Performance measurement of construction suppliers under localization, agility, and digitalization criteria: Fuzzy Ordinal Priority Approach

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Abstract

The suppliers’ performance plays a vital role, with a domino effect, in project success, organizational competitiveness, protecting supply chain and construction industry from disruptions and PESTEL risks (political, economic, social, technological, environmental, and legal). Therefore, measuring the performance of the construction suppliers has become the primary focus of project-oriented organizations and the core of business decision-making, especially during global megatrends. The question that may arise here is, “How can the performance of the construction suppliers be determined under uncertainties considering the post-COVID-19 era?” Organizations need eligible suppliers for the rapid recovery of the supply chain and construction sector at this critical stage. Given the importance of the issue, this study aims to propose a novel approach for measuring the performance of construction suppliers using the fuzzy ordinal priority approach (OPA-F). OPA-F is a recent development in multiple criteria decision-making (MCDM) that can determine the criteria weights for performance measurement using fuzzy linguistic variables. We do not always have access to a complete data set in real-world situations and business environments. Nevertheless, OPA-F can handle this dilemma, even with incomplete input data. This research intends to consider three main aspects of the construction suppliers, known as (L-A-D) capabilities, including localization, agility, and digitalization. In this regard, we bring up a case study from the construction industry to demonstrate the application of the proposed framework. The findings show that the most critical criterion is “digitalization” for the case study. This criterion covers “supply chain automation” and “virtualization and dematerialization” of services/products. The proposed approach is practical and straightforward, particularly for academicians and decision-makers; it can also incorporate uncertainties.

Keywords Performance measurement · Supply chain disruptions · Localization · Agility · Digitalization · Fuzzy ordinal priority approach
1 Introduction

In an increasingly unpredictable and volatile world, the construction industry and supply chain (SC) are evolving rapidly and experiencing various external risks, uncertain events, and transformational changes. Leading organizations and pioneering companies grasp these opportunities to get ahead of emerging trends and keep pace with technological advancements, shaping the next generations of supply chain management (SCM). To achieve this goal, they usually outsource part of external tasks to qualified suppliers to stay up-to-date and ensure the success of their projects, businesses, and entire SCM.

Over the last decades, sustainable supply chain management (SSCM) has received significant attention among market players and organizations. Sustainability pillars usually drive organizations to increase their sustainability efforts, including selecting and engaging sustainable suppliers. In this regard, the triple-bottom-line (TBL) approach can be employed to measure suppliers’ performance in 3Ps of social responsibilities (people), environmental protection (plant), and economic growth (profit) (Sarkis & Dhavale, 2015). Circular closed-loop supply chain management (CSCM) is another newly developed concept that questions the traditional linear supply chain and emphasizes the environmentally friendly economy. Proper evaluation of suppliers is an essential step toward a circular economy (CE). This requires measuring CE suppliers’ performance based on the ReSOLVE framework: Regenerate ecosystems, Share assets, Optimize processes, Looping materials, Virtualize and dematerialize products/services, and Exchange old with advanced equipment (EMF, 2015; Kouhizadeh et al., 2020; McKinsey, 2016a). Environmental concerns have given rise to a new school of thought in SCM that leads to green supply chain management (GSCM). Successful performance of green suppliers can help organizations eliminate the negative environmental impacts of their activities and achieve green supply chain goals (Abu Seman et al., 2019; Fallahpour et al., 2020; Keshavarz Ghorabaee et al., 2016).

In uncertain circumstances and abrupt disruptions, the greenly resilient supply chain has become organizations’ focal point to take proactive strategies for quick recovery. Therefore, measuring suppliers’ Gresilience performance, considering green and resilience dimensions, allows organizations to regain the original status promptly (Mohammed, 2020). This list does not end here. By today’s world’s growing complexity, construction industries will take new approaches to be ahead of changes and unexpected transformations to meet global needs. In the early 2020s, we have witnessed widespread COVID-19 outbreaks and long-term lockdowns significantly impacting projects and organizations. It caused global economic shock, supply chain disruptions, logistics shutdowns, and shortages of high-demand materials (Chowdhury et al., 2021; Guan et al., 2020). Now with strict control of the COVID-19 epidemic and massive vaccination programs, it seems that industries are entering into the post-COVID-19 era. Lessons learned from this megatrend show that organizations need to rethink business as usual, develop capacities, and gain the ability to withstand any disturbance; this helps them return to normal conditions and become more resilient and agile (Prashara, 2021).

Kermani et al. (2012) believed that selecting qualified suppliers can determine the long-term viability of an organization. Otherwise, it may expose a project-based organization to risks of cost overruns, improper quality, and delivery delays. According to the conditions governing the post-COVID-19 era, suppliers’ localization, agility, digitalization can play a pivotal role in the construction ecosystem. At the time of writing, no research considers these three criteria simultaneously for measuring suppliers’ performance as a corporate strategy. In this regard, the current study proposes a practical and novel approach...
for estimating the construction supplier’s performance based on L-A-D capabilities. It is an emergent concept that brings impressive results not only for organizations but also for entire supply chain resilience and its rapid recovery while facing unforeseen market volatility (Nandi et al., 2020; Sarkis, 2020). L-A-D capabilities is a holistic approach including several sub-criteria. To gauge suppliers’ performance in each localization, agility, digitalization criterion, we employed the OPA extension under the fuzzy environment, known as fuzzy OPA (hereinafter OPA-F) proposed by Mahmoudi, Abbasi, et al. (2021). OPA-F can calculate the weight of criteria under uncertain conditions, which is essential for performance measurement.

