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A multi-agent based big data analytics system for viable supplier selection

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Abstract

The world is characterized by volatility, uncertainty, complexity, and ambiguity (VUCA). In such an environment, the viability in terms of digitalization, resilience, and sustainability capabilities has gained worldwide attention in supply chain management. Therefore, it is crucial to give special consideration to these paradigms when selecting suppliers. Moreover, the availability of data in digital supply chain systems can aid in supplier selection by using Artificial Intelligence techniques to identify viable suppliers. This approach can streamline the supplier selection process and lead to more efficient and effective manufacturing operations. Thus, it is necessary to have a big data analytics infrastructure in today's data-driven world. In this context, this paper aims to design a multi-agent system that belongs to the theory of Distributed Artificial Intelligence based on big data analytics to give a strong tool for finding the best viable suppliers based on a thorough and data-driven evaluation. To do so, designing a multi-agent-based big data analytics system model necessitates identifying the multiple criteria needed for selecting viable suppliers in real-time decision-making. To this end, through a literature review, this paper analyzes more than 140 publications and identifies the main criteria needed for viable suppliers' selection in the VUCA world. Therefore, the proposed system can be used as an intelligent viable supplier selection that improves the quality of the process and controls it while considering different capabilities. It presents a comprehensive model for viable supplier selection, consisting of four main layers: decision-making system, data resources, supplier selection, and big data analytics. The model incorporates six types of agents: Suppliers agent, Resource Agent, Knowledge Management Agent, Pilot Agent, Analyst Agent, and Decision-Making Agent. The integration of these layers and agents enables real-time data-driven decision-making, contributing to the selection of viable suppliers in a volatile and uncertain environment. The proposed model enhances supply chain performance in the digital era, offering a robust tool for both academics and practitioners to improve the quality of supplier selection.

Keywords Supplier selection · Multi-agent system · Big Data Analytics · Viability · VUCA World

Introduction

Supply chain (SC) performance is directly affected by a range of disruptive events, including supply fluctuations, unanticipated currency rates, dynamic markets, unpredictable demand, geopolitical conflicts, and natural disasters, which are making organizations more vulnerable (Nicoletti, 2023). Epidemics, such as Covid-19, are instances of supply chain vulnerabilities characterized by long-term disruption, disruption spread (i.e., ripple effect), and high uncertainty (Ivanov, 2021a). Therefore, the unpredictability of the world has increased, and the ability to predict probabilities has shifted. This is due to the fast-paced and constantly changing nature of our world, which is characterized by volatility, uncertainty, complexity, and ambiguity (VUCA) (Kotha &

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Sony, 2023). As a result, supply chains are not only incorporated into VUCA circumstances, but they also exhibit VUCA features (Gao et al., 2021). In this context, transparency, visibility, and viability are required for achieving supply chain performance (Dolgui & Ivanov, 2022). Particularly, ensuring the viability of the supply chain is important in today's fast-paced business environment, where organizations must "react agilely to positive changes, be resilient to absorb negative events and re-cover after disruptions, and survive at long-term periods" (Ivanov, 2021a). Thus, there has been a rise in recent years in demand for enhanced supply chain viability research and practice (Ivanov and Dolgui, 2022; Nasir et al., 2021). Such an objective demanded the selection of reliable suppliers More specifically, the chosen suppliers should be able to adapt to challenges and work in a VUCA world. Indeed, one of the supply chain management concerns that has piqued the interest of academic scholars is supplier selection (ForouzeshNejad, 2023). In this context, to remain competitive and enhance their performance, organizations must explore and integrate viable capacity in supplier selection criteria (Rostami et al., 2023; Zekhnini et al., 2021a, c).

Therefore, to ensure viability, organizations need to consider new criteria in the supplier selection process such as digitalization, resilience, and sustainability (Chaouni Benabdellah et al., 2023). By prioritizing viability in supplier selection, organizations can ensure the long-term sustainability and profitability of their supply chain operations (Bag et al., 2023), even in a VUCA world. This can help to reduce risks and maintain business continuity, even in the face of significant disruptions or changes. In other words, by emphasizing on digitalization, resilience, and sustainability, suppliers can improve their viability and competitiveness in the supply chain (Rostami et al., 2023). Thus, using such criteria in an intelligent system attempts to identify an overview of the meeting and improve the viability in a complementary way (Zekhnini et al., 2021b, c). More clearly, it is important to consider resilience criteria for supplier selection due to the potential negative impact of supply chain disruptions on business operations and performance (Hosseini & Khaled, 2019; Mahmoudi et al., 2022a). Resilience criteria should be assessed to prepare for potential disruptions, minimize the impact on operations, and improve supply chain efficiency (Mishra et al., 2021). By selecting suppliers with strong resilience capabilities, organizations can reduce the risk of delays or production stoppages, resulting in better overall performance and business continuity (Wissuwa et al., 2022). In addition, sustainability is also crucial as it helps to reduce the environmental impact and ensure ethical practices throughout the supplier supply chain (Yazdani et al., 2022). Moreover, digitalization allows for increased visibility, collaboration, and efficiency (Zekhnini et al., 2020a). In fact, digital tools such as artificial intelligence and big data analytics can help organizations optimize their supply chain operations, improve decision-making, and adapt to changing circumstances more quickly (Mohammed et al., 2022).

The literature review reveals that numerous quantitative approaches, incorporating multi-criteria decision-making, have been proposed for supplier selection (Kang et al., 2012; Menon & Ravi, 2022; Pang & Bai, 2013; Sharma & Balan, 2013; Stević et al., 2020; Wang et al., 2017). These approaches are commonly used to evaluate and select suppliers for supply chain management. While these methods offer advantages, they often neglect the behavioural aspects of the supplier selection process, and the preferences and beliefs of decision-making agents are not adequately captured. Many of these approaches rely on traditional theories, which may not fully account for the complexities and dynamic nature of supplier selection in modern supply chains. Therefore, there is a need for a more comprehensive and intelligent approach that considers both quantitative and behavioral elements in supplier selection. More clearly, a multi-agent system offers unique advantages over traditional MCDM methods, including flexibility, adaptability, decentralized decision-making, real-time data-driven decisions, collaboration, consideration of behavioral elements, enhanced resilience, and improved decision quality. These advantages make MAS a promising approach for supplier selection in modern and dynamic supply chain environments.

Therefore, due to its potential to revolutionize the way software systems are designed, developed, and deployed, agent-based systems technology, a branch of distributed artificial intelligence, has gained significant attention in recent years. This is particularly attractive for creating software that operates in decentralized and open environments like the internet. In this regard, some researchers proposed the multi-agent system (MAS) approach to deal effectively with supplier selection considering different types of criteria and in different contexts. Achatbi et al. (2020) have formally and concurrently used a multi-agent decision-making model for supplier selection with an integrated choice between the procurement and transportation departments. Yang (2011) presents a supplier evaluation approach based on multi-Agent that assists in analyzing work-team criteria and the weight of the supplier criterion. Other researchers used the MAS for the negotiation protocol in the supplier selection (Achatbi et al., 2020; Nejma et al., 2019) while further ones highlighted the criteria used in developing the MAS for supplier selection. More clearly, Ghadimi et al. (2018) used agent technology to solve the dual challenge of sustainable supplier selection and order allocation. The proposed and deployed MAS solution in this work highlights the contributions of agent technology in tackling communication and information exchange difficulties in SC partnerships considering the sustainability criteria. In addition, Ghadimi and Heavey (2014) introduced a multi-agent sustainable/green supplier assessment and order allocation system which is divided into two major sub-models. The first sub-model covers the process of supplier evaluation based on sustainability qualities while the second one handles the order allocation procedure. Moreover, Lima et al. (2013) presented a MAS to provide an appropriate communication channel, organized information sharing, and visibility across suppliers and manufacturers. Ghahremanloo and Tarokh (2011) provide a multi-agent-based model of Agile Supply Chain Management that may facilitate resource coordination between agents via a multimodal action mechanism while also selecting agile suppliers. Therefore, from such analysis to the best of our knowledge, in the supplier selection issue, there are no academic studies investigating the MAS in the supplier selection for digital supply chain in the VUCA world considering the viability criteria.

Building on the previous literature review and the identified gaps, the theoretical background of the current work differentiates itself from previous studies related to viable digital supply chain management by proposing a MAS-based Big Data analytics architecture for addressing the viable supplier selection problem. Indeed, Big data analytics can improve MAS for supplier selection by enabling the processing and analysis of large volumes of data from a variety of sources. In addition, the integration of big data analytics can help to identify patterns and trends in supplier performance data, market trends, and customer feedback, providing valuable insights for decision-making. Thus, by integrating big data analytics with a MAS for supplier selection, the system can become more sophisticated, and data driven. This can lead to more accurate and effective supplier selection, as well as improved supply chain performance. In fact, MAS can facilitate real-time decision-making and allow for timely adjustments to be made as new data becomes available, helping to reduce the risk of bias or error in decision-making. Besides, MAS with big data analytics can enable timely adjustments to be made as new data becomes available, helping to reduce the risk of bias or error in decision-making. This can help to enhance supply chain performance and improve risk management, ensuring the resilience and adaptability of supply chains in a VUCA world. As far as we know, there has been no available research that investigates including viability criteria in the supplier assessment and selection problem especially when paired with MAS and big data analytics. As a result, greater academic attention and practical demonstrations are required for study into incorporating viability elements in agent-based supplier assessment and selection to actualize the uncertain SC environment. In this regard and to consider all the previous research gaps, this paper addresses the essential requirement for a comprehensive and standardized data-driven agent-based model, specifically tailored for viable supplier selection. By conducting a thorough literature review and relying on experts' judgment, the proposed approach aims to equip agents with the capability to analyze material offerings and identify the most suitable suppliers that align with viability criteria in (VUCA) world. In essence, this research seeks to advance decision-making practices that prioritize supplier viability, facilitating organizations in navigating the uncertainties and complexities of the modern business landscape. The model integrates multiple criteria to ensure a well-informed and robust supplier selection process, contributing to improved supply chain performance. By developing this approach, the paper contributes to enhancing the efficiency and effectiveness of supplier selection in supply chain management. More clearly, this article discusses the following research questions (RQ):

- RQ1: What are the supplier selection criteria needed to deal with the VUCA world?
- RQ2: How can the integration of viability in terms of digitalization, resilience, and sustainability criteria impact supplier performance?
- RQ3: How can a data-driven approach such as MAS and Big data analytics improve the viable-oriented supplier selection?

