

A Conceptual Framework for Designing Resilient and Sustainable Supply Chains: Integrating ERP-based Supplier Selection and Dual-use Readiness in the Metal-Automotive Sector

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Abstract

In the face of a rapidly changing geopolitical situation and new developments on the global market, traditional logistics management models based on cost optimization have significant limitations. This article presents a conceptual framework for designing resilient and sustainable supply chains in the metal and automotive sector. The aim of the model is to demonstrate the link between sustainable development goals (i.e. ESG), maintaining high stability and agility of production processes, and strategic security requirements (i.e. dual-use). The proposed solution is based on three pillars: redefining the role of the partner, algorithmizing the selection process using ERP data, and integrating with dual-use production requirements. The model enables the objective evaluation of suppliers and the transformation of dispersed SME production resources into a flexible critical infrastructure capable of supporting the industrial sovereignty of the state in crisis situations. The presented solution is part of the research trend on agile and self-configuring manufacturing systems in the Industry 4.0 and 5.0 paradigm.

Keywords

Supply Chain Resilience, ESG, ERP systems, Dual-use Readiness, Metal and Automotive Sector, Supplier Selection.

Introduction

The increasing volatility of global markets, combined with geopolitical tensions, technological transformation, and large-scale supply chain disruptions, has revealed significant limitations of traditional cost-oriented supply chain management models. Contemporary supply networks require new design principles that integrate sustainability, resilience, and digital decision-support mechanisms (Fan & Stevenson, 2018).

The aim of this paper is to develop a conceptual framework for designing resilient and sustainable supply chains in the metal-automotive sector by integrating ERP-based supplier selection mechanisms with sustainability indicators and dual-use industrial readiness. The proposed

framework seeks to demonstrate how digital data integration, sustainability-oriented supplier evaluation, and strategic production flexibility can jointly contribute to strengthening supply chain resilience and long-term industrial stability. To achieve the main research aim, the study pursues the following objectives:

- To analyze the role of global disruptions and technological transformation in reshaping contemporary supply chains.
- To identify key characteristics of resilient and sustainable supply networks in the context of Industry 4.0 and Industry 5.0 environments.
- To conceptualize the role of the “Sustainable Partner 2.0” model in modern supply chain ecosystems.
- To develop an ERP-based supplier selection mechanism based on the Sustainability and Resilience Index (S&R Index).
- To integrate the concept of dual-use readiness into supply chain design in order to enhance strategic industrial resilience.
- To propose a conceptual framework linking sustainability, digital transparency, operational agility, and strategic production readiness in supply networks.

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Based on the identified research gap and the objectives of the study, the following research questions are formulated:

RQ1: How do contemporary global disruptions influence the design and resilience requirements of supply chains in technologically advanced industries?

RQ2: What characteristics define a sustainable and resilient supplier within modern supply chain networks?

RQ3: How can ERP-based data integration support algorithmic supplier selection using sustainability and resilience indicators?

RQ4: What role can digital transparency and interoperability play in enhancing supply chain resilience?

RQ5: How can the concept of dual-use readiness be incorporated into supply chain design to strengthen strategic industrial resilience?

RQ6: How can sustainability, resilience, and digital decision-support systems be integrated into a coherent conceptual framework for supply chain management?

The proposed research framework integrates three key dimensions that jointly determine the resilience and sustainability of supply chains in technologically advanced industries.

The first dimension refers to the redefinition of supplier roles within supply networks. Traditional supplier relationships are increasingly being replaced by collaborative partnerships characterized by shared responsibility for sustainability, operational stability, and technological interoperability. In this study, this concept is described as the Sustainable Partner 2.0, representing suppliers capable of maintaining high process stability, operational agility, and digital transparency while simultaneously meeting environmental, social, and governance (ESG) requirements.

The second dimension concerns the digitalization of supplier evaluation processes through the use of enterprise resource planning (ERP) systems. Modern ERP platforms provide access to large volumes of operational data that can be used to evaluate suppliers based on multiple criteria. In the proposed framework, supplier selection is supported by the Sustainability and Resilience Index (S&R Index), which combines three categories of indicators:

- engineering indicators reflecting production capabilities and process reliability
- ESG indicators aligned with sustainability reporting standards
- interoperability indicators representing the level of digital integration and cybersecurity readiness.

