
All unit quantity discounts schedule

| Volume range | Discount in (%) | Unit price |
|---|---|---|
| 0–200 | 0 | 8.3 |
| 201–400 | 2 | 8.13 |
| 400 onwards | 4 | 7.97 |

**Source:** Authors' own work

## 5. Results and discussion

Insights derived from the study proved that the proposed method can have a significant impact on the performance of SMEs. The proposed approach can assist purchase managers in making supplier selection decisions and can result in significant cost savings. The total annual cost and percentage savings for each of the three stages are shown in Figure 7.

It shows that the total annual cost for the component External Circlip A20 can be reduced by 30.70%. Furthermore, this strategy significantly reduces the computational burden of professionals working in SMEs. The practicality of the proposed methodology is examined with the remaining 201 components, resulting in an average cost savings of 12.25% per annum. The findings of the other five components are depicted in Figure 8.

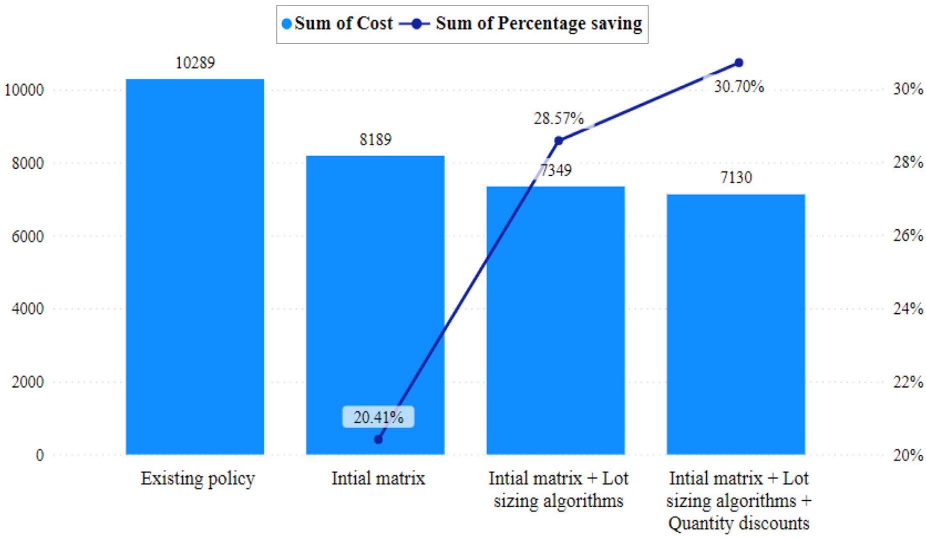
The findings of this case study proved that the suggested strategy can be beneficial for any manufacturing company. Therefore, the insights gained from this case study filled the literature gap with an integrated strategy that provides a practical solution for SMEs to manage their operations.

An Excel spreadsheet program is developed for the proposed approach so that decision-makers of SMEs can easily use this approach for the SSOA process. The spreadsheet program is also developed to incorporate modifications to criteria or subcriteria, and the same change will be reflected across the program. No prior understanding of optimization techniques and Excel programming is necessary to use this spreadsheet program, making it useful in realistic situations. A real-life case is explored to demonstrate the applicability of the suggested approach.

| Period | Demand | Orders | Qty to be ordered | Discount (%) | Procurement cost before the discount | Procurement cost after discount | Ordering cost | Inventory cost |
|---|---|---|---|---|---|---|---|---|
| 1 | 89 | 1 | 329 | 2 | 2,730.70 | 2,676.09 | 150 | 33.20 |
| 2 | 164 | | | | 0.00 | | 0 | 10.51 |
| 3 | 26 | | | | 0.00 | | 0 | 6.92 |
| 4 | 0 | | | | 0.00 | | 0 | 6.92 |
| 5 | 50 | | | | 0.00 | | 0 | 0.00 |
| 6 | 0 | | | | 0.00 | | 0 | 0.00 |
| 7 | 115 | 1 | 495 | 4 | 4108.50 | 3,944.16 | 150 | 52.57 |
| 8 | 130 | | | | 0.00 | | 0 | 34.58 |
| 9 | 0 | | | | 0.00 | | 0 | 34.58 |
| 10 | 75 | | | | 0.00 | | 0 | 24.21 |
| 11 | 128 | | | | 0.00 | | 0 | 6.50 |
| 12 | 47 | | | | 0.00 | | 0 | 0.00 |
| | | | | Sum | 6839.20 | 6,620.25 | 300 | 209.99 |
| | | | | | Total cost | | 7,130.24 | |