This paper is organized as follows: Sect. 2 presents the theoretical background. Section 3 presents the research methodology. Section 4 presents the data collection in terms of viable supplier criteria that include criteria related to digitalization, resilience, and sustainability. Section 5 illustrates the MAS-based big data analytics model by presenting different layers namely the decision-making system layer, data resources layer, supplier selection layer, and big data analytics layer. Section 6 presents theoretical and practical implications.

Theoretical background

Supply chain viability in the era of VUCA

Resilience means the capacity of SCs to adapt, recover, and adjust from harmful disruptions to ensure SC performance, satisfy consumer demand, and sustain operations in uncertain environments (Ralston & Blackhurst, 2020). Anticipated events provide the context for evaluating resilience capacities, which are intrinsic qualities that can be harnessed in a crisis (Ivanov, 2021a). Traditionally, resilience has been associated solely with the ability to recover after a disruption. However, it is now viewed as a performance metric that can counterbalance recovery and disruption resistance, particularly in a VUCA world and this could be inefficient. For this reason, viability has emerged.

Viability is a behavior-driven property of a structural dynamic system. It considers the evolution of systems while facing disruptions to meet open system uncertainties. This means that viability is “the capacity to preserve system identity in a changing environment” (Ivanov & Dolgui, 2020a). Thus, a viable system is mainly concerned with controlling management, processes, and the environment (Ivanov & Dolgui, 2020b), and viability especially allows systems to fulfill the demands of survivability in an evolving environment such as the VUCA world. Hence, the viability analysis is focused on long-term longevity without set time windows. The SC can be considered viable if it can sustain itself and meet environmental necessities (sustainability) (Ivanov & Dolgui, 2020a). Figure 1 presents a comparison between resilience and viability.

Despite the increased research on supply chain viability, there are still several issues that need to be resolved, particularly in the volatile, uncertain, complex, and ambiguous (VUCA) environment. The acronym VUCA succinctly describes the difficulties that organizations encounter in the unpredictable and quickly changing business environment of today. While supply chain management has traditionally focused on efficiency and cost reduction, the VUCA environment necessitates a paradigm shift towards a more flexible and adaptable approach that requires an increased emphasis on viability. To do so, we need first to understand each word in the VUCA acronym. More clearly:

- **Volatility** refers to the magnitude, velocity, and dynamism of change (Pandit et al., 2018). In fact, the world is always altering and getting more unstable by the day, where changes are becoming more unexpected, and they are becoming more severe and happening quicker. As events occur in wholly unanticipated ways, determining cause and effect becomes increasingly difficult (Gao et al., 2021). Thus, the supply chain players should spend efforts to mitigate threats with a low probability of improving supply chain resilience (Hosseini, Ivanov et al., 2019).
- **Uncertainty** is the absence of prediction of situations and events (Pandit et al., 2018). Even historical predictions and previous experiences are losing significance and are unlikely to be sufficient as a basis for anticipating the nature of future events. It is getting practically hard to plan for investment, expansion, and growth as the path becomes increasingly unclear. In other words, in an uncertain world, the probability of a risk is unknown, but its impact is known. This category often includes risks resulting from human decisions (Gao et al., 2021). To address risks in an unpredictable world, a continued emphasis on behavioral digital supply chain management is required.
- **Complexity** is the lack of clarity about circumstances faced by an organization (Pandit et al., 2018). Our modern world is more complex than ever before. Difficulties and their consequences are increasingly complex and difficult to comprehend. Thus, in a complex environment, it is unknown how risk might interrupt the digital supply chain, but the possibility of it happening is known (Benabdellah et al., 2020). Supply chain architectures are getting more interconnected and complex, with supply chain members situated in many countries with disparate institutional contexts, legislation, and logistical systems (Gao et al., 2021). As a result, a little risk encountered by one supply chain member may eventually lead to the failure of the entire supply chain, resulting in the so-called ripple effect (Ivanov et al., 2018).
- **Ambiguity** is the lack of clarity about conditions facing the organization (Pandit et al., 2018). In an ambiguous world, neither the incidence nor the intensity of a threat is known. As a result, the supply chain is confronted with “unknown unknowns.“ At the moment, supply

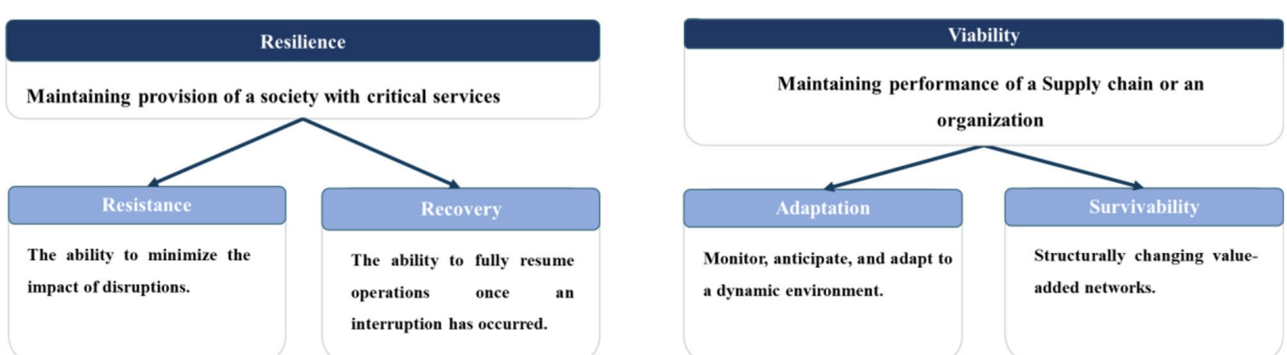

Fig. 1 Resilience VS Viability

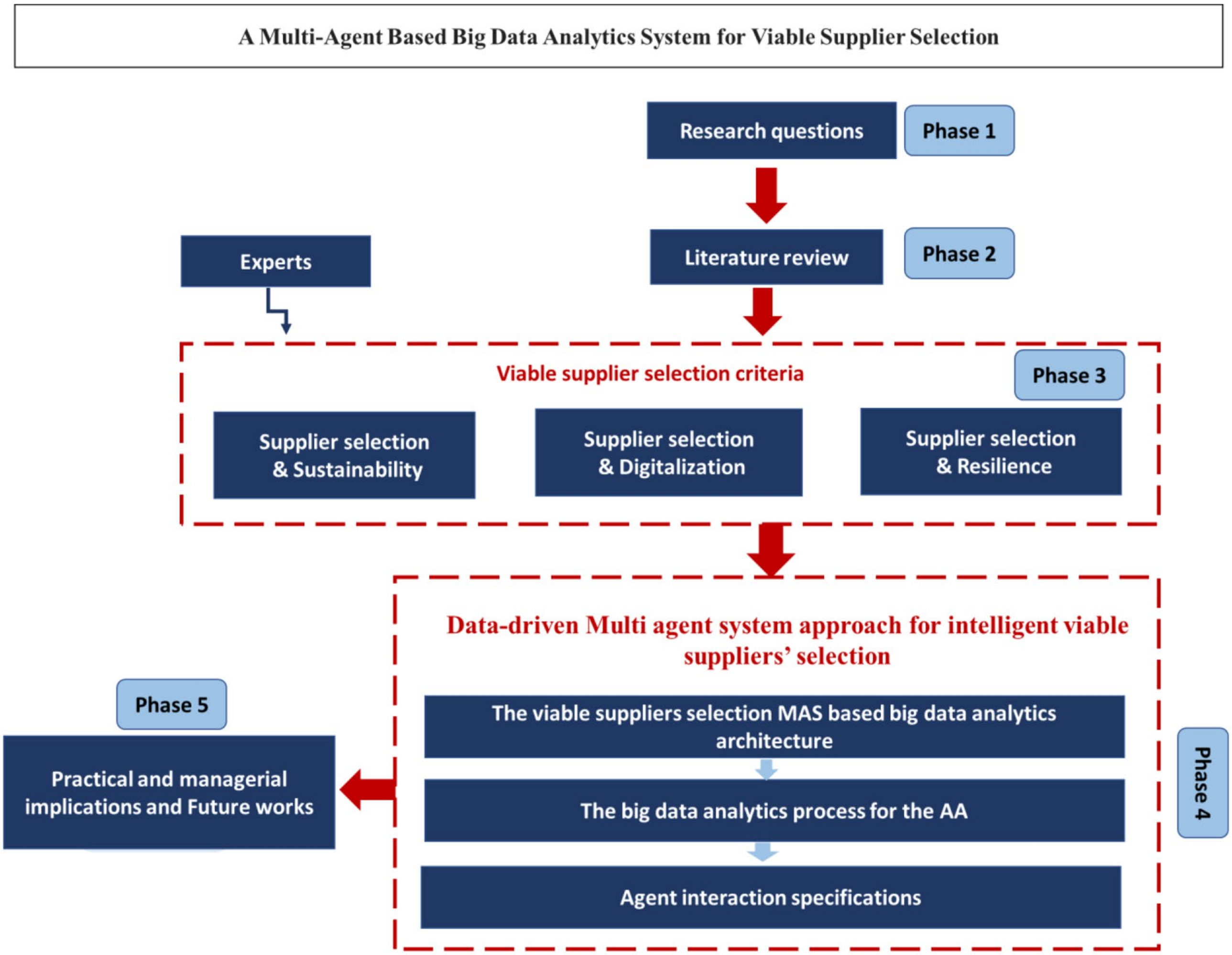

Fig. 2 Adopted methodology for Intelligent viable supplier selection

> chains are facing a rising number of events for the first time, and dealing with these "unknown unknowns" would become their "new normal" (Gao et al., 2021). A current example is the COVID-19 pandemic, which was completely unexpected (Ivanov & Das, 2020). Other skills may be useful in dealing with risks in an ambiguous world. Even though certain threats are unique to a particular supply chain, they may have been encountered by other supply networks. As a result, the learned lessons might be passed to the supply chain, allowing it to deal with its own "unknown unknowns".