To clarify the scope of the study, we try to answer three main Research Questions (RQs) throughout the current paper:

RQ1
What sub-criteria needs to be considered for measuring suppliers’ performance to address disruptions in supply chain management and construction industry?

RQ2
How can a multi-criteria-decision-making (MCDM) tool be employed to evaluate suppliers and measure their performance under uncertainties?

RQ3
How can OPA-F be applied in real-world business and help organizational decision-makers measure suppliers’ performance in each criterion and sub-criterion?

Based on the information above, the contributions of the current study can be summarized below:

- We present an integrated framework to measure the performance of the construction suppliers based on localization, agility, and digitalization in the fuzzy environment.
- For the first time, we employ the OPA-F, a new method in the MCDM context, for performance measurement with a new use-case.

The rest of the current study is organized as follows: After Introduction, the literature review is provided in Sect. 2 to identify the influential criteria and sub-criteria. Sect. 3 is devoted to preliminaries. Section 4 outlines research Methodology; and a novel approach based on OPA-F is elaborated in more detail. After that, the proposed approach is employed in an actual case study in the construction industry. Related results and discussion are presented in Sect. 5. Finally, the conclusion is provided in Sect. 6.

2 Literature review

2.1 Performance measurement in supply chain

One of the popular areas in the supply chain has been evaluating suppliers, selection, and measuring their performance. Exiting literature (mainly 2015 afterward) shows that scholars and practitioners attempted to measure the performance of the suppliers in various types of problems and approaches. In this regard, we reviewed 14 studies from two aspects: (i) criteria used for performance appraisal and (ii) methods used for calculating the criteria weight and suppliers’ score in each criterion. The fuzzy set theory is
appropriate for handling uncertainties in all selected studies. Furthermore, fuzzy decision-making tools are popular since they can choose optimal probable choices (Mardani et al., 2015).

Govindan et al. (2013) explored the initiatives of SSCM based on the TBL approach. Then, the authors performed qualitative performance evaluation for criteria weighting and then they used fuzzy TOPSIS for suppliers ranking. Kayhan and Cebi (2014) determined the importance of reliability criteria and used fuzzy DEMATEL to analyze the interaction among the factors. This possibility allows firms to prioritize suppliers based on their reliability in the construction industry. Akman (2015) used fuzzy c-means and VIKOR methods to prioritize suppliers based on their environmental/green performance. Zhou et al. (2016) employed Fuzzy type-2 multi-objective DEA for supplier evaluation in the field of SSCM. Chen et al. (2019) focused on careful supplier selection in cooperative and specialized industrial chains. The authors used six sigma indicators to develop a fuzzy supplier selection based on 4R green concepts (Reduce, Reuse, Recycle, and Recovery). Alikhani et al. (2019) employed interval type-2 fuzzy DEA for strategic supplier selection considering sustainability and risk criteria. Rashidi and Cullinane (2019) used Fuzzy TOPSIS and fuzzy DEA to assess service quality commitments and price for selecting potential sustainable suppliers.

Alegoz and Yapicioglu (2019) proposed a hybrid approach based on goal programming, trapezoidal type-2 fuzzy AHP, and fuzzy TOPSIS. The authors used this model to determine the appropriate supplier(s). Tong et al. (2020) developed the extended fuzzy PROMETHEE II for supplier performance evaluation in highly polluting and high-risk industries. The authors consider three main dimensions: processing, sustainability, and other basic criteria (time, cost, and quality of service). Tavassoli et al. (2020) employed Stochastic-fuzzy DEA for evaluating suppliers in the field of SSCM. Mina et al. (2021) used fuzzy AHP to determine the weight of sub-criteria and employed a fuzzy inference system to rank CE supplies’ in the CSCM. Liou et al. (2021) proposed a novel hybrid MCDM tool comprised of fuzzy TOPSIS and fuzzy best-worst method (FBWM) for selecting proper suppliers in GSCM. As we can see, the scholars have widely used various MCDM methods such as AHP, TOPSIS, and PROMETHEE, along with DEMATEL and DEA. Tirkolaee et al. (2020) employed a new hybrid approach based on fuzzy logic, including fuzzy ANP and fuzzy DEMATEL, to determine criteria weights and fuzzy TOPSIS to select sustainable-reliable suppliers.

To the best of our knowledge, no one has employed the OPA-F for performance measurement. Nevertheless, its use-cases in other areas are remarkable, and its application will be discussed in Sect. 4. In this regard, the current study makes a pioneering attempt to measure the performance of the construction suppliers through the OPA-F. Furthermore, the literature shows that a wide range of criteria is being used for evaluation, selection, and performance measurement of suppliers, considering supply chain needs and conditions of the business environment.

Given the current megatrends and delicate state of the post-COVID-19 era, this study focuses on suppliers’ performance associated with supply chain localization (Sub-Sect. 2.2), supply chain agility (Sub-Sect. 2.3), and supply chain digitalization (Sub-Sect. 2.4) for recovery of construction industry and supply chain disruptions. Figure 1 is illustrated to show integration among L-A-D capabilities.