The S&R Index enables algorithmic matching between original equipment manufacturers (OEMs) and potential suppliers, allowing organizations to prioritize partners that demonstrate higher resilience and sustainability performance.

The third dimension of the framework introduces the concept of dual-use readiness, which refers to the ability of industrial supply networks to rapidly reconfigure production processes in response to strategic or crisis-related demands. In the metal-automotive sector, many manufacturing technologies – such as CNC machining, precision metal processing, and advanced materials engineering – have potential applications in both civilian and defense production. Embedding dual-use readiness within supply chain architecture increases industrial adaptability and contributes to national economic resilience (Schmidt et al., 2023; Liu et al., 2024; Govardhan et al., 2025).

The integration of these three dimensions leads to the formation of an agile adaptive industrial ecosystem characterized by digital transparency, operational flexibility, and sustainability-driven decision making. Such an ecosystem enables supply networks not only to withstand disruptions but also to dynamically adapt to changing economic and geopolitical conditions (Setyadi et al., 2025; Ivanov & Dolgui, 2025).

The proposed framework therefore links sustainability, digitalization, and strategic industrial resilience, providing a foundation for designing next-generation supply chains capable of operating effectively in highly uncertain environments.

The proposed research framework contributes to the existing literature in three main ways.

First, it integrates sustainability and resilience concepts within a unified supply chain design approach. Second, it introduces an ERP-based algorithmic supplier selection mechanism based on the S&R Index. Third, it expands the discussion on supply chain resilience by incorporating the concept of dual-use readiness and strategic industrial adaptability.

By combining these perspectives, the study proposes a novel conceptual approach to supply chain design that addresses both operational efficiency and long-term strategic resilience.

Literature review

Contemporary supply chains operate in an increasingly volatile and unpredictable environment characterized by rapid technological change, geopolitical instability, and large-scale systemic disruptions. In recent years, the complexity and global scope of supply chains have significantly increased, making them more vulnerable to disturbances occurring at different points of the network. Modern supply chains often cover the entire lifecycle of products and involve numerous geographically dispersed actors, which

increases the probability that disruptions occurring in one part of the system propagate across the entire network (Grzybowska & Stachowiak, 2022).

Global disruptions and the vulnerability of supply chains

Recent global developments have highlighted the fragility of existing supply chain structures. Among the most important factors influencing the functioning of modern supply networks are the rapid development of digital technologies associated with Industry 4.0, the global consequences of the COVID-19 pandemic, and significant changes in consumer behavior and sustainability expectations. These phenomena have intensified supply chain volatility and demonstrated the need to rethink traditional supply chain design principles (Grzybowska & Stachowiak, 2022; Vali-Siar & Roghanian, 2022).

Disruptions in supply chains can be defined as events that interrupt material or information flows within the network, often leading to delays, shortages, or even complete interruption of production processes. Even relatively small disturbances affecting a single node or transportation link may propagate through the network and generate cascading effects across multiple actors in the supply chain (Hosseini et al., 2019; Ivanov & Dolgui, 2019; Grzybowska & Stachowiak, 2022).

The growing frequency and scale of disruptions have led to an increasing research focus on supply chain resilience and sustainability. Recent studies emphasize that organizations must develop mechanisms enabling them not only to mitigate disruptions but also to adapt and recover from them while maintaining operational continuity (Ivanov, 2022; Grzybowska & Stachowiak, 2022; Katsaliaki et al., 2022).

Characteristics of supply chain disruptions

Disruptions affecting supply chains can originate from both internal and external sources. External disruptions include natural disasters, pandemics, geopolitical conflicts, cyberattacks, and economic crises, while internal disruptions may arise from operational failures, supplier problems, workforce shortages, or technological issues (Peng et al., 2026; Grzybowska & Stachowiak, 2022; Queiroz et al., 2022).