Therefore, achieving viability in the supply chain is not a straightforward task, as it requires the coordination and cooperation of multiple stakeholders, including suppliers, manufacturers, distributors, and customers. Additionally, the VUCA environment brings with it a new set of challenges, such as increased complexity, greater uncertainty, and heightened ambiguity. Managing these issues necessitates distinct approaches for all businesses, as the latter cannot rely only on the resilience that comes with an abundance of financial and material resources (Brink, 2018). Supply chain agility is likely the most important method for addressing the VUCA problem. Digital technologies can increase supply chain agility, transparency, and visibility by allowing for greater adaptation to changing external situations (Ivanov, 2021b; Zekhnini et al., 2021a, c). Indeed, surviving and competing in the 'VUCA world' necessitates the ability to be sustainable and anticipate or respond quickly and effectively to external changes (Ravichandran, 2018), particularly in today's competitive landscape characterized by technological advancements and digitalization (Troise et al., 2022). Therefore, an organization's viability is a key capability to compete. In today's volatile world, supply chain viability is a survival tool. It has an impact on business performance and increases competitiveness. It may be viewed as a "dynamic trend" in which organizations must build new skills in order to become more viable. Besides, it requires organizations to continuously develop new skills and adopt innovative approaches to build a resilient and sustainable supply chain. By doing so, organizations can improve their business performance, enhance competitiveness, and achieve long-term success.

Multi-agent systems

Multi-agent system (MAS) is an area of Distributed artificial intelligence (DAI) which is a branch of artificial intelligence that has grown in popularity due to its capacity to address complicated real-world issues. Three areas have been the core focus of study in the field of distributed artificial intelligence: Parallel AI, Distributed problem solving (DPS), and Multi-agent systems (MAS). Like parallel AI, distributed problem-solving analyzes how a problem might be handled by sharing resources and knowledge across many cooperating modules known as Computing entities. Communication between computing entities and the amount of information communicated is defined and included in the architecture of the computing entity in distributed problem-solving. Because of the entrenched techniques, distributed issue-solving is inflexible and offers little or no flexibility (Balaji & Srinivasan, 2010). In addition, MAS deals with the behavior of the computational entities available to solve a given issue, as opposed to distributed problem-solving (Jahani et al., 2015). Each computational entity in a multi-agent system is referred to as an agent. According to Jacques Ferber, a pioneer in the field of multi-agent systems, a multi-agent system (MAS) is a "system composed of multiple interacting intelligent agents, which interact with each other and with their environment". In other words, a multi-agent system is a system made up of multiple autonomous agents that can perceive their environment, make decisions, and interact with other agents to achieve their individual and collective goals. Ferber's definition emphasizes the importance of agent autonomy, communication, and cooperation in multi-agent systems. To distinguish between a basic distributed system and a multi-agent system, it is critical to understand the properties of the agent or computing unit (Balaji & Srinivasan, 2010). Intelligent agents are a new paradigm in the creation of software systems. They are employed in a wide and expanding range of applications (Jahani et al., 2015). For a significant period, there was no precise characterization of an agent or a multiagent system, and just common properties coexisted. In fact, the word "agent" refers to a hardware or (more commonly) software-based computer system that possesses the following properties (Wang Yu et al., 2007):

- Autonomy: Agents function without explicit human involvement or others and have some autonomy over their activities and internal states.
- Social ability: Agents communicate with other agents (and perhaps humans) using some type of agent-communication language.
- Adaptivity: Agents are capable to learn from experience and modify their behavior accordingly.
- Reactivity: agents sense their environment (which might be the actual world, a user, a collection of other agents, the Internet, or all these together) and respond to changes in it promptly.
- Proactivity: rather than just reacting to their surroundings, agents might demonstrate goal-directed behavior by taking the initiative.

Methodology

The objective of this paper is to introduce an intelligent decision-making model for the selection of appropriate suppliers, considering the viability capability. To achieve this goal, Figure 2 depicts the research methodology employed in this study, which presents the theoretical steps taken to address the research objective. The suggested methodology comprises five phases that are closely interconnected.

- **Phase 1: Research questions**.

Defining a research question is typically the first and critical step in any research methodology. A clear research question is essential to ensure that the study is focused, and data is gathered and analyzed in a meaningful way. Hence, the first step in developing a methodology to integrate subcriteria for digitalization, resilience, and sustainability into the viability criterion for selecting suppliers is to establish a clear and specific research question. In this context, the research questions are: How will the integration of digitalization, resilience, and sustainability criteria as part of viability affect supplier performance? And, in what ways can data-driven approaches such as MAS and Big data analytics enhance the selection of suppliers with a focus on viability?

- **Phase 2: Literature review**.

This phase is about conducting a comprehensive literature review about suppliers' selection in the context of digital supply chain. It is an essential step in developing a methodology for including viability criteria in terms of digitalization, resilience, and sustainability in supplier selection. To ensure that the literature review is comprehensive and relevant to the research questions, a methodology for selecting keywords was followed (Durach et al., 2017). It involves several key steps, including brainstorming potential keywords related to the research questions, refining the list based on relevance and importance, conducting a preliminary search to assess the effectiveness of the keywords, and utilizing controlled vocabulary to further refine the search. By following this approach, we can ensure that all pertinent literature is captured and that the literature review is a thorough and accurate representation of the available research on the viable supplier selection topic. Hence, the final keywords and terms used in the searches of the various databases were those that are frequently used to describe and define the use of digital technologies, sustainability, and resilience capabilities in suppliers' selection. In addition, the keywords used by the authors are "Supplier selection OR evaluation And (Smart Supply chain management OR Digital Supply chain management, OR Intelligent Supply chain management OR Cyber-physical systems OR CPS OR Big data OR Cloud manufacturing OR Internet of things OR IOT OR Blockchain OR Augmented reality OR 3DP OR Additive manufacturing OR 3D printing OR Multi-agent system OR data-driven) Or (Supplier selection And (Industry 4.0 OR viability OR digitalization OR Sustainability OR Resilience OR disruption)".

Therefore, to address the research objectives and identify a large possible scope of research articles, the following databases were used:

- Elsevier (www.sciencedirect.com),
- Scopus (www.scopus.com),
- Emerald (http://www.emeraldinsight.com),
- Taylor &Francis (http://www.taylorandfrancis.com),
- Springer (https://www.springer.com/gp).
- Google Scholar.

After that, it is crucial to establish clear inclusion and exclusion criteria before conducting a literature review. In this study, the criteria were developed independently and based on specific guidelines to ensure that only relevant and high-quality articles were included in the analysis. The inclusion criteria were used to select articles published in scientific journals with high-impact factors or indexed conference proceedings, written in English, and relevant to the research question. Conversely, the exclusion criteria were applied to eliminate articles that were not peer-reviewed or unrelated to the topic. By using these criteria, the study was able to ensure that the selected articles met certain quality standards and were pertinent to the research question. Besides, to ensure that relevant studies were not missed during the analysis, the search filter used in this study encompassed title, abstract, and keyword searches for the selected terms. Additionally, articles in press and reviews were included as document types to cover any significant literature that may have been overlooked by only searching for published articles. This approach helped to ensure that all pertinent research was captured and evaluated in the study, preventing the exclusion of relevant literature that may have been overlooked in a more limited search.

The inquiry procedure was created by first exploring the relevant information sources. The literature review contained 144 published papers from 1997 to 2022. This period can be explained by the fact that discussion over adopting technologies and/or one of the studied paradigms is traced back to this period (Barua et al., 1997). The literature review on supplier selection in the industry 4.0 era represents an important step to collect the relevant scientific papers discussing the studied field. It aims to identify suppliers' selection criteria.

- **Phase 3: Viable supplier selection criteria**.

After conducting the literature review, it is important to analyze the potential novel subcriteria that could be included in the supplier selection process for digitalization, resilience, and sustainability. It is necessary to evaluate these subcriteria based on their relevance to the research question, and potential impact on the supplier selection process. This evaluation helps to ensure that the identified subcriteria are effective in enhancing the viability criterion for supplier selection and are not redundant with existing subcriteria.