In this regard, the following sub-sections are elaborated to answer “RQ1. What sub-criteria needs to be considered for measuring suppliers’ performance to address disruptions in supply chain management and construction industry?”
2.2 Supply chain localization

Supply chain localization (hereinafter SC localization) has always been the focal point of scholars and practitioners. Bateman (1998) outlined the SC localization and its strategic role in the development of Kazakhstan during the 1990s. The author stated that accelerating the localization can be a way for shoring up the situations of the key companies, reconstruction of the supply chain, and national economic recovery of Kazakhstan. According to Albino et al. (2002), the supply chain is a network of processes and flows that can be localized within or outside an area. The authors proposed input-output models to understand relationships among the environment and the processes. This paves the way for managing the global and local supply chain regarding the sustainability of a local community.

Martin and Rickard (2012) identified and ranked the external factors affecting companies’ decisions and strategies for localizing the supply chain. The authors believed that SC localization could help Swedish companies stay competitive and sustainable in future markets. Wu and Jia (2018) investigated the relationship between corporations’ strategies and localized supply chain operations within western multinational enterprises (MNEs) in China. According to findings, SC localization is an institutional process that causes cognitive and normative changes in MNEs and improves economic, environmental, and social performance. Reza-Gharehbagh et al. (2020) evaluated the role of the government in enhancing supply chain localization. Government policy and support can directly increase the profit of the local supply chains.

Today, SC localization is still a hotly debated topic. In a report of Prashara (2021) published by Project Management Institute (PMI), it is said that working with local suppliers, partners, non-governmental organizations, and service providers contributes to local communities in terms of building trust, market sustainability, and societal benefits. Local and regional partners will eliminate the risks posed by megatrends in the 2020s, including COVID-19, climate crisis, social movements, globalization, artificial intelligence, and so
forth. For managing supply chain disruptions and risks in the post-COVID-19 era, more retailers, suppliers, and SC participants are interested in localization strategies in their respective regions (Sakthivel et al., 2021). All of the above studies emphasized the importance of SC localization in the economy and development. Therefore, this sub-section considered localization as one of the main criteria for performance measurement that covers the following definition and four sub-criteria.

C1. Localization (Christopher, 2011; Martin & Rickard, 2012; Nandi et al., 2021): Localization is defined as the placement of the organization, physical assets, and supply chain functions. From the industrial perspective, local presence is essential to meet market demands for faster, more cost-efficient, reliable, and flexible product and service delivery. Localization is a strategic solution to secure suppliers from supply chain disruptions and external risk factors. It minimizes distance-related issues, transportation costs, international currency fluctuations, global market changes, geopolitical risks, and so forth.

C1.1. Localized processes: This criterion determines the suppliers’ efforts in regionalizing processes associated with planning, research and development (R&D), purchasing, sourcing, manufacturing, procurement, distributing, and recycling activities (Albino et al., 2002; Martin & Rickard, 2012; Nandi et al., 2021). According to Sadeghi et al. (2022b), emerging technologies enable suppliers to benefit from localized processes with minimum time, cost, and transportation with maximum quality.

C1.3. Developing local capabilities: This criterion indicates suppliers’ engagement in making capacity for communities by running local businesses and accessing local skills, knowledge, financial resources, technologies, equipment, and facilities (Nandi et al., 2021; Reza-Gharehbagha et al., 2020). According to Sadeghi et al. (2022b), suppliers can use emerging technologies for local economic prosperity and the growth of nearby businesses for improving living standards.

C1.4. Local waste management and value recovery: The traditional linear model of “take-make-waste” does not work in the supply chain and economy anymore. This field demands sustainable approaches, like the circular economy, to minimize raw material usage, design-out waste, and improve value recovery (EMF, 2015). This criterion indicates suppliers’ efforts to keep products as long as possible within local closed-loops and make new and by-products out of local wastes (Albino et al., 2002; Nandi et al., 2021; Sillanpää & Ncibi, 2019).

2.3 Supply chain agility

Some scholars discussed supply chain agility (hereinafter SC agility) and its importance in responding to unprecedented changes. White et al. (2005) addressed the position of emergent information technologies in improving the agility of SC and suppliers. The authors measured the SC agility based on the time taken for suppliers to address a customer’s order and meet their needs. Lin et al. (2006) presented a framework for evaluating enterprises based upon business processes, people, technologies, information systems, and facilities. An enterprise can accomplish agile capabilities in terms of responsiveness, competency, flexibility, and quickness. Braunscheidel and Suresh (2009) extended a theatrical
framework to enhance the supplier’s agility and address the effect of two cultural antecedents, such as learning orientation and market orientation, on SC agility. They also investigated the impact of three organizational practices, including (i) internal and external integration with stakeholders and suppliers, and (ii) external flexibility, on SC agility. Kumar Sharma and Bhat (2014) employed interpretive structural modeling (ISM) to provide a hierarchy-based framework and examine the relationship among the drivers of an agile SC. Lee et al. (2015) evaluated the suppliers based on agility criteria using the MCDM approach. In this study, fuzzy AHP calculates the weights of the criteria, and Fuzzy TOPSIS obtains suppliers’ rank for each defined criterion.

Today, SC agility has attracted a lot of attention. Russell and Swanson (2019) addressed the gap between SC agility and information processing theory. At the organizational level, bridging trending technologies to agile practices can lead to information processing, demand sensing, and SC agility. Ivanov (2020) presented a new notation named viable supply chain, a combination of agility, sustainability, and resilience. He mentioned that the viable supply chain could help the firms redesign and recover their business from a global pandemic like COVID-19. Al Humdan et al. (2020) provided a systematic review on the SC agility context, including enablers, definitions, and performance implications. Raji et al. (2021) explored the Industry 4.0 technologies for agile and lean supply chain strategies to promote companies’ performance. All of the above studies emphasized the benefits of SC agility. Therefore, this sub-section considered agility as one of the main criteria for performance measurement that covers the following definition and four sub-criteria.