The literature identifies several key characteristics that determine the impact of disruptions on supply chain performance. These include disruption frequency, duration, severity, and geographic scope. Frequency refers to the time interval between disruption events, whereas duration describes the time period during which the disturbance affects the functioning of the supply chain. Severity refers to the scale of losses caused by the dis-

ruption, while scope reflects the extent to which the disturbance spreads across the network (Manupati et al., 2025; Grzybowska & Stachowiak, 2022).

Understanding these characteristics is essential for designing effective disruption mitigation strategies. The magnitude of supply chain damage is strongly influenced by the duration and scope of the disruption, as longer and more widespread disturbances typically generate more severe operational and economic consequences (Alem Fonseca et al., 2026; Prathapage et al., 2025; Grzybowska & Stachowiak, 2022).

The increasing number of disruptions observed in recent years demonstrates that traditional cost-oriented supply chain management approaches are insufficient in highly uncertain environments. As a result, organizations increasingly seek to develop more resilient supply chain structures capable of absorbing and adapting to disruptions (Dabbous et al., 2025).

Supply chain resilience and sustainability

Supply chain resilience has emerged as a key concept in modern supply chain management research. Resilience refers to the ability of a supply chain to prepare for unexpected events, respond to disruptions, and recover from them while maintaining operational continuity and system functionality (Grzybowska & Stachowiak, 2022).

According to Ponomarov and Holcomb, resilience can be defined as the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them while maintaining continuity of operations Ponomarov & Holcomb (2009).

To increase resilience, organizations employ various strategies such as supplier diversification, emergency inventory buffers, capacity expansion, backup facilities, and increased visibility across supply chain operations. Simulation and optimization models are also used to design more resilient production and distribution networks capable of absorbing disturbances (Ma et al., 2025; Safari et al., 2024; Grzybowska & Stachowiak, 2022).

Recent studies emphasize that resilience should not be considered independently from sustainability. The integration of environmental, social, and economic considerations into supply chain management practices allows organizations to build long-term stability and adaptability while simultaneously meeting growing regulatory and societal expectations (Florez-Jimenez et al., 2025; Reyers et al., 2022).

Organizational agility and resilience

Resilience extends the concept of agility by emphasizing not only responsiveness but also the ability to anticipate, withstand, and recover from disruptive

events. A resilient organization is capable of maintaining operational continuity and achieving long-term development despite adverse environmental conditions (Stachowiak & Pawłyszyn, 2021).

The development of resilience is closely related to the concept of organizational maturity. Maturity models are commonly used to assess the ability of organizations to manage processes, technologies, and organizational structures effectively. These models typically define several stages of development representing increasing levels of organizational capability (Niewiadomski & Stachowiak, 2024a).

In the context of dynamic and uncertain environments, maturity can be interpreted as the gradual development of capabilities enabling organizations to adapt to change. At higher maturity levels, organizations demonstrate not only agility in responding to environmental changes but also resilience in maintaining stability and continuity despite disruptions (Niewiadomski & Stachowiak, 2024b).

Research gap and motivation for the proposed framework

Although the literature extensively addresses supply chain resilience, sustainability, and organizational maturity, existing studies often analyze these concepts separately. Limited research has focused on integrating resilience-oriented supply chain design with digital decision-support mechanisms and strategic industrial readiness.

Moreover, traditional supplier selection approaches remain heavily cost-oriented, frequently neglecting resilience, sustainability, and technological interoperability considerations. This gap becomes particularly visible in industries characterized by high technological complexity and strategic importance, such as the metal-automotive sector.

Therefore, there is a growing need for conceptual frameworks that combine sustainability, resilience, and digital decision-making tools in supplier selection and supply chain design. The framework proposed in this study addresses this research gap by integrating ERP-based supplier evaluation mechanisms with sustainability indicators and dual-use industrial readiness.

Research Methodology

This study adopts a conceptual research approach aimed at developing a theoretical framework for designing resilient and sustainable supply chains in the metal-automotive sector. Conceptual research is particularly appropriate when the objective is to integrate existing theoretical perspectives and propose new models or frameworks that explain complex organizational phenomena.

Research design

The research design combines literature analysis, conceptual synthesis, and framework development. The study draws upon existing research in supply chain resilience, sustainability, digital supply chain management, and organizational maturity models to construct an integrated conceptual model linking ERP-based supplier evaluation mechanisms with dual-use industrial readiness.