**Source:** Authors' own work

**Table 22.** Impact of the discount policy




**Source:** Authors' own work

**Figure 7.** Percentage savings for each of the three steps solution

## 6. Conclusion

Large businesses have already been using SSOA techniques to manage their operations and enhance productivity because they have already recognized that conventional work practices would not be sufficient to survive in the highly competitive market environment. However, attempts to implement SSOA approaches in SMEs are relatively very small due to shortages of funds and a lack of approaches that are both affordable and simple to use. Although a number of tools and approaches have been suggested in the literature, these

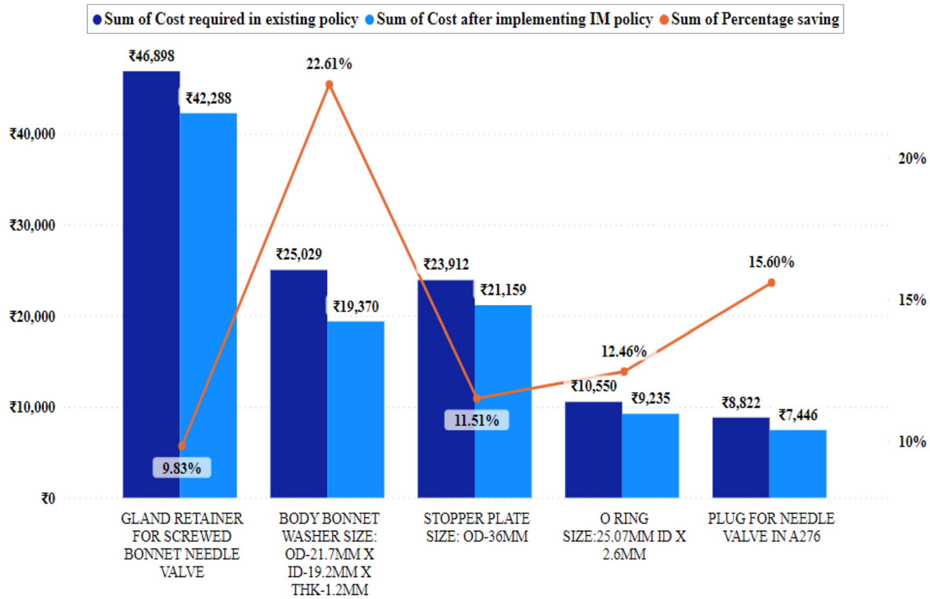



**Figure 8.**
Percentage cost savings

**Source:** Authors' own work

approaches have not been thoroughly examined from the perspective of SMEs. In addition, there are very few studies available in the literature that have considered the limitations of SMEs. SSOA is found to be a crucial strategic decision in every organization, especially in manufacturing SMEs. Therefore, the purpose of this research was to develop an effective SSOA strategy for the sustainable development of manufacturing SMEs.

The presented supplier selection strategy consists of two stages. Criteria were prioritized using AHP, and a recently developed MARCOS is used next to rate the performance of suppliers and rank them. The developed spreadsheet program provides flexibility to change criteria or subcriteria, and the same change will be replicated throughout the entire program. In the context of supplier selection decision-making, SMEs will benefit from using the proposed strategy to evaluate and select suppliers based on predetermined criteria.