C2. Agility (Al Humdan et al., 2020; Lee et al., 2015; Nandi et al., 2021; Tallon & Pinsonneault, 2011): Agility is defined as firms’ capability to meet time and speed requirements within product and service delivery. Agility indicates suppliers’ performance in identifying and responding to environmental opportunities and threats.

C2.1. Stakeholder agility: This sub-criterion is about detecting and capturing market opportunities for competitive advantages and innovation. Stakeholder agility is achievable through (i) Gathering customers’ needs and their preferences as a source of innovative ideas, (ii) Understanding market requirements and predicting prospective changes, (iii) Developing novel products, services, and creating value (iv) Receiving stakeholders’ feedbacks for continual improvement, and finally, (v) Accelerating responsiveness based on delivery time and speed requirements (Kohli & Jaworski, 1990; Lee et al., 2015; Sambamurthy et al., 2003).

C2.2. Partnering agility: This criterion indicates strategic cooperation, alliances, and forming joint ventures with partners to grasp market opportunities, create synergy and gain competitive advantages. In this regard, suppliers benefit from partnering agility in the following ways: (i) Utilizing partners’ knowledge, competencies, resources, and their value proposition, (ii) Involving agile partners and sub-suppliers at upstream and downstream, and (iii) Collaborating with key and powerful suppliers (Al Humdan et al., 2020; Nandi et al., 2021; Sambamurthy et al., 2003).

C2.3. Operational agility: Operational agility is at the core of the business model and implies suppliers’ operations/practices/processes for product and service delivery in a cost-efficient, accurate, and rapid manner. This criterion illustrates
firms’ capability to adapt or respond to uncertainties and turbulent markets to gain competitive advantage by (i) Redesigning existing processes or designing new processes, (ii) Swiftness in decision-making and solution providing, and (iii) Flexibility in the organizational and business processes (Al Humdan et al., 2020; Braunscheidel & Suresh, 2009; Lee et al., 2015; Nandi et al., 2021; Raji et al., 2021; Sambamurthy et al., 2003).

C2.4. Marketing agility: Marketing agility is suppliers’ market sensitivity, alertness, responsiveness, and adaptability to market changes promptly. This criterion helps firms to have reactive/proactive responses for changing demand patterns (Al Humdan et al., 2020).

2.4 Supply chain digitalization

Supply chain digitalization (hereinafter SC digitalization) has been a popular topic in recent years. Büyüközkan and Göçer (2018) provided a review on the digital supply chain and its challenges both in industry and academic. The authors tried to discover how digitalization could be integrated with the supply chain. Frederico et al. (2019) defined the term Supply Chain 4.0 by considering the industry 4.0 in the supply chain context. Supply Chain 4.0 can be the reorganization of the supply chain using frontiers technologies that could significantly improve conventional supply chain management. Indeed, Supply Chain 4.0 is the new generation of the digital supply chain that makes the supply chain participants faster and more flexible than before. Srai and Lorentz (2019) extended a framework for SC digitalization. This framework allows practitioners to employ digital technologies and artificial objects in the firms.

Schneiderjans et al. (2020) explored the future trend of research about the role of knowledge management in supply chain digitization. The authors used textual analysis large-scale literature using data from 2010 to 2018. Their results could contribute to the readers exploring the human dimension for optimizing SC digitalization. They also discussed the niche areas in the digital supply chain where scholars could focus in future. Agrawal et al. (2020) stated that Industry 4.0 has a significant impact on the construction supply chain; however, it faces several challenges which should be identified and addressed carefully. They used the AHP method for prioritizing the enablers, in which E-supply achieved the highest rank. After that, digitization, tracking, and localization come at the other top positions. Gupta et al. (2020) identified and ranked the critical drivers of the digital supply chain. Based on the results, “big data and data science skills” and “tracking and localization of products” achieved the first and second positions, respectively, as the most critical factors in the digital supply chain.

Based on the studies above, digitalization is an essential aspect of the construction suppliers. Therefore, this sub-section considered digitalization, as a crucial pillar of L-A-D capabilities, covering the below definitions and three sub-criteria.

C3. Digitalization (Nandi et al., 2021): Digitalization deals with embedding technology into processes, practices, activities, assets, and services, which disrupts the traditional supply chain. With the arrival of industry 4.0, a new form of trust, transparency, connectivity, security, traceability, and automation emerges in projects, businesses, supply chain, and the entire construction industry (Sadeghi et al., 2022a).
C3.1. Value exchange using IT infrastructures: Three flows go parallel within the supply chain: goods/services flow, information flow, and financial flow. Suppliers can use comprehensive technology stacks (software, hardware, and infrastructure) for value exchange with other supply chain participants (Hofmann & Belin, 2011; Nandi et al., 2021).

C3.2. Virtualization and dematerialization: Technological innovations can replace physical products/services with digital products/services. Such dematerialization results in remote service delivery, resource-saving, and less dependence on resources. Virtualization has also revolutionized collaboration and communication mechanisms. Suppliers use technological platforms to reduce unnecessary travel, time-consuming transportation, and face-to-face meetings (Al Humdan et al., 2020; Büyükozkan & Göçer, 2018; Lee et al., 2015; McKinsey, 2016b; Mussomeli et al., 2015; Nandi et al., 2021).