The methodological approach follows three main stages:

- Literature-based identification of key theoretical constructs, including supply chain resilience, sustainability, agility, and organizational maturity.
- Conceptual synthesis of the identified constructs, leading to the development of the Sustainable Partner 2.0 concept and the Sustainability and Resilience Index (S&R Index).
- Development of an integrated conceptual framework combining ERP-based supplier selection with dual-use readiness in order to enhance supply chain resilience and sustainability.

Literature review and theoretical synthesis

The first stage of the research involved a review of academic literature addressing supply chain disruptions, resilience, sustainability, and organizational maturity. The analysis focused on identifying key theoretical constructs explaining how supply chains respond to environmental uncertainty and systemic disruptions.

Particular attention was given to research addressing:

- supply chain disruptions and their characteristics
- resilience strategies in global supply networks
- sustainable supply chain management
- digitalization and ERP-based supply chain management.

The literature review enabled the identification of several theoretical gaps. While numerous studies analyze resilience or sustainability independently, relatively limited research integrates these perspectives with digital decision-support mechanisms and strategic industrial readiness. This gap provided the foundation for the development of the proposed conceptual framework.

Conceptual framework development

Based on the theoretical synthesis, a conceptual model of resilient and sustainable supply chain design was developed. The model integrates three complementary dimensions that jointly determine supply chain resilience in technologically advanced industries.

The first dimension concerns the redefinition of supplier roles within supply networks, represented by the

concept of the Sustainable Partner 2.0. This concept expands traditional supplier evaluation approaches by incorporating sustainability, operational stability, agility, and digital transparency.

The second dimension introduces an ERP-based supplier evaluation mechanism, represented by the Sustainability and Resilience Index (S&R Index). The index is designed as a multi-criteria decision-support tool integrating three categories of indicators:

- engineering indicators reflecting technological and production capabilities
- ESG indicators aligned with sustainability reporting standards
- interoperability indicators related to digital integration and cybersecurity readiness.

The third dimension of the framework introduces dual-use readiness, referring to the ability of industrial supply networks to reconfigure production capabilities between civilian and strategic applications in response to crisis situations.

These three dimensions were integrated into a unified conceptual model representing an agile adaptive industrial ecosystem, capable of supporting resilient and sustainable supply chain operations.

Sectoral focus: the metal-automotive industry

The conceptual framework is developed with particular reference to the metal-automotive sector, which represents one of the most complex and globally interconnected industrial supply networks.

Several characteristics make this sector particularly suitable for analyzing resilient supply chain design, including high technological intensity of production processes, extensive multi-tier supplier networks, strong dependence on international supply flows, growing integration of digital manufacturing technologies, potential dual-use applications of manufacturing capabilities (Staniewska, 2025; Rodríguez-González et al., 2022).

Technologies widely used in this sector, such as CNC machining, advanced metal processing, and precision manufacturing, are also applicable in strategic industries, including the defense sector. Consequently, the metal-automotive industry provides a relevant context for exploring the integration of resilience, sustainability, and dual-use readiness in supply chain design (Singh et al., 2023; Eldem et al., 2022).

Results

The current macroeconomic environment is characterized by high volatility and uncertainty, which implies significant systemic risk for global supply chains.

The cost optimization paradigm, which has dominated logistics management to date, shows significant shortcomings in the face of unpredictable supply shocks. Disruptions caused by global epidemiological crises, ongoing armed conflicts, and the ongoing struggle for economic influence (including, for example, the trade and technology war between the United States and China) are forcing a profound reconfiguration of the existing operating models of manufacturing companies. In conditions of intensified external risk, basing supplier selection decisions on the one-dimensional criterion of the lowest unit price generates a strategic threat to the continuity of production processes.

The Proposed Concept

In response to the identified limitations of traditional supply chain management systems, this article proposes an innovative conceptual framework for the metal and automotive sector. The aim of the model is to demonstrate the link between sustainable development goals (i.e. ESG), maintaining high stability and agility of production processes, and strategic security requirements (i.e. dual-use). The proposed solution is based on three pillars: redefining the role of the partner, algorithmizing the selection process using ERP data, and integrating with dual-use production requirements.