In this context, experts can play a crucial role in refining the viable supplier selection criteria because of their specialized knowledge and experience in the relevant fields. Experts can provide valuable insights into the current industry practices and standards, as well as emerging trends and technologies that should be considered in the supplier selection process. They can also help to evaluate the feasibility and potential impact of potential subcriteria for digitalization, resilience, and sustainability that were identified through the literature review and other sources of information. Additionally, involving experts in the refinement process can help to enhance the credibility and validity of the study. As a result, with personal interviews that lasted more than three months, four specialists from diverse industries and three academic experts in the field consented to take part in the study. They were approached by email and calls. Therefore, a decision-making committee of seven individuals was formed to extensively analyze the viability criteria. One IT Manager, one Ph.D. engineer, one digital transformation responsible, one operation general manager, two university professors specializing in operations management, and one professor specializing in supply chain management are the decision-making committee. Furthermore, all these experts had more than 6 years of experience. The experts' profile is summarized in Table 1.

- **Phase 4: Data-driven multi-agent system approach for viable supplier selection**.

The proposed approach for selecting viable suppliers involves the development of a Multi-Agent System (MAS) that utilizes big data analytics to enable intelligent decision-making. This data-driven approach facilitates intelligent decision-making, allowing for a more comprehensive evaluation of suppliers based on real-time data and insights. By utilizing big data analytics within the MAS framework, the approach ensures a more informed and accurate selection process, enhancing the efficiency and effectiveness of supplier selection in a dynamic and unpredictable business environment. The architecture of the MAS for viable supplier selection is described in detail for different agents, and the process for big data analytics is outlined specifically for the analyst agent (AA). Furthermore, the specifications for agent interaction are provided, which explain how the different agents within the system will communicate and work together to achieve the objective of selecting viable suppliers. The goal of this approach is to leverage cutting-edge technologies and techniques to enhance the supplier selection process and ultimately improve the overall viability of the supply chain while considering the data-driven perspective.

- **Phase 5: Theoretical and practical implications and future research perspectives**.

In the final phase of the research, the focus shifts toward discussing the practical and managerial implications of the study's findings. The aim is to identify how the research can be applied to real-world scenarios and what implications it may have for decision-makers in the field. Additionally, the study presents potential future research directions based on the gaps identified in the literature and limitations encountered during the study. The final phase is critical in ensuring that the research has practical relevance and can be translated into actionable insights.

Table 1 Experts profile

Position	Academic background	Years of experience
IT Manager (1)	Engineering degree	> 6 years
Ph.D. Engineer (1)	Engineering and Ph.D. degree	10 years
Operation General Manager (1)	Engineering degree	10 years
Supply chain professor (1)	Engineering and Ph.D. degree	10 years
Professors in Operations management (1)	Ph.D. degree with SCM certificates	> 6 years

Supplier selection criteria: related works and data collection

Roodhooft and Konings (1997) conducted a literature review on the problem of supplier evaluation and selection, analysing 74 articles published between 1966 and 1990. The study found that the criteria identified by Dickson were still widely used in most of the articles (Wilson, 1994), though their relative importance may have changed over time due to changes in the industry and other factors. Building on this work, this study has considered the primary performance criteria for supplier evaluation and selection. These criteria, including cost, quality, delivery, technical requirements, service performance, and manufacturing capability, have been categorized to suit many different industries. This classification aims to help researchers and practitioners better understand and apply these criteria in their work. It may be beneficial to consider additional or updated criteria in addition to those identified by Dickson, as the relative importance of each criterion may change over time due to changing industry dynamics and other factors. This could help to ensure that the supplier evaluation and selection process is comprehensive and relevant to current circumstances. Possible areas for new criteria could include digitalization, sustainability, and resilience, among others. These areas may be particularly relevant in the context of the VUCA world, as they can help to ensure that suppliers are equipped to meet evolving technological and environmental challenges.

Supplier's sustainability

Supply chain sustainability is driven by current challenges (Hofmann et al., 2014). As a result, it is vital to develop an efficient and robust supply chain capable of facing any disturbance and providing the same sustainability in the case of disruption (Amindoust, 2018). Numerous researchers have extensively explored the field of sustainable supplier selection (Dang et al., 2022; Giri et al., 2022; Gören, 2018; Rahman et al., 2022; Shang et al., 2022; Tong et al., 2022). For instance, the emergence of the COVID-19 pandemic has had a significant impact on the selection of long-term suppliers, emphasizing the critical need for sustainable supply chains. Researchers such as Shang et al. (2022) have focused on evaluating suppliers based on their adaptability to the COVID-19 epidemic, ensuring sustainable operations and preparedness for future crises. Additionally, Rahman et al. (2022) have proposed a novel fuzzy MULTIMOORA-based method for sustainable supplier selection, aiming to enhance the resilience and sustainability of supply chains. These studies underscore the increasing importance of considering sustainability criteria in supplier selection. Thus, it is critical to analyze and select sustainable suppliers to accomplish sustainable supply chain management. Sustainability may be divided into three categories: environmental, economic, and social. Human rights, education, training, and other social aspects are prioritized (Tavassoli et al., 2020). Compliance with environmental standards, for example, decreasing the use of water and resources, are examples of environmental considerations.

Sustainability criteria are crucial for supplier selection (Shang et al., 2022). It enables minimal environmental impact, improves social responsibility, and satisfies consumer demand for sustainable products and services (Kellner & Utz, 2019). It also assists in avoiding supply chain interruptions. Organizations may increase market share, boost their reputation, and better manage risk by choosing sustainable suppliers. More clearly, organizations may reduce the possibility of supply chain interruptions and maintain their credibility by choosing sustainable suppliers (Menon & Ravi, 2022). They may minimize their negative effects on the environment and show that they are committed to sustainability. Because environmentally friendly suppliers try to decrease their negative effects on the environment by taking steps to cut back on waste, greenhouse gas emissions, and natural resource consumption (Bakeshlou et al., 2017; Wren, 2022). Moreover, legal and moral labor standards, respect for human rights, and advancement of diversity and inclusion are all priorities for sustainable suppliers (Castaldi et al., 2023). As a result, organizations may satisfy consumer demand for goods and services that are socially and environmentally conscious.

Considering all aspects of sustainability necessitates decision-makers exploring a wide variety of economic, social, and environmental performance evaluation criteria throughout a single planning horizon (Jain & Singh, 2020). More clearly, Environmental competencies involve information for successful environmental management. It is the capacity to define environmental standards and green characteristics (Albino et al., 2009). In addition, social competencies are the capacity of a supplier to maintain standards that encourage justice, respect for policies, and individual rights (Jain & Singh, 2020). Furthermore, economic competencies are supplier's capability to satisfy company objectives in today's competitive market. Table 2 summarizes the supplier selection sustainability criteria.

Table 2 Supplier selection Sustainability criteria

Criteria	Subcriteria	Source
Sustainability	Environmental competencies Social competencies Economic competencies	(Amindoust, 2018; Jain & Singh, 2020; Kellner & Utz, 2019; Wren, 2022)

Supplier's digitalization capability

Several organizations must improve their products to take advantage of technology developments and transition to a greater scale of digitalization. More clearly, information and communication technology advancements provide enormous prospects for supply chain intelligence and autonomy, laying the groundwork for digital supply chains (Ghadimi et al., 2019). In other words, the term "digital SCM" refers to the use of industry 4.0 tools in all SCM processes (Ivanov et al., 2018), including product recycling, workplace management, packaging transportation, on-site logistics, and supplier selection. In this regard, the same features of Industry 4.0, which are primarily intended for manufacturing applications, can be applied across the entire value chain thanks to the dynamic, autonomous, and distributed environments included in SCs (Ghadimi et al., 2019). In other words, digitalization improves the end-to-end value chain through the quick development of digital technologies (Ageron et al., 2020yüközkan and Göçer, 2018). These digital technologies are designed to provide process industrial organizations with integrated sources of innovativeness. These solutions, which take advantage of enhanced operational data openness and enhance human skills, boost production efficiency, enhance worker safety, and lessen environmental effects and life-cycle costs (Kamalaldin et al., 2021).

Therefore, numerous organizations have been driven into uncertain collaborations with suppliers outside their traditional supplier base or with organizations working on a technically problematic project (Pazirandeh Arvidsson and Melander, 2020). Thus, finding the best supplier(s) quickly and thoroughly is one of the major responsibilities of a real-time system. While few researchers have explored the integration of digitalization criteria in supplier selection, some studies have utilized digital technologies to enhance the selection process. For instance, Mohammed et al. (2022) proposed a comprehensive framework that incorporates digitalization, economic, green, and resilient supplier selection criteria. This framework was evaluated through multi-attribute decision-making algorithms and a multi-objective optimization approach. Similarly, Cavalcante (2019) proposed an approach using hybrid machine learning and simulation to create digital twins for suppliers, leveraging data-driven decision support systems to enhance resilience in supplier selection. Another study by Mahmoudi et al., (2022) aims to consider the (L-A-D) capabilities of construction suppliers, which encompass localization, agility, and digitalization aspects. These examples highlight the growing recognition of the significance of digital technologies in supplier selection, offering innovative approaches to improve decision-making processes in the context of modern supply chain management.