C3.3. Supply chain automation: This criterion refers to leveraging computing, physical, and digital technologies (i.e., Internet of things (IoT), artificial intelligence (AI), robotics, distributed ledger technologies, and so forth) for value proposition in a real-time and cost-efficient manner. These technologies provide suppliers with self-executed contracts, automated processes and operations, and intelligent information systems. The use of technology improves information transparency, immutability, reliability, and generate traceable data for real-time SCM (Agrawal et al., 2020; Büyükozkan & Göçer, 2018; Nandi et al., 2021).

3 Preliminaries

One of the most well-known approaches for dealing with uncertainty is the “fuzzy set theory” proposed by Zadeh (1965). Scholars have widely employed and developed fuzzy set theory since then. There is a wide range of fuzzy numbers, distinguished by the type of membership function. The proposed framework used triangular fuzzy numbers (TFNs) during the performance measurement of supplier construction. Referring to Pedrycz (1994), obvious motivation for TFN utilization lies in popularity and simplicity compared to other types of fuzzy numbers. In addition, TFN has desirable achievements to deal with uncertainty and imprecision.

Definition 1 (Pedrycz, 1994) The TFN can be presented as $\tilde{q} = (l, m, u)$ while $l \leq m \leq u$ and its membership function can be defined by Eq. (1).

$$\mu_{\tilde{q}}(x) = \begin{cases} 
0, & x < l \\
\frac{x - l}{m - l}, & l \leq x < m \\
\frac{u - x}{u - m}, & m \leq x \leq u \\
0, & x > u 
\end{cases}$$

The membership function associated with TFN is depicted in Figure 2.

Definition 2 Giachetti and Young (1997) For two positive fuzzy numbers $\tilde{A} = [l, m, u]$ and $\tilde{B} = [l', m', u']$, the primary operations are as Eq. (2) to Eq. (5).
Definition 3 Kumar et al., (2011) Graded Mean Integration Representation (GMIR) for the fuzzy number $\tilde{q} = (l_i, m_i, u_i)$ is calculated as Eq. (6).

$$R(\tilde{q}) = \frac{l_i + 2m_i + u_i}{4}$$

Definition 4 Mahmoudi, Javed, et al. (2021) Fuzzy linguistic variables are scaled terms convertible to fuzzy numbers. Tables 1 and 2 illustrate the fuzzy linguistic variables employed in this study.

Definition 5 Kaur and Kumar (2016) The fuzzy linear programming model with TFNs can be defined as Model (7).

| Table 1 Transformation of fuzzy linguistic variables for criteria importance as input data |
|---------------------------------|-----------------|---|
| Linguistic Variables | TFN for Criteria | Rank (r) |
| Very Low (VL) | (0.9, 1, 1) | 7 |
| Low (L) | (0.7, 0.9, 1) | 6 |
| Medium Low (ML) | (0.5, 0.7, 0.9) | 5 |
| Medium (M) | (0.3, 0.5, 0.7) | 4 |
| Medium–High (MH) | (0.1, 0.3, 0.5) | 3 |
| High (H) | (0, 0.1, 0.3) | 2 |
| Very High (VH) | (0, 0, 0.1) | 1 |
To solve Model (7), it should be converted into a conventional linear programming model. In this regard, Model (7) should be converted into Model (8). Then, it can be solved using the simplex algorithm (Mahmoudi, Javed, et al., 2021).

Maximize (or Minimize) $\sum_{j=1}^{n} (p_j, q_j, r_j) \otimes (x_j, y_j, z_j)$

Subject to $\sum_{j=1}^{n} (a_{ij}, b_{ij}, c_{ij}) \otimes (x_j, y_j, z_j) < (b_i, g_i, h_i) \quad \forall i = 1, 2, \ldots, m.$ \hspace{1cm} (7)

$x_j \leq y_j \leq z_j$

Note: To solve Model (7), it should be converted into a conventional linear programming model. In this regard, Model (7) should be converted into Model (8). Then, it can be solved using the simplex algorithm (Mahmoudi, Javed, et al., 2021).

Maximize (or Minimize)$R\left(\sum_{j=1}^{n} (p_j, q_j, r_j) \otimes (x_j, y_j, z_j)\right)$

Subject to

$\sum_{j=1}^{n} a_{ij} x_j + s_i = b_i \quad \forall i = 1, 2, \ldots, m.$

$\sum_{j=1}^{n} b_{ij} y_j + t_i = g_i \quad \forall i = 1, 2, \ldots, m.$ \hspace{1cm} (8)

$\sum_{j=1}^{n} c_{ij} z_j + f_i = h_i \quad \forall i = 1, 2, \ldots, m.$

$(x_j, y_j, z_j), (p_j, q_j, r_j)$ and $(a_{ij}, b_{ij}, c_{ij})$ are non-negative fuzzy numbers

$x_j \leq y_j \leq z_j$

$s_i \leq t_i \leq f_i$

In Table 1, the numbers close to zero should be considered "0.01" instead of absolute zero while transforming linguistic variables to fuzzy numbers.