The concept of “Sustainable Partner 2.0” – a new approach to the role of a cooperating partner

The central element of the proposed model is a departure from the traditional treatment of suppliers in favor of building a network of so-called “sustainable partners 2.0.” In the existing literature on the subject, sustainable development is often reduced to its pro-environmental dimension (e.g., emissions). The social and economic aspects are often overlooked. In the presented concept, this definition is expanded in response to the market and political instability described above.

Within the proposed model, a sustainable partner 2.0 is defined as an entity demonstrating close synergy between the three pillars of sustainable development, process stability, strategic operational agility, and resilience, based on high digital transparency. Stability over a longer time horizon guarantees repeatability and high quality, e.g., of components, while minimizing resource losses, while agility and resilience enable rapid reconfiguration of production lines in the face of sudden supply disruptions.

In macro terms, it is assumed that, in the event of a crisis, a network of partners defined in this way will evolve from a commercial supply chain into a dis-

persed critical national infrastructure. This infrastructure becomes a prerequisite for maintaining industrial sovereignty and securing the continuity of strategically important supplies in the event of armed conflicts, pandemic threats, or intensifying economic changes in various regions of the world.

Sustainable Partner Selection Mechanism 2.0

In order for the concept of a sustainable partner 2.0 to be implemented in Industry 4.0/5.0 conditions, a selection mechanism based on ERP (Enterprise Resource Planning) system modules has been proposed. It is assumed that despite the diversity of software providers, key production and logistics modules have a similar information architecture. Therefore, instead of relying on the traditional, one-dimensional criterion of the lowest price (which has led to a dangerous dependence of Western industry on Asian suppliers, among others), it is proposed to introduce an algorithmic Sustainability & Resilience Index (S&R Index).

Current research focuses on developing an algorithm and S&R Index that will be calculated in real time using data from three areas: engineering indicators, ESG indicators (compliant with the GRI standard), and interoperability indicators (e.g., the degree of readiness for secure data sharing in the supply chain, the level of cybersecurity).

The algorithm being developed will, in principle, collect and use data from the ERP modules of potential and current partners in real time. By using the S&R Index, the initiating company (OEM) will perform automatic matching, selecting partners that guarantee the highest resilience, minimizing the risk resulting from global geopolitical turmoil.

Dual-Use Readiness Framework

The third pillar of the proposed concept is to build strategic operational agility and resilience into the supply chain, which is a direct response to the observed militarization of economies and deficits in defense sector supply systems. In the metal and automotive industries, technological capabilities (e.g., advanced CNC machining, casting technologies) are of fundamental importance to the defense industry.

In the proposed model, resilience is equated with the concept of Dual-Use Readiness. This means that in the current geopolitical situation, the supply chain should be designed in such a way that algorithmically selected small and medium-sized enterprises (SMEs) with proven digital maturity have the operational capacity to smoothly transfer technology – from the production of civilian products to components of mili-

tary importance (dual-use) – in conditions of extreme threat to national security.

High digital transparency (achieved through the integration of ERP environments) would allow, in the above scenario, for the automated verification of certification and quality standards (e.g., defense standards) at sub-contractors. As a result, the proposed model and concept transform the classic supply chain, which is vulnerable to external shocks, into an adaptive, self-configuring ecosystem capable of actively supporting, for example, a country's defense strategy. The diagram (Fig. 1) below presents the supply chain developed by the authors.

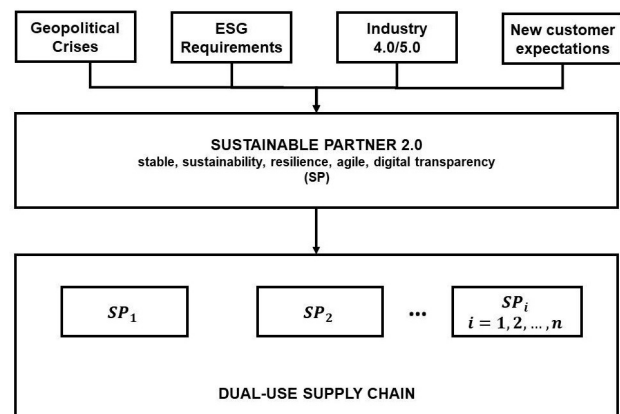


Fig. 1. Elements comprising the supply chain concept

Discussion

The proposed conceptual framework of “Sustainable Partner 2.0” represents a significant extension of existing supply chain management theories, shifting the focus from the paradigm of cost efficiency to that of strategic resilience. Analysis of the proposed model allows us to formulate several key conclusions and identify implementation challenges.