A single-item, multiperiod, lot-sizing problem was studied to establish trade-offs among cost objectives and determine appropriate lot sizes and their timings to minimize total cost considering quantity discounts. Purchase cost, ordering cost and inventory carrying cost were the multiple cost objectives of this study. Quantity discounts also have an impact on lot-sizing decisions. The recommended order allocation strategy has been divided into three stages. First, a matrix of components versus assemblies was prepared to aggregate the requirements. The W-W algorithm was used next to determine the economic order lot sizes and their timings. Furthermore, all unit quantity discounts were applied, which significantly reduced costs. A real case example is presented to demonstrate how the proposed approach can lead to significant cost savings. This suggested strategy yielded yearly cost reductions of 12.25%, which can give SMEs a competitive edge. This research bridges a gap in the literature with a practical, cost-effective and easy-to-implement approach in the context of manufacturing SMEs. Additionally, this approach can significantly reduce the computational workload of purchase managers or decision-makers of SMEs while making SSOA decisions. Additionally, it will help SMEs to survive in the highly competitive business world.

In summary, it can be inferred that the proposed strategy enables SMEs to manage their operations effectively more than ever in an era of increased quality, delivery and cost challenges which is crucial for the sustainable development of SMEs.



### *6.1 Implications of the study*

#### *6.1.1 Theoretical implications.*

- The developed SSOA approach has the potential to reshape the perspective of top management in SMEs regarding supplier selection, positioning it as a strategic tool for enhancing overall performance.

#### *6.1.2 Practical implications.*

- The managerial insights derived from this research study can serve as a practical guide for decision-makers, aiding in the formulation of tailored and efficient sourcing strategies.
- In a practical sense, purchase managers within SMEs stand to benefit directly from the integrated SSOA approach and the accompanying spreadsheet program. This study demonstrates that the presented approach, grounded in a rigorous analytical process, is effective in evaluating supplier capabilities and making well-informed choices.

### *6.2 Research limitations*

- Criteria selected in this study are based on the advice of the managers in the selected manufacturing organizations. So, the methods applied are limited to manufacturing SMEs.
- There were some aspects of the supplier selection process that this study could not explore. The development of an effective, reliable supplier selection procedure is a continuous process and it is indeed certainly possible that there are other aspects of supplier selection that are more crucial but are not considered in the proposed approach.

### *6.3 Future scope for research*

In light of the research conducted, the authors believe that there remain unexplored directions that require further investigation:

- It is unlikely that all of the suppliers will offer the same kind of quantity discounts. As a result, a potential extension of this research can be the formulation of a joint replenishment strategy that includes various types of quantity discounts on multiple products.
- Criteria identified in the current research are limited to manufacturing enterprises. Some more criteria may be explored for different types of products and enterprises.
- A replenishment system for individual items is developed here. However, a combined replenishment model may be developed for a group of items.

## References

Albaz, A., Dondi, M., Rida, T. and Schubert, J. (2020), *Unlocking Growth in SMEs*, McKinsey and Company, June, available at: www.mckinsey.com/industries/public-sector/our-insights/unlocking-growth-in-small-and-medium-size-enterprises

Aouadni, S., Aouadni, I. and Rebaï, A. (2019a), "A systematic review on supplier selection and order allocation problems", *Journal of Industrial Engineering International*, Vol. 15 No. 2009, pp. 267-289, doi: 10.1007/s40092-019-00334-y.

Arabsheybani, A., Paydar, M.M. and Safaei, A.S. (2018), "An integrated fuzzy MOORA method and FMEA technique for sustainable supplier selection considering quantity discounts and supplier's risk", *Journal of Cleaner Production*, Vol. 190, pp. 577-591, doi: 10.1016/j.jclepro.2018.04.167.

Arabzad, S.M., Ghorbani, M., Razmi, J. and Shirouyehzad, H. (2015), "Employing fuzzy TOPSIS and SWOT for supplier selection and order allocation problem", *The International Journal of Advanced Manufacturing Technology*, Vol. 76 Nos 5/8, pp. 803-818, doi: 10.1007/s00170-014-6288-3.

Armagan Tarim, S. and Kingsman, B.G. (2004), "The stochastic dynamic production/inventory lot-sizing problem with service-level constraints", *International Journal of Production Economics*, Vol. 88 No. 1, pp. 105-119, doi: 10.1016/S0925-5273(03)00182-8.