### Table 2: Transformation of fuzzy linguistic variables for performance-rating as input data

| Linguistic Variables | TFN for Performance-rating |
|----------------------|---------------------------|
| Worst (W)            | (0, 0.5, 1.5)             |
| Very Poor (VP)       | (1, 2, 3)                 |
| Poor (P)             | (2, 3.5, 5)               |
| Fair (F)             | (3, 5, 7)                 |
| Good (G)             | (5, 6.5, 8)               |
| Very Good (VG)       | (7, 8, 9)                 |
| Excellent (E)        | (8.5, 9.5, 10)            |
4 Methodology

This section addresses the second research question, “RQ2. How can a multi-criteria decision-making (MCDM) tool be employed to evaluate suppliers and measure their performance under uncertainties?” In practice, supplier evaluation and selection based on criteria is a type of MCDM problem. Typically, an MCDM tool (i) aggregates the multiple experts’ viewpoint about criteria and alternatives, (ii) determines the importance of each criterion, and (iii) ranks alternatives based on criteria. The current study needs a novel approach for measuring performance. One of the recent state-of-the-art MADM tools is the Ordinal Priority Approach (OPA) proposed by Ataei et al. (2020). OPA calculates the weights of criteria, the rank of alternatives, and experts’ weights in parallel. Several strengths make it superior to other MCDM tools. It is independent of normalization, pairwise comparison, complete data set, positive/ negative ideal solutions, and averaging methods for accumulating experts’ opinions. Furthermore, OPA enables decision-makers to leave some items unanswered, for cases they do not have adequate knowledge or experience around the subject, to improve the accuracy and reliability of output data.

Mahmoudi, Javed et al. (2021) asserted that OPA needs some improvements for (i) handling linguistic information by embedding fuzzy set theory, and (ii) subjective evaluation of values considering uncertainties of real-world situations. Given the above sore points, the authors extended OPA to the Fuzzy OPA (also called OPA-F) with the following features:

- The convergence of fuzzy linear programming and fuzzy MCDM,
- The conversion of linguistic variables to fuzzy numbers;

OPA extensions have received significant attention among researchers and scholars in a short time. Mahmoudi et al. (2022) proposed Robust OPA (also called OPA-R) in MCDM. Authors employed this novel method for optimal project portfolio selection considering the resilience strategies of project-based organizations. They also proposed a new concept which was a combination of profitability and resilience (Presilient) for portfolio selection problems. The first OPA use-case is a study about “blockchain technology in the construction sector” conducted by Sadeghi et al. (2022b). The authors applied OPA to evaluate barriers to blockchain and distributed ledger adoption in the construction industry based on sustainability dimensions. Mahmoudi and Javed (2021) proposed a novel relative performance index to measure the performance of the sub-contractors of construction projects using the OPA. Moreover, Mahmoudi, Abbasi et al. (2021) combined the DEA with the OPA to provide a hybrid approach for the performance measurement of the suppliers. In context of blockchain technology in construction, Sadeghi, Mahmoudi, and Deng (2022b), used trapezoidal OPA-F to develop a risk assessment model.

Here, the current study aims to develop a framework based on Lin et al. (2006) for measuring performance index using OPA-F. To illuminate the concept behind OPA-F, the steps of the proposed framework are presented. Before anything, it is required to provide information for utilized variables, parameters, and sets.

| Sets       | Description                  |
|------------|------------------------------|
| I          | Set of experts ∀ i ∈ I       |
| J          | Set of criteria ∀ j ∈ J      |
| K          | Set of suppliers ∀ k ∈ K     |
The steps of the proposed framework are as follows:

**Step 1**
Specifying the expert(s) who has enough knowledge about the suppliers and their background.

**Step 2**
Specifying the criteria/sub-criteria which are essential for the business objectives and play a vital role in project success, organizational competitiveness, and in the long-term, supply chain recovery through localization, agility, and digitalization.

**Step 3**
Collecting the experts’ opinions regarding the criteria importance using fuzzy linguistic variables in Table 1.

**Step 4**
Collecting the experts’ opinions associated with the performance of each supplier in each criterion using fuzzy linguistic variables in Table 2 and calculating the average value.

**Step 5**
Constructing and solving Model (9) using the collected data in Step 3 and Model (8).

Max $\tilde{Z}$

S.t :

\[
\begin{align*}
\tilde{a}^i_{ij} \left( \tilde{W}_{ij}^r - \tilde{W}_{ij}^{r+1} \right) & \geq \tilde{Z} \quad \forall i \text{ and } r \\
\tilde{a}^n_{ij} \tilde{W}_{ij}^n & \geq \tilde{Z} \quad \forall i \text{ and } r = n \\
\sum_{i=1}^{p} \sum_{j=1}^{n} \tilde{W}_{ij} & = (0.8, 1, 1.2) \\
\tilde{\ell}_{ij}^w & \leq \tilde{m}_{ij}^w \leq \tilde{u}_{ij}^w \quad \forall i \text{ and } j \\
\tilde{\ell}_{ij}^w & \geq 0 \quad \forall i \text{ and } j
\end{align*}
\]
The weight of the criteria can be calculated using Eq. (10).

\[
\tilde{W}_j = \sum_{i=1}^{p} \tilde{W}_{ij} \quad \forall j
\]  

(10)

**Step 6**
Calculating the fuzzy performance of the suppliers using Eq. (11). It should be noted that the authors could not use the formula of Lin et al. (2006) for calculating the performance index because the authors of the current study could not confirm the fuzzy division in their performance index formula. Therefore, the authors revised and extended the formula of Lin et al. (2006) as follows:

\[
FPI_k = (\text{Localization}_{\text{index}}, \text{Agility}_{\text{index}}, \text{Digitalization}_{\text{index}})
\]  

(11)

where:

\[
\text{Localization}_{\text{index}}(FLPI_k) = \frac{\sum_{j=1}^{n \in C_1} (R(\tilde{W}_j) \times \tilde{x}_{jk})}{\sum_{j=1}^{n \in C_1} R(\tilde{W}_j)}
\]  