In this regard, digitalization criteria are crucial for supplier selection (Zekhnini et al., 2021b, c). Because it affords suppliers to offer their clients competitive advantages via innovative and productive solutions, Additionally, it improves supply chain management procedures, provides insightful data analytics, aids businesses in minimizing risks, and gets them ready for upcoming technological advancements. In general, considering digitalization factors when choosing suppliers can offer businesses several advantages, including improved efficiency, and better risk management. In other words, by sending real-time data to all elements of the supply chain, digital technologies facilitate adaptive decision-making (Dubey et al., 2019). They will also increase supplier selection agility, automated interoperability, performance, and cost savings (Alcácer & Cruz-Machado, 2019). Moreover, for decades, the industry has prioritized profitability, resource efficiency, and responsiveness. As a result, new economic forces necessitate a greater level of innovation, security, technological skill, and participation capability (Isaksson et al., 2018). As a result, while selecting suppliers, such criteria should be considered. Table 3 summarizes the supplier selection digitalization criteria.

Suppliers' resilience

Technical, man-made, or natural risks are becoming increasingly common. Such occurrences cause supply chain challenges that are detrimental to enterprises (Amindoust, 2018). Thus, it is critical to implement supply chain resilience approaches to protect customers against disruptions and shortages (Dubey et al., 2019; Hosseini & Ivanov, 2020). Particularly, supplier selection is a complex problem encountered in supply chain management (Durach et al., 2020). In fact, the current selection procedure incorporates different aspects and competing criteria such as primary ones (e.g., cost, lead time, and quality) to ensure an effective supply of materials along the supply chain (Hosseini & Barker, 2016). Material flows in current supply chains can be affected by many disruption events that might have a big commercial impact (Sawik, 2013). Given the aforementioned reasons, selecting appropriate and resilient suppliers can help decrease purchasing costs and delay times and can improve the capacity for business stability in case of disruptions (Azadeh et al., 2017). So, resilience must be addressed in the supplier selection (Amindoust, 2018). In other words, resilience, or the system's adaptive ability to adjust to perturbations (Ivanov, 2020; Ivanov & Dolgui, 2020b), is a key feature of any supply chain (Wang et al., 2017). In other words, selecting resilient suppliers may be a critical strategic choice in the context of supply chain disruption management (Hosseini et al., 2019a). Especially, the idea of supplier resilience has just recently developed.

Due to the unpredictable and evolving nature of the world, several organizations place a strong emphasis on resilience in order to deal with the uncertain economy in general (Sonar et al., 2022). Thus, to survive enough against disruptions, a resilient supply chain must be designed (Mohammed et al., 2022). In this regard, a resilient supplier has to supply good quality items at economic costs and is flexible enough to meet demand changes with shorter lead times over a reduced ambiance of risk without sacrificing safety and environmental norms (Sonar et al., 2022). Moreover, it has the capacity to handle risk and contingencies better than rivals (Wang et al., 2017). So, when selecting a resilient supplier, resiliency must be prioritized alongside normal supplier selection criteria. In this regard, some authors have studied the supplier selection issue considering resiliency. Azadeh et al. (2017) used resilience engineering in supply chain management to determine a suitable set of suppliers as a novel idea that could regulate probable disruptions. Sawik (2013) presents a new mathematical programming technique for selecting a robust supplier portfolio in a supply chain with interruption risks.

To resist disruption, a resilient supplier is essential in the sourcing choice process while functioning under industry 4.0 principles. A resilient supplier often has a strong adaptive capability to decrease vulnerability to interruptions, absorb catastrophe effects, and swiftly recover from disruption to guarantee the appropriate degree of operational continuity following a disaster (Hasan, 2020). In addition, With the growing use of IoT, cyber-physical systems, and information technology, emphasis has shifted to the supplier's performance and capacity to adapt to changing consumer demand with agility, warehouse automation, logistics system digitalization, information management, and IT security, among other things. Relevant data from these domains is typically gathered in multiple forms at high velocity and in great volume, resulting in Big Data, which is frequently available as real-time and historical data. Real-time data is defined by time series, but historical data is frequently displayed in graphical style (Hasan, 2020). In this regard,

Table 3 Supplier selection digitalization criteria

Criteria	Sub-criteria	References
Digitalization	Participation	(Amindoust, 2018; Güneri et al., 2011; Guneri & Kuzu, 2009)
	Innovation	(Rajesh & Ravi, 2015)
	Security	(Amindoust, 2018; Rajesh & Ravi, 2015)
	Technological capability	(Dubey et al., 2019; Rajesh & Ravi, 2015)

Table 4 Supplier Selection Resilience criteria

Criteria	Sub-criteria	Source
Resilience	Ambidextry	(Dunlap et al., 2016; Eltantawy, 2016; Raisch et al., 2009)
	Vulnerability	(Guneri & Kuzu, 2009; Rajesh & Ravi, 2015)
	Collaboration	(Rajesh & Ravi, 2015)
	Risk awareness	(Guneri & Kuzu, 2009; Rajesh & Ravi, 2015)

the technical progress in SC4.0 necessitates ambidextrous thinking in order to access new markets or improve existing lines of product. For example, digital exploitation and integration have an influence on company operations, commodities, and supply chains. Recent research recognises ambidextrous organizations as capable of utilizing existing competencies while exploring new business opportunities in this context (Raisch et al., 2009). More intrinsic key measures, such as organizational crisis resistance and business reputation, are strongly related to ambidexterity. Ambidextrous supply chains may manage alignment and adaptability simultaneously, resulting in long-term competitive advantages. As a result, considering ambidexterity in supply chains will result in improved performance (Raisch et al., 2009). Furthermore, suppliers would be the least susceptible to disruptions. They should also be more aware of potential threats and well-prepared to deal with them (Rajesh & Ravi, 2015). Furthermore, working with suppliers jointly minimizes the risks involved with forecasting and inventory management (Cousins et al., 2005). Table 4 summarizes the supplier selection resiliency criteria.

Supplier viability

In addition to selecting resilient suppliers, it is essential to have a commitment to sustainability goals (Mahmoudi et al., 2022b). In this context, the literature states the links between resilience and sustainability. In other words, resilience is a vital component for sustainability, and resilience management is critical for properly dealing with sustainability (Mohammed et al., 2022). Also, sustainable measures aid in the recovery from a major disruption. Hence, integrating sustainability and resilience in supply networks can enhance supply chain resiliency while reducing uncertainty and improving sustainability (Ivanov, 2018). Add to this, it's noteworthy that a portion of the research opted to combine digital supply chain methods with resilient, sustainable, and/or green tactics.

Therefore, using viability criteria in terms of digitalization, sustainability, and resilience for supplier selection is crucial because it ensures that suppliers can not only meet the company's immediate needs but also provide long-term value and support (Rostami et al., 2023). When it comes to digitalization, selecting suppliers that have invested in digital capabilities ensures that they can provide innovative solutions that improve efficiency, reduce costs, and enhance the customer experience (Mohammed et al., 2022). However, it is also important to consider their long-term viability in terms of digitalization, as technology and innovation are continuously evolving. Similarly, when considering sustainability criteria in supplier selection, assessing a supplier's long-term viability is essential to ensure that they can maintain their sustainability practices and continue to reduce their environmental impact in the long run (Menon & Ravi, 2022). This will not only benefit the environment but also ensure that the supplier can maintain their commitment to sustainability, which is increasingly becoming a critical aspect of business operations. Finally, resilience criteria in supplier selection help to ensure that suppliers can not only provide products and services during times of disruption but also that they can recover quickly from any potential disruptions in the long run (Chaouni Benabdellah et al., 2022). This is especially important in today's fast-paced and unpredictable business environment, where supply chain disruptions can have severe consequences for a company's operations and reputation standards, ensuring that companies can meet their legal and ethical obligations (Zekhnini et al., 2021b, c).

Table 5 Supplier selection viability criteria

Criteria	Sub-criteria	Source
Viability	Primary performance	(Deshmukh & Chaudhari, 2011; Weber et al., 1991)
	Sustainability	(Amindoust, 2018; Jain & Singh, 2020)
	Digitalization	(Dubey et al., 2019; Rajesh & Ravi, 2015; Zekhnini et al., 2020b)
	Resilience	(Amindoust, 2018; Hosseini, Morshedlou et al., 2019b; Wissuwa et al., 2022)

To sum up, using viability criteria in supplier selection helps companies build resilient, sustainable, and digitally enabled supply chains that can adapt to changing business environments and deliver long-term value (Rostami et al., 2023). Table 5 summarizes the supplier selection viability criteria.

Data-driven multi-agent system approach for viable supplier selection

The core emphasis of the proposed approach lies in its data-driven nature, where the integration of big data analytics and the utilization of a MAS creates a powerful platform for supplier selection. By adopting a data-driven strategy, the approach transcends the limitations of traditional

Multi-Criteria Decision-Making methods, enabling decision-makers to access real-time and diverse data from various sources. In this context, the MAS acts as a network of intelligent agents, each possessing unique capabilities and knowledge. These agents collaborate and share information to collectively evaluate suppliers' performance considering viability criteria. The utilization of big data analytics enhances the decision-making process by providing valuable insights from vast and continuously evolving datasets.

Leveraging multi-agent systems and big data analytics can provide significant benefits for supplier selection viability. In fact, it can facilitate real-time monitoring and analysis of supplier performance, which can help organizations respond quickly to changes in the supply chain environment. This can enable organizations to proactively manage supply chain disruptions and improve overall supply chain resilience. Besides, this can lead to more accurate and informed decision-making in supplier selection, as well as a better understanding of the impact of individual suppliers on the overall supply chain. In addition, the use of big data analytics can enable a more proactive and data-driven approach to supplier management, which can lead to improved supplier relationships, increased efficiency, and reduced costs. As a result, the data-driven approach with multi-agent systems and big data analytics can help organizations adapt to VUCA environments by selecting the most viable suppliers based on objective data analysis.