The traditional Lean Management approach, dominant in the metal and automotive industries, sought to eliminate all inventory and excess capacity (Deshmukh et al., 2022). However, in the current geopolitical situation, redundancy and technological flexibility are becoming strategic assets. In this context, the concept of Dual-Use Readiness is no longer just an addition to the production profile, but a new form of business sustainability. Partner 2.0, being able to reconfigure production for defense purposes, for example, minimizes the risk of complete operational downtime in wartime or under sanctions, which gives it an advantage over suppliers specializing exclusively in civilian products.

Currently, sustainability reporting is often based on declarations and descriptions (so-called soft data), which creates the risk of greenwashing. The proposed S&R (Sustainability & Resilience) Index takes this discussion to the level of so-called hard data. The use of indicators such as OEE or process stability to assess a supplier's sustainability allows for objective verification of its real condition. However, the interoperability of data systems remains a challenge. Different data recording standards in ERP systems at small and medium-sized enterprises can be a barrier to the full automation of the S&R Index.

The implementation of the model in the metal and automotive sector faces two main limitations:

- Competency gap: many SMEs still have low digital maturity, which limits their ability to retrieve data from ERP in real time.
- Data security: there is significant concern among suppliers about sharing sensitive operational data with OEMs.

Therefore, the use of trust-enhancing technologies (e.g., blockchain or secure industrial clouds) should be considered, which would allow the S&R Index to be calculated without revealing all of the partners' trade secrets.

The most innovative element of the discussion is the recognition of sustainable supplier networks as part of a country's critical infrastructure. Critical infrastructure is commonly associated with energy or transportation. This model argues that in an era of hybrid conflicts and trade wars, the dispersed production capacity of SMEs (especially in metalworking and automotive technology) has strategic importance. Ensuring the stability of these companies through long-term contracts based on the S&R Index is therefore an action in the interest of national security.

Conclusions

The article provides a theoretical and conceptual response to the growing instability of global supply chains caused by geopolitical and geoeconomic crises. The proposed model proves that in the era of unpredictable "supply shocks," the existing paradigm of cost optimization must be replaced with a model based on strategic resilience and operational agility. The foundation of this change is the redefinition of the role of the cooperator and the introduction of the concept of "Sustainable Partner 2.0."

The key scientific contribution of the article is to demonstrate that process stability and digital transparency, monitored in real time through ERP-class systems, allow for an objective assessment of suppliers.

The proposed S&R (Sustainability & Resilience) Index changes the nature of ESG reporting from declarative to technical, making engineering data (such as performance or quality) an integral part of sustainability assessment. In this approach, the supply chain ceases to be merely a commercial structure and becomes a dispersed critical infrastructure of the state. This is particularly important for companies operating at the intersection of the metal and automotive industries.

Limitations and future research directions

As a conceptual study, the proposed framework focuses on theoretical integration and model development rather than empirical validation. Therefore, the framework should be considered a foundation for future empirical research.

Further studies may involve empirical validation of the proposed S&R Index using ERP datasets, case studies of supply networks implementing Sustainable Partner 2.0 principles, simulation models analyzing the impact of dual-use readiness on supply chain resilience, quantitative analysis of supplier selection using multi-criteria decision-making methods.

Additionally, further research could focus on determining how to balance priorities in S&R indicators and how to potentially offset them (e.g., when a supplier is highly agile but has a low ESG rating). The proposed full integration of ERP systems among manufacturers, which could enable the automatic exchange of operational data, creates new risks that must be minimized. Therefore, further research should include the detailed design of a method that effectively protects users in the context of cybersecurity.

Such empirical investigations would enable verification and refinement of the proposed framework and provide additional insights into the practical implementation of resilient and sustainable supply chain design.

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