(11.1)

\[
\text{Agility}_{\text{index}}(FAPI_k) = \frac{\sum_{j=1}^{n \in C_2} (R(\tilde{W}_j) \times \tilde{x}_{jk})}{\sum_{j=1}^{n \in C_2} R(\tilde{W}_j)}
\]  

(11.2)

\[
\text{Digitalization}_{\text{index}}(FDPI_k) = \frac{\sum_{j=1}^{n \in C_3} (R(\tilde{W}_j) \times \tilde{x}_{jk})}{\sum_{j=1}^{n \in C_3} R(\tilde{W}_j)}
\]  

(11.3)

**Step 7**
The distance of \(FLPI_k, FAPI_k,\) and \(FDPI_k,\) with the labels in Table 3, should be calculated using Eqs. (12.1) to (12.3). The minimum distances show the performance of suppliers in terms of localization, agility, and digitalization, respectively.

\[
D(FLPI_k, LL_t) = \left\{ \sum_{x \in \nu} \left[ FLPI_k(x) - LL_t(x) \right]^2 \right\}^{1/2} \quad \nu \subset [0, 10]
\]  

(12.1)

**Table 3** Transformation of fuzzy performance of labels for L-A-D capabilities

| Localization Level | Labeling for Agility Level | Digitalization Level | TFN for Labels |
|--------------------|---------------------------|---------------------|---------------|
| Slowly Local       | Slowly Agile              | Slowly Digital      | (0, 1.5, 3)   |
| Fairly Local       | Fairly Agile              | Fairly Digital      | (1.5, 3, 4.5) |
| Local              | Agile                     | Digital             | (3.5, 5, 6.5) |
| Very Local         | Very Agile                | Very Digital        | (5.5, 7, 8.5) |
| Extremely Local    | Extremely Agile           | Extremely Digital   | (7, 8.5, 10)  |
where $LL_t$ is $t$th linguistic variables of localization level, $AL_t$ is $t$th linguistic variables of agility level, and $DL_t$ is $t$th linguistic variables of digitalization level.

## 5 Case study, results, and discussion

In this section, we bring an actual case study to answer “**RQ3. How can OPA-F be applied in real-world business and help organizational decision-makers measure suppliers’ performance in each criterion and sub-criterion?**” We employ the proposed framework in a project-oriented organization from the construction sector to answer this question. This organization requires to evaluate the performance of the switch and socket suppliers. For a better conception, we illustrated the structure of the MCDM problem in Fig. 3.

To demonstrate the applicability of the proposed framework, we followed the procedure of the Methodology (Sect. 4). For this, we selected four eligible experts from the organization under study (Step 1). After finalizing the criteria (Step 2), we collected experts’ opinions on the criteria and sub-criteria (Step 3), presented in Table 4.

In the case study, the performance of four suppliers will be evaluated and measured. In Step 4, we gathered experts’ opinions about the suppliers in each sub-criterion, presented in Table 5.

---

**Fig. 3** The structure of the MCDM problem, including the objective, criteria, and sub-criteria
After constructing and solving the model (Step 5), we obtained the fuzzy weights of the criteria and sub-criteria, which are listed in Table 6.

It is worthwhile to mention that we also calculated the defuzzification value of sub-criteria using Eq. (6), which are illustrated in Fig. 4.

As can be seen from Fig. 4, the top-ranked weights are W33, W32, and W13, respectively. In other words, “C33: supply chain automation” with a weight of 0.194981 achieved the first position; “C32: virtualization and dematerialization” with a weight of 0.168175 is in the second position; And, “C13: developing local capabilities” reached the third rank.
The findings prove that experts reached a consensus on the importance of digitalization in suppliers’ performance. From their perspective, the ideal suppliers need to employ big data technology, the internet of things (IoTs), advanced robotics, distributed ledgers, and other emerging technologies for proactive strategies and predictive analytics. Furthermore,
digitalization allows suppliers to expand value networks everywhere, automate every pro-
cess for operational effectiveness, customer satisfaction, at the highest level, rapid recovery
of supply chain disruptions. McKinsey (2016b) verifies that digitization can bring about (i)
Agility and on-time delivery time, (ii) Flexibility and responding to changing demands by
new business models, (iii) Granularity and managing customers in granular clusters and
providing them with diverse suited products and services, (iv) Accuracy and proving real-
time and transparent data throughout the supply chain, and (v) Efficiency both in physical
tasks and planning activities.

In Step 6 of the proposed approach, we calculated the fuzzy performance of the suppli-
ers in terms of localization, agility, and digitalization, summarized in Table 7.

As shown in Fig. 6, the fuzzy performance of the suppliers in terms of localization is
based on the following relation: Supplier 2 > Supplier 4 > Supplier 1 > Supplier 3. The
result implies that Supplier 2 reached the first position with the highest performance in the
localization criterion.

It is worth mentioning that the performance of the suppliers in terms of Agility is illus-
trated in Fig. 7, with the following order: Supplier 3 > Supplier 4 > Supplier 1 > Supplier 2.
As can be seen, Supplier 3 reached the first position with the highest performance in agility
criterion.