Azadnia, A.H., Saman, M.Z.M. and Wong, K.Y. (2015), "Sustainable supplier selection and order lot-sizing: an integrated multi-objective decision-making process", *International Journal of Production Research*, Vol. 53 No. 2, pp. 383-408, doi: 10.1080/00207543.2014.935827.

Babbar, C. and Amin, S.H. (2018), "A multi-objective mathematical model integrating environmental concerns for supplier selection and order allocation based on fuzzy QFD in beverages industry", *Expert Systems with Applications*, Vol. 92, pp. 27-38, doi: 10.1016/j.eswa.2017.09.041.

Bektur, G. (2020), "An integrated methodology for the selection of sustainable suppliers and order allocation problem with quantity discounts, lost sales and varying supplier availabilities", *Sustainable Production and Consumption*, Vol. 23, pp. 111-127, doi: 10.1016/j.spc.2020.05.006.

Birgün Barla, S. (2003), "A case study of supplier selection for lean supply by using a mathematical model", *Logistics Information Management*, Vol. 16 No. 6, pp. 451-459, doi: 10.1108/09576050310503420.

Bodaghi, G., Jolai, F. and Rabbani, M. (2018), "An integrated weighted fuzzy multi-objective model for supplier selection and order scheduling in a supply chain", *International Journal of Production Research*, Vol. 56 No. 10, pp. 3590-3614, doi: 10.1080/00207543.2017.1400706.

Bohner, C. and Minner, S. (2017), "Supplier selection under failure risk, quantity and business volume discounts", *Computers and Industrial Engineering*, Vol. 104, pp. 145-155, doi: 10.1016/j.cie.2016.11.028.

Burke, G.J., Carrillo, J. and Vakharia, A.J. (2008), "Heuristics for sourcing from multiple suppliers with alternative quantity discounts", *European Journal of Operational Research*, Vol. 186 No. 1, pp. 317-329, doi: 10.1016/j.ejor.2007.01.019.

Büyüközkan, G. and Çifçi, G. (2011), "A novel fuzzy multi-criteria decision framework for sustainable supplier selection with incomplete information", *Computers in Industry*, Vol. 62 No. 2, pp. 164-174, doi: 10.1016/j.compind.2010.10.009.

Çebi, F. and Bayraktar, D. (2003), "An integrated approach for supplier selection", *Logistics Information Management*, Vol. 16 No. 6, pp. 395-400, doi: 10.1108/09576050310503376.

Çebi, F. and Otay, I. (2016), "A two-stage fuzzy approach for supplier evaluation and order allocation problem with quantity discounts and lead time", *Information Sciences*, Vol. 339, pp. 143-157, doi: 10.1016/j.ins.2015.12.032.

Cha, B.C. and Moon, I.K. (2005), "The joint replenishment problem with quantity discounts under constant demand", *Or Spectrum*, Vol. 27 No. 4, pp. 569-581, doi: 10.1007/s00291-005-0196-8.

Chan, F.T.S. and Kumar, N. (2007), "Global supplier development considering risk factors using fuzzy extended AHP-based approach", *Omega*, Vol. 35 No. 4, pp. 417-431, doi: 10.1016/j.omega.2005.08.004.

Cheraghalipour, A. and Farsad, S. (2018), "A bi-objective sustainable supplier selection and order allocation considering quantity discounts under disruption risks: a case study in plastic industry", *Computers and Industrial Engineering*, Vol. 118, pp. 237-250, doi: 10.1016/j.cie.2018.02.041.

Dickson, G.W. (1966), "An analysis of vendor selection systems and decisions", *Journal of Purchasing*, Vol. 2 No. 1, pp. 5-17, doi: 10.1111/j.1745-493x.1966.tb00818.x.

Dye, C.Y. and Hsieh, T.P. (2012), "An optimal replenishment policy for deteriorating items with effective investment in preservation technology", *European Journal of Operational Research*, Vol. 218 No. 1, pp. 106-112, doi: 10.1016/j.ejor.2011.10.016.

Ellram, L.M. (1990), "The supplier selection decision in strategic partnerships", *Journal of Purchasing and Materials Management*, Vol. 26 No. 4, pp. 8-14, doi: 10.1111/j.1745-493x.1990.tb00515.x.