To do so, this section describes the proposed MAS based big data analytics approach for intelligent viable supplier selection which incorporates four layers: decision making system layer, supplier selection layer, data resources layer, and big data analytics layer. Figure 3 illustrates the architecture of the viable supplier selection decision-making system. In the following subsections, each of the developed layers is explained.

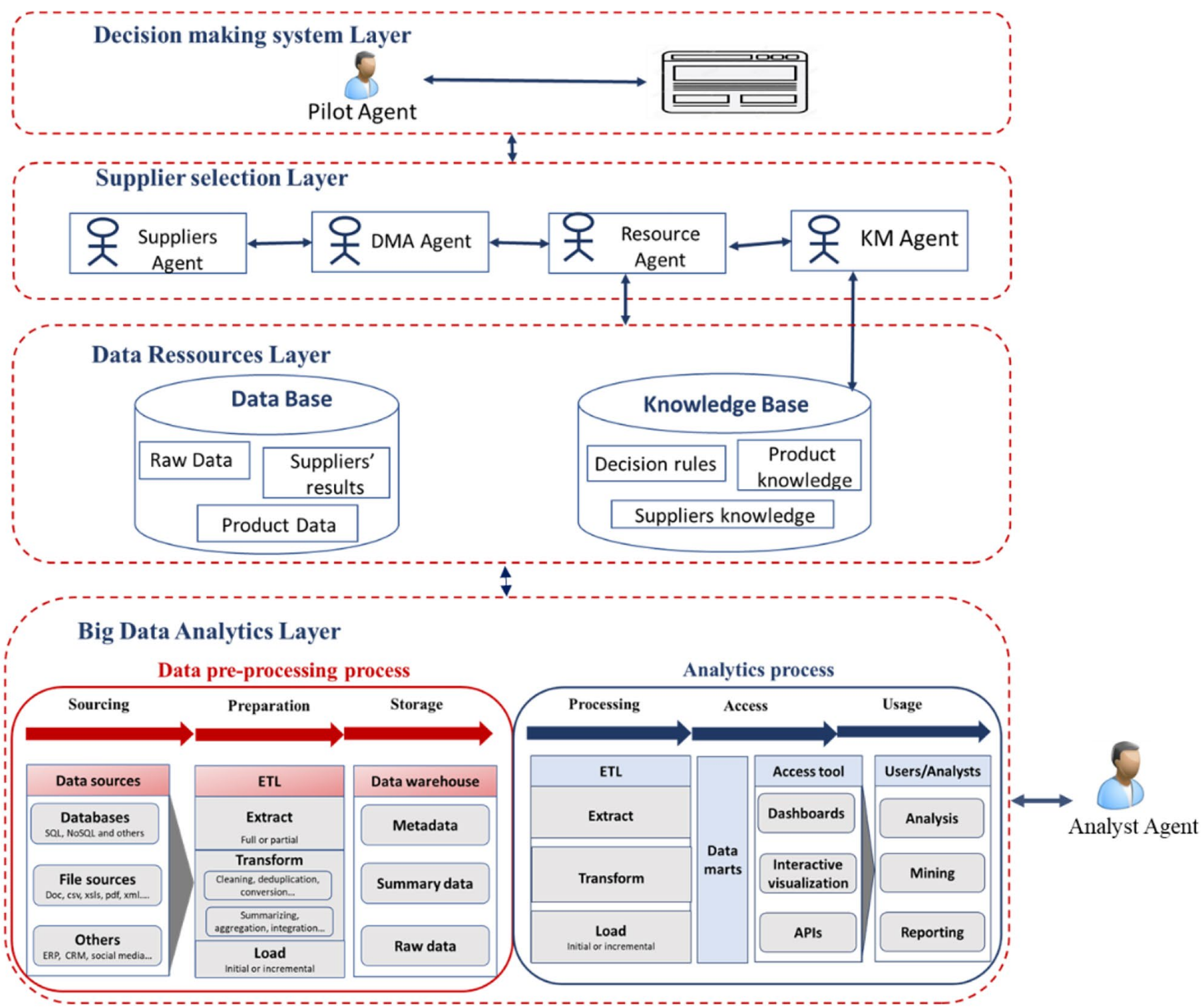

Fig. 3 The viable supplier selection data-driven MAS architecture

Decision-making system layer

This layer consists of software that assists suppliers and organization's pilot agent in adding or updating required data for the assessment, visualization of the dashboards, and suppliers' selection process reports. An agent in the proposed MAS can carry out agent-user communication. In this context, during the analysis phase, agents with any form of contact with users should be recognized and represented by an actor element in the agent diagram. The supplier agent (SA) requires an agent-user graphical interface in this layer. Thus, the decision-making interface is accessible by a human user, the pilot agent (PA), who is responsible for gathering and entering the necessary information relating to the defined sets of specified criteria regarding the viability capability. The decision-making agent's (DMA) internal behavior is guided by a thoroughly established viable supplier evaluation model (Fig. 4). The evaluation of suppliers is conducted through a designated decision-making system that employs a specific fuzzy inference system (FIS) model. The performance of each supplier is assessed using the defined evaluation criteria and sub-criteria. It is important to note that the FIS is just one concrete example of a decision-making system used in the evaluation process. Other decision-making systems can be utilized for supplier evaluation based on the same criteria and sub-criteria. More clearly, the description of the proposed model is presented in two stages.

The Fuzzy inference model uses fuzzy logic to analyze and evaluate different dimensions of viability, including digitalization, resilience, and sustainability, which are increasingly important in today's business environment. By using separate FIS engines for each dimension, the model can provide a more detailed and accurate assessment of each criterion, allowing for a more comprehensive evaluation of supplier viability. In addition, the FIS model is based on a set of rules that define the relationships between different criteria. The rules are derived from expert knowledge and data analysis and are used to develop a set of membership functions that can be used to represent the uncertainty and imprecision inherent in the data. In the final phase of the supplier evaluation process, each supplier will receive a score based on the results generated by the fuzzy inference system (FIS) model, which utilizes big data analytics. This score will be used to rank all potential suppliers based on their viability.

By using fuzzy logic to model this uncertainty, the model can provide more robust and accurate results that are less susceptible to errors and biases. The main advantage of using the FIS model is its flexibility and adaptability in evaluating supplier viability. It allows for a data-driven approach that can adjust to dynamic and uncertain environments, ensuring the identification of the most viable suppliers for the supply chain. In fact, by integrating big data from various sources, the FIS can effectively evaluate supplier viability and make data-driven decisions. While big data analytics can provide additional advantages in terms of real-time analysis and scalability, the FIS can still be a valuable tool for supplier selection with the integration of relevant data from different sources.

Data resources layer

This layer incorporates a database to store input data related to criteria evaluation, product data, and supplier

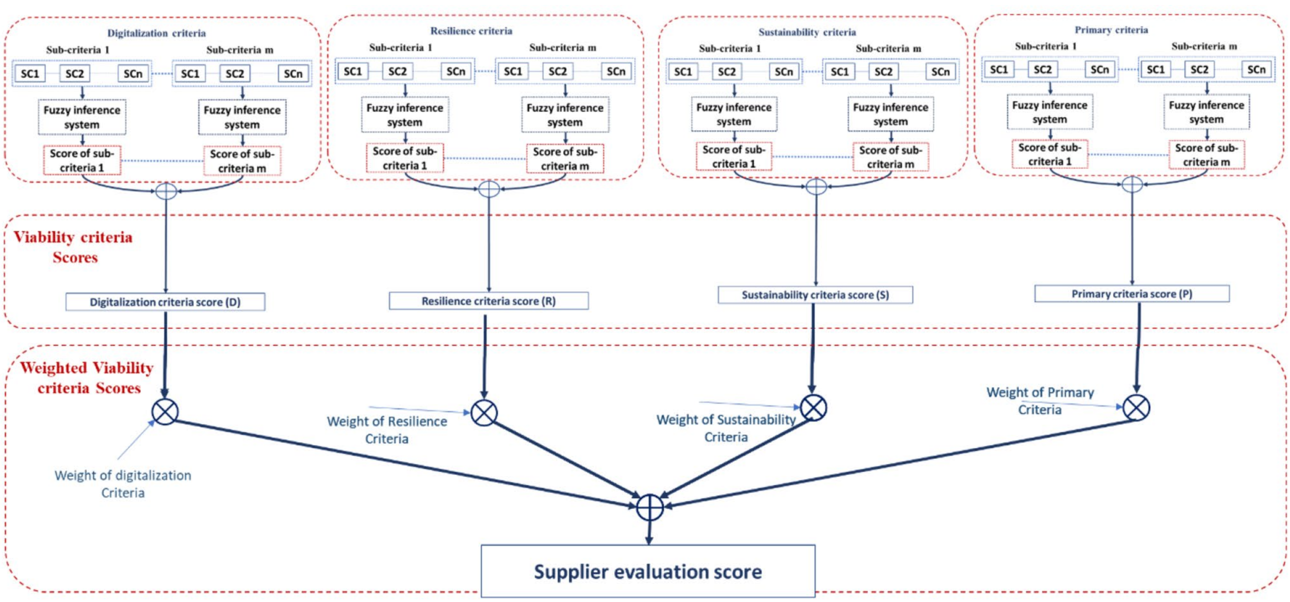

Fig. 4 Supplier performance evaluation model

performance data. It also includes a knowledge base that stores supplier and product knowledge, helping to ensure a standardized evaluation process. By using a database and knowledge base, the evaluation process can be enhanced in terms of both accuracy and efficiency. These tools enable a more systematic and data-driven approach to supplier evaluation, allowing for a more comprehensive and detailed analysis of supplier performance. This can provide valuable insights that can be used to identify areas for improvement and inform decision-making in supplier selection. Ultimately, incorporating these tools can contribute to improving overall supply chain viability by ensuring that the right suppliers are selected for the right reasons and that they are able to meet the organization's needs in a sustainable and resilient manner.