It should be noted that the performance of the suppliers in terms of digitalization is
illustrated in Fig. 8. As can be seen, the suppliers’ performance is based on Supplier

| Suppliers | Localization | Agility | Digitalization |
|-----------|--------------|---------|---------------|
|           | l  | m   | u              | l  | m   | u          | l  | m   | u          |
| Supplier 1 | 4.2035 | 5.8750 | 7.5232 | 3.0287 | 4.7621 | 6.4954 | 5.9734 | 7.3057 | 8.5371 |
| Supplier 2 | 5.7474 | 7.0933 | 8.3955 | 2.1586 | 3.7379 | 5.3485 | 2.8674 | 4.4022 | 5.9370 |
| Supplier 3 | 3.0534 | 4.4383 | 5.8231 | 6.0305 | 7.3943 | 8.5962 | 7.2332 | 8.3251 | 9.2167 |
| Supplier 4 | 4.8962 | 6.4397 | 7.9598 | 4.9200 | 6.4400 | 7.9600 | 5.2690 | 6.7017 | 8.1345 |

Table 7 The fuzzy performance of the suppliers

Fig. 5 The fuzzy weight of the criteria
Fig. 6  The fuzzy performance of the suppliers in terms of localization

Fig. 7  The fuzzy performance of the suppliers in terms of agility
Supplier 3 reached the first position with the highest performance in digitalization.

By taking Step 7 of the proposed approach, the performance of the suppliers can be presented based on linguistic variables. As shown in Table 8, final results become more tangible for the decision-makers.

According to Table 8, Supplier 4 has a good situation in all three criteria and can be a good option for our case study. However, the decision-makers should decide based on business objectives and organization strategies. This approach is flexible, which lets them check the performance of the suppliers in different aspects and makes the optimal decision based on the needs. For example, Suppliers 3 can be the optimal option for a decision-maker who pays more attention to digitalization, while Supplier 4 can be the optimal option for another decision-maker who pays more attention to three criteria simultaneously.

In the end, key points are extracted from the case study and discussion, as listed below:

![Membership Function for Suppliers](image)

**Fig. 8** The fuzzy performance of the suppliers in terms of digitalization

| Suppliers   | Localization | Agility   | Digitalization   |
|-------------|--------------|-----------|------------------|
| Supplier 1  | Local        | Agile     | Very Digital     |
| Supplier 2  | Very Local   | Fairly Agile | Digital         |
| Supplier 3  | Local        | Very Agile | Extremely Digital|
| Supplier 4  | Very Local   | Very Agile | Very Digital     |

More information about the labeling mechanism of L-A-D capabilities is provided in Table 3.
• Digitalization is an essential dimension of L-A-D capabilities. Therefore, suppliers’ effort in “C3.3. Supply chain automation,” “C3.2. Virtualization and dematerialization,” and “C3.1. Value exchange using IT infrastructures” are solutions to supply chain disruption and PESTELL risks.

• From now on, we will witness a wide range of disruptive transformations and various megatrends overshadowing the construction industry. To be on the safe side, supply chain participants should put their digitalization and localization strategies at high priority.

• The proposed framework shows high flexibility in performance measurement under uncertainty.

6 Conclusion

In the sensitive circumstance of the post-COVID-19 era, construction organizations are interested in collaborating with qualified suppliers for the success of projects, advancing organizational goals, and quick recovery of supply chain disruptions. Given the importance of this topic, a comprehensive approach is highly needed to evaluate suppliers, measure their performance, and prioritize them. This study’s contributions are mainly rooted in the application of OPA-F to develop a framework for measuring suppliers’ performance. The proposed framework considers three essential aspects of localization, agility, and digitalization in the construction suppliers’ performance. The reasons why the L-A-D capabilities of construction suppliers are critical in the post-crisis era that were reviewed in the literature thoroughly. Furthermore, the current study employed the fuzzy set theory to handle the input and output uncertainty. Indeed, we defined the performance measurement of the suppliers as a fuzzy MCDM problem. The proposed approach is easy to employ and presents the performance of the suppliers in both fuzzy numbers and fuzzy linguistic variables, which is more perceivable for the decision-makers and scholars.

This paper also put the proposed framework into practice to illustrate its applicability in real-world conditions. In this regard, we targeted a construction company, and we got four experts involved in evaluating their suppliers’ performance based on 11 sub-criteria from localization, agility, and digitalization aspects. According to the results, “C3.3: supply chain automation” is a high-ranked criterion that needs consideration in the supplier evaluation process. Leveraging digital technologies in supply chain practices enables suppliers to reduce operational costs and time for an efficient product and service delivery. The findings also show that “C3.2: virtualization and dematerialization” is the second high-ranked criterion. From the experts’ perspective, suppliers can use information and communication technologies in the business process to substitute or eliminate materials, energy, and waste in the supply chain, where it is possible. According to the findings, the least important criterion is “C1.2: insourcing process and activities.” It can be perceived that suppliers are basically selected according to their internal ability, capacity, and knowledge to undertake ongoing functions and execute projects, then outsourcing to a third party. In other words, the low weight of criterion does not undermine its importance but makes it less challenging.

While conducting current research, we encountered some limitations. One of the sore points of the proposed approach is the lack of consideration of the experts’ reliability during the performance measurement. The experts with different working experiences and academic degrees can play a different role in determining the performance. Hence, extending
the proposed approach to Z-numbers in future is suggested, which can present more reliable results based on the experts’ competencies. We hope that our research will serve as a base for future studies in this context. Scholars can expand the framework for a wide variety of criteria in performance appraisal and answer this question: what other capabilities should suppliers have for supply chain resilience and protecting the supply chain and construction industry from risks and unexpected disruptions? Finally, it is strongly suggested to utilize OPA-F to make the optimal decision in the research projects and real-world cases to take wise response actions.

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Declaration

Conflict of interest No potential conflict of interest was reported by the authors.

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