Gencer, C. and Gürpinar, D. (2007), "Analytic network process in supplier selection: a case study in an electronic firm", *Applied Mathematical Modelling*, Vol. 31 No. 11, pp. 2475-2486, doi: 10.1016/j.apm.2006.10.002.

Gilding, B.H. (2014), "Inflation and the optimal inventory replenishment schedule within a finite planning horizon", *European Journal of Operational Research*, Vol. 234 No. 3, pp. 683-693, doi: 10.1016/j.ejor.2013.11.001.

Gören, H.G. (2018), "A decision framework for sustainable supplier selection and order allocation with lost sales", *Journal of Cleaner Production*, Vol. 183, pp. 1156-1169, doi: 10.1016/j.jclepro.2018.02.211.

Govindan, K. and Sivakumar, R. (2016), "Green supplier selection and order allocation in a low-carbon paper industry: integrated multi-criteria heterogeneous decision-making and multi-objective linear programming approaches", *Annals of Operations Research*, Vol. 238 Nos 1/2, pp. 243-276, doi: 10.1007/s10479-015-2004-4.

Govindan, K., Rajendran, S., Sarkis, J. and Murugesan, P. (2015), "Multi criteria decision making approaches for green supplier evaluation and selection: a literature review", *Journal of Cleaner Production*, Vol. 98, pp. 66-83, doi: 10.1016/j.jclepro.2013.06.046.

Govindan, K., Mina, H., Esmaeili, A. and Gholami-Zanjani, S.M. (2020), "An integrated hybrid approach for circular supplier selection and closed loop supply chain network design under uncertainty", *Journal of Cleaner Production*, Vol. 242, p. 118317, doi: 10.1016/j.jclepro.2019.118317.

Hamdan, S. and Cheaitou, A. (2015), "Green supplier selection and order allocation using an integrated fuzzy TOPSIS, AHP and IP approach", *IEOM 2015 – 5th International Conference on Industrial Engineering and Operations Management, Proceeding*, pp. 1390-1399, doi: 10.1109/IEOM.2015.7093826

Hamdan, S. and Cheaitou, A. (2017a), "Dynamic green supplier selection and order allocation with quantity discounts and varying supplier availability", *Computers and Industrial Engineering*, Vol. 110, pp. 573-589, doi: 10.1016/j.cie.2017.03.028.

Hamdan, S. and Cheaitou, A. (2017b), "Supplier selection and order allocation with green criteria: an MCDM and multi-objective optimization approach", *Computers and Operations Research*, Vol. 81, pp. 282-304, doi: 10.1016/j.cor.2016.11.005.

Higgs, C.J. and Hill, T. (2019), "The role that small and medium-sized enterprises play in sustainable development and the green economy in the waste sector, South Africa", *Business Strategy and Development*, Vol. 2 No. 1, pp. 25-31, doi: 10.1002/bsd2.39.

Hruška, R., Průša, P. and Babić, D. (2014), "The use of AHP method for selection of supplier", *TRANSPORT*, Vol. 29 No. 2, pp. 195-203, doi: 10.3846/16484142.2014.930928.

Hudymáčová, M., Benková, M., Pócsová, J. and Škovránek, T. (2010), "Supplier selection based on multi-criterial AHP method", *Acta Montanistica Slovaca*, Vol. 15 No. 3, pp. 249-255.

Jamil, N., Besar, R. and Sim, H.K. (2013), "A study of multicriteria decision making for supplier selection in automotive industry", *Journal of Industrial Engineering*, Vol. 2013, pp. 1-22, doi: 10.1155/2013/841584.

Kaur, H. and Prakash Singh, S. (2021), "Multi-stage hybrid model for supplier selection and order allocation considering disruption risks and disruptive technologies", *International Journal of Production Economics*, Vol. 231, p. 107830, doi: 10.1016/j.ijpe.2020.107830.

Khoshfetrat, S., Rahiminezhad Galankashi, M. and Almasi, M. (2020), "Sustainable supplier selection and order allocation: a fuzzy approach", *Engineering Optimization*, Vol. 52 No. 9, pp. 1494-1507, doi: 10.1080/0305215X.2019.1663185.