Supplier selection layer

This layer communicates with the other two layers to retrieve the necessary data and knowledge to promote the viable supplier evaluation process. In fact, the proposed MAS is constituted of agents who represent different roles and parties involved in the selection process. In this context, there are six types of agents designed to represent different functions of the intelligent viable supplier selection approach, namely Suppliers agent (SA), Decision Maker Agent (DMA), Resource Agent (RA), Knowledge Management Agent (KMA), Pilot Agent (PA) and Analyst Agent (AA). The Agents involved in the supplier's selection phase are the PA, SA, DMA, RA, and KM. The functionalities and responsibilities of these agents are specified in the analysis phase, as taught by (Nikraz et al., 2006), and are summarized in Table 6. This responsibility is then used to define the behavior of the agents (s). More clearly, agent behaviour refers to the real work that an agent needs to execute inside.

Table 6 The agents responsabilities

Agent	Responsabilities
AA	Analyzes supplier selection data through the big data analytics process; Stores raw data in DB; Stores processed data into database and Knowledge base.
PA	Initiates the evaluation; Send the supplier evaluation request to DMA; Requests the supplier evaluation related data from the SA and sends the requested data to DMA; Receives the supplier evaluation results from DMA; Sends the evaluation results to SAs; Visualizes results.
SA	Obtains the required data for viable supplier selection from the database; Sends the viability criteria input data to the PA; Receives the viability criteria input data and sends it to RA; Requests the DMA about the evaluation results; Receives the suppliers' results from DMA.
RA	Stores the treated data from the AA; Receives the evaluation data from SA; Saves the received data in DB; Informs the SA of successful save of data; Receives the request of supplier evaluation input data from the DMA and sends it to DMA; Receives suppliers results from DMA and saves them in the database.
DMA	Receives the evaluation request from PA; Requests the evaluation data from RA; Receives the evaluation data from RA; Requests decision rules from KMA; Receives decision rules from KMA; Evaluates the suppliers by the proposed FIS algorithm; Informs the evaluation results to the RA; Inform the evaluation results to the involved SAs.
KMA	Receives the supplier knowledge request from the DMA, and informs the result to the RA; Receives the decision rules request from the DMA, and informs the decision rules to the RA;

The registered agents' communication and external connection behaviors are facilitated by specifications and interaction protocols (IPs). The sender and receiver will encrypt and decode each message's content. The supplier selection MAS manages the interactions of agents who assist with the supplier selection process. Its purpose is to identify several competent and competitive applicant providers. Through interaction protocols, which are communication patterns consisting of two or more agents, FIPA allows typical kinds of inter-agent exchanges. These protocols range in complexity from simple query and request protocols to more complicated ones. A conventional communication structure for direct communication protocol is presented in the FIPA agent platform reference model. The agent platform is a critical component of an environment in FIPA. An agent platform contains a "run-time environment" that specifies the agent system's life cycle. The agent platform is comprised of three components: (1) a directory facilitator operating as a Yellow Pages facility for agents to promote and explore service offerings, (2) an agent management system that allows agents to log on to the platform and pinpoint each other and control mechanisms resource usage, and (3) a message transport system, that is a communication service for local and inter-platform message exchange. Message transport protocols and message transport envelopes are defined by the message transport system (Weyns et al., 2005). The additional FIPA requirements cover many areas, including agent-software integration, ontology service agent security, agent mobility, and human-agent communication (Weyns et al., 2005).

In order to handle MAS interactions, FIPA Semantic Language (SL), a human-readable content language, might be used. An interaction table is constructed during this stage of MAS design by mapping each agent's stated functions. After determining the interaction of different agents, The FIPA interaction Protocol may be used to implement the conceptualized scheme on the JADE platform. Figure 5 illustrates the protocol's sequence diagram.

Big Data Analytics Layer

Big data, or data-intensive technology, is a thriving field in research and industry. Big data is vital in every aspect of human activity enabled by the technology advancement.

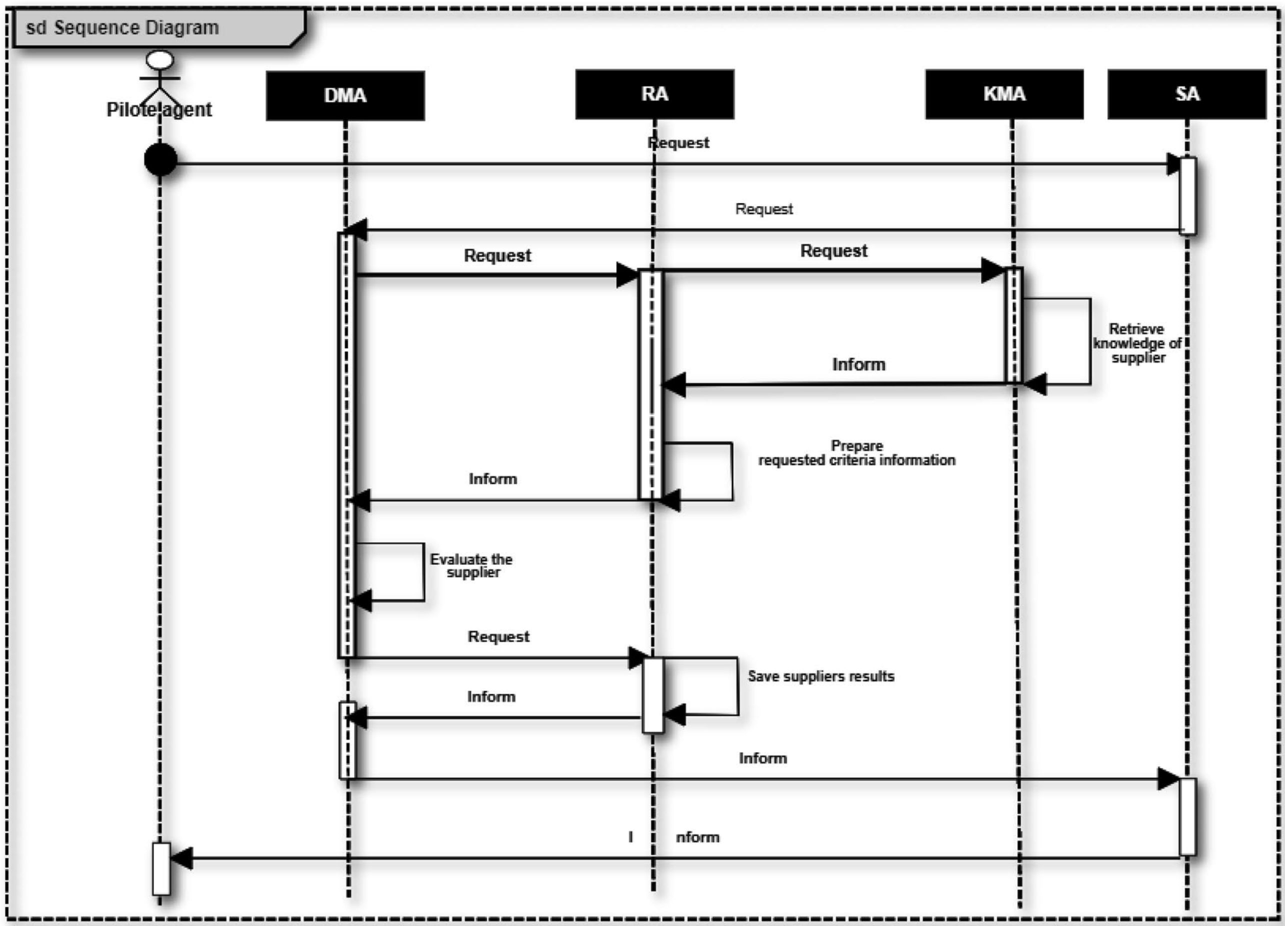

Fig. 5 The viable supplier selection protocol

In other words, Big data technologies are designed to process high-volume, high-variety, and high-velocity data sets in order to extract the needed data value (Zekhnini et al., 2020a). Thus, the process of analyzing or evaluating huge data sets comprising a range of data kinds, such as semi-structured, structured, or unstructured data that can be streamed or batch-processed refers to big data analytics. So, by using sophisticated analysis tools, big data analytics enables improved decision-making, the discovery of new business possibilities, the improvement of performance, and the reduction of costs (Glake et al., 2021). For this reason, we used big data analytics to obtain relevant information concerning viable supplier selection from collected data by employing efficient techniques to analyze and display the data. In this context, this layer aims to prepare relevant information concerning suppliers' selection from collected data and analyze and display the data. More clearly, this layer plays a critical role in supplier selection by helping organizations to make informed decisions based on a comprehensive understanding of supplier performance and enabling the provision of many types of information, including basic, dashboard, APIs, and data science output. All this information addresses the viable supplier's selection issue. Therefore, by leveraging advanced analytics and visualization tools, this layer helps to ensure that the supplier selection process is efficient, effective, and data driven. It presents an overview of a suppliers' general information required for the intelligent viable selection, with two blocks: data pre-processing and Analytic process. Those blocks are divided into six steps namely sourcing, preparation, storage, processing, access, and utilization. Depending on the analytics requirements, this layer enables key elements for each step:

- **Data sourcing process.** It includes all tasks required to get data from the organization's data sources. Databases (SQL, NoSQL, and others), file sources (Doc, CSV, XSLS, pdf, XML,…), and others such as ERP systems, CRM systems or financial applications, operational systems, and social media are examples of data sources. More clearly, this phase consists of identifying the source data required to address the supplier selection issue. This is an important step because data is the backbone of any analysis. All sources of data that may be of interest must be highlighted. In fact, it is better to have many data. Then, the analytical model will select the relevant ones. In other words, the data set may be available internally or externally to the organization. Thus, it is necessary to determine if the data is sufficient to perform the intended analysis. If the available data is insufficient, new data must be obtained or existing data must be transformed.