Kilic, H.S. (2013), "An integrated approach for supplier selection in multi-item/multi-supplier environment", *Applied Mathematical Modelling*, Vol. 37 Nos 14/15, pp. 7752-7763, doi: 10.1016/j.apm.2013.03.010.

Kull, T.J. and Talluri, S. (2008), "A supply risk reduction model using integrated multicriteria decision making", *IEEE Transactions on Engineering Management*, Vol. 55 No. 3, pp. 409-419, doi: 10.1109/TEM.2008.922627.

Kumar, P., Bhattacharya, A. and Ho, W. (2014), "Strategic supplier performance evaluation: a case-based action research of a UK manufacturing organisation", *International Journal of Production Economics*, Vol. 166, pp. 192-214, doi: 10.1016/j.ijpe.2014.09.021.

Kumar, G.K., Rao, M.S. and Rao, V.V.S.K. (2018), "Supplier selection and order allocation in supply chain", *Materials Today: Proceedings*, Vol. 5 No. 5, pp. 12161-12173, doi: 10.1016/j.matpr.2018.02.194.

Kurniawan, S., Nugraha, B.S. and Yolanda, P. (2018), "Analytical hierarchy process to evaluate supplier performance in timber industry", *Binus Business Review*, Vol. 9 No. 2, pp. 133-143, doi: 10.21512/bbr.v9i2.4404.

Lee, A.H.I. (2009), "A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks", *Expert Systems with Applications*, Vol. 36 No. 2, pp. 2879-2893, doi: 10.1016/j.eswa.2008.01.045.

Liao, C.N. and Kao, H.P. (2011), "An integrated fuzzy TOPSIS and MCGP approach to supplier selection in supply chain management", *Expert Systems with Applications*, Vol. 38 No. 9, pp. 10803-10811, doi: 10.1016/j.eswa.2011.02.031.

Manucharyan, H. (2021), "Multi-criteria decision making for supplier selection: a literature critique", *Independent Journal of Management and Production*, Vol. 12 No. 1, pp. 329-352, doi: 10.14807/ijmp.v12i1.1265.

Meena, P.L. and Sarmah, S.P. (2016), "Supplier selection and demand allocation under supply disruption risks", *The International Journal of Advanced Manufacturing Technology*, Vol. 83 No. 1-4, pp. 265-274, doi: 10.1007/s00170-015-7520-5.

Memon, M.S., Lee, Y.H. and Mari, S.I. (2015), "Group multi-criteria supplier selection using combined grey systems theory and uncertainty theory", *Expert Systems with Applications*, Vol. 42 No. 21, pp. 7951-7959, doi: 10.1016/j.eswa.2015.06.018.

Mendoza, A. and Ventura, J.A. (2012), "Analytical models for supplier selection and order quantity allocation", *Applied Mathematical Modelling*, Vol. 36 No. 8, pp. 3826-3835, doi: 10.1016/j.apm.2011.11.025.

Mohamed, M. (2018), "International journal of supply and operations management", *International Journal of Supply and Operations Management*, Vol. 5 No. 3, pp. 256-265.

Moheb-Alizadeh, H. and Handfield, R. (2018), "An integrated chance-constrained stochastic model for efficient and sustainable supplier selection and order allocation", *International Journal of Production Research*, Vol. 56 No. 21, pp. 6890-6916, doi: 10.1080/00207543.2017.1413258.

Moheb-Alizadeh, H. and Handfield, R. (2019), "Sustainable supplier selection and order allocation: a novel multi-objective programming model with a hybrid solution approach", *Computers and Industrial Engineering*, Vol. 129, pp. 192-209, doi: 10.1016/j.cie.2019.01.011.

Mukherjee, S. (2018), "Challenges to Indian micro small scale and medium enterprises in the era of globalization", *Journal of Global Entrepreneurship Research*, Vol. 8 No. 1, pp. 1-19, doi: 10.1186/s40497-018-0115-5.

Narkhede, G. and Rajhans, N. (2022), "An integrated approach to redesign inventory management strategies for achieving sustainable development of small and medium-sized enterprises: insights from an empirical study in India", *Business Strategy and Development*, Vol. 5 No. 4, pp. 308-321, doi: 10.1002/bsd2.200.

Nourmohamadi Shalke, P., Paydar, M.M. and Hajiaghaei-Keshteli, M. (2018), "Sustainable supplier selection and order allocation through quantity discounts", *International Journal of Management Science and Engineering Management*, Vol. 13 No. 1, pp. 20-32, doi: 10.1080/17509653.2016.1269246.

Pasi, B.N., Mahajan, S.K. and Rane, S.B. (2020), "The current sustainability scenario of industry 4.0 enabling technologies in Indian manufacturing industries", *International Journal of Productivity and Performance Management*, Vol. 70 No. 5, pp. 1017-1048, doi: 10.1108/IJPPM-04-2020-0196.

Pooya, A., Fakhlaei, N. and Alizadeh-Zoeram, A. (2020), "Designing a dynamic model to evaluate lot-sizing policies in different scenarios of demand and lead times in order to reduce the nervousness of the MRP system", *Journal of Industrial and Production Engineering*, Vol. 38 No. 2, pp. 1-15, doi: 10.1080/21681015.2020.1858982.

PrasannaVenkatesan, S. and Goh, M. (2016), "Multi-objective supplier selection and order allocation under disruption risk", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 95, pp. 124-142, doi: 10.1016/j.tre.2016.09.005.

Rahman, M., Akter, M., Odunukan, K. and Haque, S.E. (2020), "Examining economic and technology-related barriers of small- and medium-sized enterprises internationalisation: an emerging economy context", *Business Strategy and Development*, Vol. 3 No. 1, pp. 16-27, doi: 10.1002/bsd2.71.

Raj, R. (2012), "Multi-item inventory model with two price-breaks under multiple recovery and procurement set-ups", *Mathematics Today*, Vol. 28, pp. 27-42.

Rajak, S., Parthiban, P. and Dhanalakshmi, R. (2021), "Analysing barriers of sustainable transportation systems in India using Grey-DEMATEL approach: a supply chain perspective", *International Journal of Sustainable Engineering*, Vol. 14 No. 3, pp. 419-432, doi: 10.1080/19397038.2021.1929553.

Rajhans, A.N.R. and Barshikar, B.S.R. (2013), "Vendor selection using analytical hierarchy process", *Proceedings of International Conference on Computers and Industrial Engineering, CIE*, Vol. 2, pp. 1145-1152.

Razak, D.A., Abdullah, M.A. and Ersoy, A. (2018), "Small medium enterprises (SMES) in Turkey and Malaysia a comparative discussion on issues and challenges", *15th Kuala Lumpur International Business Economics and Law Conference 2018 (KLIBEL 15)*, pp. 1-12, available at: http://irep.iium.edu.my/63627/

Rezaei, A., Rahiminezhad Galankashi, M., Mansoorzadeh, S. and Mokhatab Rafiei, F. (2020), "Supplier selection and order allocation with lean manufacturing criteria: an integrated MCDM and Bi-objective modelling approach", *Engineering Management Journal*, Vol. 32 No. 4, pp. 253-271, doi: 10.1080/10429247.2020.1753490.

Samak-Kulkarni, S.M. and Rajhans, N.R. (2013), "Determination of optimum inventory model for minimizing total inventory cost", *Procedia Engineering*, Vol. 51 No. NUiCONE 2012, pp. 803-809, doi: 10.1016/j.proeng.2013.01.115.

Scott, J., Ho, W., Dey, P.K. and Talluri, S. (2015), "A decision support system for supplier selection and order allocation in stochastic, multi-stakeholder and multi-criteria environments", *International Journal of Production Economics*, Vol. 166, pp. 226-237, doi: 10.1016/j.ijpe.2014.11.008.

Shadkam, E. and Bijari, M. (2017), "Multi-objective simulation optimization for selection and determination of order quantity in supplier selection problem under uncertainty and quality criteria", *The International Journal of Advanced Manufacturing Technology*, Vol. 93 Nos 1/4, pp. 161-173, doi: 10.1007/s00170-015-7986-1.