- **Data preparation.** It includes all tasks performed to prepare data before storing it. In fact, the collected data from diverse sources may be incorrect, inaccurate, or inconsistent, and so have no substantial value to the analysis issue. As a result, the data must be preprocessed before being used for analysis in order to acquire the essential insight from the gathered data. Besides, the collected data may be in a format that is incompatible with big data analysis. As a result, the data must be collected and transformed into a format that the big data layer can use to extract the needed insight from the data. For this reason, data from several sources is delivered to a single staging location where ETL (Extract, Transform, and Load) is handled. Data is extracted from the data source first in ETL. It is then cleaned and transformed to meet the needs of the analysis before being loaded in a pre-defined format into data warehouses for analysis. In other words, the ETL component aims to standardize, clean, and enhance the data, remove redundancy, and do any necessary conversions or data migrations before loading it into an appropriate database. In addition, it incorporates quality verification to ensure that the system's data is of good quality. It is responsible of incorporating cross-database verification to find anomalies.
- **Data storage**: Throughout this phase, all data is saved in a certain format and form based on the storage approach. The data warehouse centrally stores data according to a predefined structure. The data warehouse is where the system keeps the data once it has been cleaned and organized by the system. It is, often known as an Enterprise Data Warehouse, is a repository for data collected by various organizations and corporate businesses. It is the primary repository where metadata, summary data, and raw data from each source are stored. In other words, Metadata is information that defines data. It aims to make working with data objects easier. It enables data analysts to categorize, find, and guide queries to the appropriate data. In addition, the warehouse manager generates summary data. It is updated as fresh data in the warehouse. This component may comprise data that has been moderately or extensively summarized. Its aim is to improve query performance. Furthermore, raw data refers to data that has not been processed when it is loaded into the repository. Having the data in its raw form allows it to be processed and analyzed further.
- **Data processing**: It includes various operations to alter data for meeting the supplier's selection issue. In fact, data warehouses examine data in batches. However, Data in data lakes may be evaluated in batches as well as in streams for real-time processing (so-called Lambda architecture). In this phase, Data from the data warehouse is extracted, transformed, and loaded into data marts in order to handle data from a certain domain. Data is studied in a data lake in a decentralized way, with numerous computer nodes processing data simultaneously. The preprocessed and converted data will be used to estimate an analytical model, to meet the studied aim, when we go on to the analytics stage.
- **Data access**: It enables access to data in numerous forms, depending on the analytical needs. Self-service analytics tools, pre-defined tools or dashboards, or customized facilities for data science resource development, or data visualization can all be used. In particular, the whole analysis life cycle is worthless without data visualization tools and procedures since the analysis outcomes can only be comprehended by analysts. Thus, the results will be examined and assessed after they have been acquired. The outcomes of analytics may include clusters, rules, patterns, or linkages, and will all be referred to as analytical models. Trivial patterns discovered by the analytical model are noteworthy since they serve to verify the model. The core problem is to uncover the unknown relevant and useful patterns that can bring novel insights into the data, which can be source of a new growth value. Some of the big data analytics techniques are quantitative analysis, qualitative analysis, and statistical analysis.
- **Data usage**: Data is widely used for a variety of objectives. We differentiate between reporting, ad hoc analysis, development, production, and real-time insights. Once the analytical model has been evaluated and verified, it may be deployed as an analytics application (decision support system, scoring engine). Important considerations, in this case, are how to present the model output in a user-friendly manner, how to integrate it with other applications (e.g., marketing campaign management tools, risk engines), and how to ensure that the analytical model can be appropriately surveilled and backtested on an ongoing basis. Data can be examined, displayed, and checked for violations of constraints and intended behavior. The findings can then be saved in the databases as input for data analysis, data mining, or reporting. All processing techniques may be operated in either real-time or batch mode.

As a result, the proposed data-driven multi-agent approach can improve supplier selection in a data-driven environment. It combines the benefits of big data analytics and multi-agent systems to achieve data-driven objectives. By collecting, analyzing, and displaying relevant data, this approach enables the selection of viable suppliers based on multiple viability dimensions such as digitalization, sustainability, and resilience. The big data analytics layer prepares and analyzes data, while the multi-agent system manages the supplier selection process and makes data-driven decisions. Therefore, using this combined approach can enhance the accuracy and efficiency of the supplier selection process. In fact, the system stores relevant data in a database, including supplier performance, product data, and viability evaluation performance scores. It also capitalizes on supplier and product knowledge through an ontology and decision rules.

Theoretical and practical implications

The theoretical implications of this study lie in the advancement of the understanding of viable-oriented supplier selection in the context of digital supply chains. This study contributes to the existing body of knowledge on supplier selection by proposing a data-driven approach using multi-agent technology and big data analytics to evaluate suppliers based on resilience, digitalization, and sustainability capabilities criteria. The proposed model can be used as a tool to enhance the efficiency and accuracy of the decision-making process. Moreover, this study opens avenues for future research in viable-oriented supplier selection in digital supply chains. Further research can explore the impact of additional viability criteria on supplier selection, such as ethical considerations, social responsibility, and environmental sustainability. Additionally, future studies can extend the proposed multi-agent system to include other decision-making processes in the digital supply chain, such as inventory management and logistics. Moreover, this study can be valuable for scholars and practitioners interested in enhancing the viability of their supply chain operations. The proposed model and criteria can serve as a foundation for further research, and the data-driven approach can provide valuable insights for organizations seeking to improve their supplier selection process.

The practical implications of this study are significant for organizations seeking to enhance their supply chain resilience, sustainability, and digitalization capabilities. By using a data-driven approach with multi-agent systems and big data analytics, organizations can make informed decisions about selecting viable suppliers that are more likely to meet their requirements and contribute to their long-term success. Furthermore, the proposed criteria and model can serve as a guide for organizations to evaluate and improve their supply chain operations, as well as those of their suppliers. This can help organizations identify areas for improvement and implement strategies to enhance their resilience, sustainability, and digitalization capabilities. By doing so, organizations can reduce the risk of disruptions and build a more robust and responsive supply chain, ultimately increasing their competitiveness in the marketplace.

Conclusion

In recent years, organizations have become more aware of the need for resilient supply chains, capable of withstanding and adapting to unexpected disruptions (Mahmoudi et al., 2022a). To achieve this, viable-oriented cooperation in end-to-end supply chains has emerged as a critical feature (Ivanov, 2021a). This approach involves selecting suppliers based on their resilience, digitalization, and sustainability capabilities, which can help reduce risks and disruptions while increasing the competitiveness of the organization (Rostami et al., 2023; Zekhnini et al., 2021b, c). By adopting a viable-oriented supplier selection strategy, organizations can ensure that they have a network of suppliers who are equipped to navigate the challenges of a VUCA environment. Despite the growing importance of viable-oriented supplier selection, there is still a lack of comprehensive research into this area. While there have been many studies on supplier selection, few have considered the viability of suppliers, and none have provided a comprehensive framework for selecting viable suppliers. As a result, there is a significant opportunity for researchers to contribute to this field. By developing a data-driven approach using multi-agent technology and big data analytics, this study can significantly improve the accuracy and efficiency of the decision-making process.

Therefore, this paper proposes a data-driven viable supplier selection approach using a multi-agent system based on big data analytics to achieve viable digital supply chain performance. The use of a data-driven approach with multi-agent systems and big data analytics can significantly enhance the accuracy and efficiency of the decision-making process. The supplier selection process is based on resilience, digitalization, and sustainability capabilities criteria.

The proposed model for data-driven viable supplier selection is a comprehensive system that utilizes multi-agent technology and big data analytics. The model is organized into four main layers: the decision-making system layer, the data resources layer, the supplier selection layer, and the big data analytics layer. To achieve its objectives, the model employs six types of agents, each with a unique set of functions: Suppliers agent, Resource Agent, Knowledge

Management Agent, Pilot Agent, Analyst Agent, and Decision-Making Agent. The Decision-Making Agent uses a well-established and effective supplier evaluation model, which is based on the fuzzy inference system model, to guide the internal decision-making process. The big data analytics layer, which is managed by the Analyst Agent, is a critical component of the model. The Analyst Agent oversees the entire process, which consists of six distinct steps: data sourcing, data preparation, data storage, data processing, data access, and data usage.

The paper concludes that there are opportunities for future research, including improving the viability criteria list and further developing the proposed multi-agent system using big data analytics. In addition, as for future studies, a geographic information system integrated with MAS-based big data analytics can be developed to add a visual representation of the localization of suppliers. This information system can be applied for data mining and big data analytics visual representation. This study provides valuable insights for organizations seeking to enhance their supplier selection process and achieve viable digital supply chain performance.

Authors contribution All authors contributed to the study conception and design. Data collection was performed by Kamar ZEKHNINI. The development of the model was performed by Kamar ZEKHNINI and Abla CHAOUNI BENABDELLAH. The methodology was performed by Anass CHERRAFI. The analysis and discussion were performed by all authors. The first draft of the manuscript was written by Kamar ZEKHNINI and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

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