Shafique, M., Asghar, M. and Rahman, H. (2017), "The impact of green supply chain management practices on performance: moderating role of institutional pressure with mediating effect of green innovation", *Business, Management and Education*, Vol. 15 No. 1, pp. 91-108, doi: 10.3846/bme.2017.354.

Shao, Y., Barnes, D. and Wu, C. (2022), "Sustainable supplier selection and order allocation for multinational enterprises considering supply disruption in COVID-19 era", *Australian Journal of Management*, Vol. 48 No. 2, doi: 10.1177/03128962211066953.

Singh, R.K. (2011), "Developing the framework for coordination in supply chain of SMEs", *Business Process Management Journal*, Vol. 17 No. 4, pp. 619-638, doi: 10.1108/14637151111149456.

Singh, R.K. and Kumar, R. (2020), "Strategic issues in supply chain management of Indian SMEs due to globalization: an empirical study", *Benchmarking: An International Journal*, Vol. 27 No. 3, pp. 913-932, doi: 10.1108/BIJ-09-2019-0429.

Sobhanallahi, M.A., Gharaei, A. and Pilbala, M. (2016), "Provide a new method to determine effectiveness or performance rate of organization strategies based on freeman model and using improved dimensional analysis method", *Proceedings of the 12th International Conference on Industrial Engineering, ICIE 2016*, pp. 125-133, doi: 10.1109/INDUSENG.2016.7519358.

Stević, Ž., Pamučar, D., Puška, A. and Chatterjee, P. (2020), "Sustainable supplier selection in healthcare industries using a new MCDM method: measurement of alternatives and ranking according to Compromise solution (MARCOS)", *Computers and Industrial Engineering*, Vol. 140, p. 106231, doi: 10.1016/j.cie.2019.106231.

Taherdoost, H. and Brard, A. (2019), "Analyzing the process of supplier selection criteria and methods", *Procedia Manufacturing*, Vol. 32, pp. 1024-1034, doi: 10.1016/j.promfg.2019.02.317.

Tan, K.C. (2006), *Buyer-Supplier Relationships and Firm Performance*, Vol. 36 No. 10, pp. 755-775, doi: 10.1108/09600030610714580.

Triantaphyllou, E. and Mann, S.H. (1995), "Using the analytic hierarchy process for decision making in engineering applications: some challenges", *International Journal of Industrial Engineering: Theory, Applications and Practice*, Vol. 2 No. 1, pp. 35-44.

Wang, X., Lin, Y. and Shi, Y. (2020), "The moderating role of organizational environments on the relationship between inventory leanness and venture survival in Chinese manufacturing", *Journal of Manufacturing Technology Management*, Vol. 31 No. 2, pp. 413-440, doi: 10.1108/JMTM-04-2019-0129.

Weber, C.A., Current, J.R. and Benton, W.C. (1991), "Vendor selection criteria and methods", *European Journal of Operational Research*, Vol. 50 No. 1, pp. 2-18, doi: 10.1016/0377-2217(91)90033-R.

Wong, J.T. (2020), "Dynamic procurement risk management with supplier portfolio selection and order allocation under green market segmentation", *Journal of Cleaner Production*, Vol. 253, p. 119835, doi: 10.1016/j.jclepro.2019.119835.

Zavadskas, E.K., Antucheviciene, J. and Chatterjee, P. (2018), "Multiple-criteria decision-making (MCDM) techniques for business processes information management", *Information (Switzerland)*, Vol. 10 No. 1, pp. 1-7, doi: 10.3390/info10010004.

Zeydan, M. (2020), "Expert systems with applications", *March 2011*, doi: 10.1016/j.eswa.2010.08.064.

Zhu, Q., Sarkis, J. and Lai, K.H. (2012), "Examining the effects of green supply chain management practices and their mediations on performance improvements", *International Journal of Production Research*, Vol. 50 No. 5, pp. 1377-1394, doi: 10.1080/00207543.2011.571937.

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