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Supply Chain Resilience in the Context of Global Production and Logistics

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Abstract

This paper presents an in-depth review of supply chain resilience in the context of global production and logistics, considering the immediate need for adaptive and robust systems in the growing global scenario of uncertainties. This study aims to investigate the needs and strategy of SCR for global production and logistics. First, 39 articles focusing on SCR in the context of global production and logistics are selected. The articles are then classified according to the resilience strategy proposed by the authors. From the selected works published, the study unravels the key themes, such as definitions of resilience, disruption drivers, integration of digital technologies (e.g. digital twins) and the importance of cybersecurity. The paper further discusses the drawbacks of lean manufacturing, resilience metrics and its industrial applications during momentous events such as COVID-19. The findings demonstrate that although applications of technology, such as AI and predictive analytics, have reinforced the resilience of production planning and control, many issues remain unaddressed in terms of the standardisation of metrics and coordinating sustainability with resilience. The paper presents recommendations endorsing hybrid resilience-efficiency models, cyber-resilience frameworks and multi-industry strategies to enable supply chains to face future disruptions.

Keywords: *supply chain resilience; production planning and control; hybrid resilience-efficiency models; cyber-resilience frameworks; multi-industry strategies.*

1. Introduction

Currently, unstable global conditions following the COVID-19 pandemic and geopolitical uncertainties, such as the Russia–Ukraine conflict and the closure of the Suez Canal, have greatly affect the effectiveness of supply chains [1][2][3]. This instability has caused significant weaknesses in global production and logistics networks, highlighting the need for stronger and more resilient supply chains. In response, the concept of supply chain resilience (SCR) was proposed, emphasising the capability of companies to operate efficiently by absorbing the uncertainties and maintaining customer confidence during crises [4][5]. Accordingly, resilience in production planning and control (PPC) is essential to respond rapidly to unexpected changes in the supply chain. SCR

includes the ability to anticipate, respond and bounce back from interruptions while controlling the manufacturing process [6][7]. These can be achieved by designing adaptable systems, as well as building backup and agile systems for immediate response to unexpected changes in demand or supply. Pawar et al. [8] and Ribeiro and Barbosa-Póvoa [9] proposed resilience models and practices for quantifying the resilience of manufacturing systems. These approaches should be included for effective PPC interventions to avoid delays, stockouts and losses during periods of volatility.

The integration of digital technologies has transformed the practice of applying resilience in modern supply chains. Innovations such as machine learning, artificial intelligence (AI) and digital twins have helped realise data-driven capability for real-time decision-making and proactive management of disruptions [10][11][12]. These technologies enhance production control by leveraging the anticipation of probable risks, resource optimisation and adaptation of production plans based on changes [13][14]. As businesses shift towards Industry 4.0, digital transformation becomes critical to enhance supply chain responsiveness and agility.

Increasing cyber threats and digital dependencies also justify the significance of cyber-resilience in supply chain strategy. Boyes [15] and Khan and Estay [16] asserted that protecting digital infrastructures is essential to ensure supply chain operations. Production planning systems must be secured, especially when combined with external suppliers and global platforms. By the same token, firms are ever more concerned with harmonising resilience with sustainability objectives, motivating them to establish reactive and responsible supply chains [14][17].

Lastly, establishing resilience in PPC must be undertaken holistically and prospectively by adopting advanced technologies, enhancing supply chain transparency, fostering cooperation and embedding risk management in operations, among other strategies [18][19]. Big and small enterprises alike must redesign traditional planning approaches and invest in capacities to adapt and thrive during disruption. An understanding of the shifting dynamics of resilience will allow firms to conceive production systems that are better poised to meet future uncertainties.

2. Methodology

This study adopted a systematic search strategy to ensure a comprehensive review of the literature on SCR in PPC, including keywords and criteria for inclusion and exclusion. The main aim was to provide as much information as possible to obtain a clear picture of the real situation regarding SCR. For the purposes of this study, 39 articles were selected focusing on SCR in the context of global production and logistics. This number was appropriate to give an early overview of SCR. Figure 1 shows the conceptual framework as explained by [20].

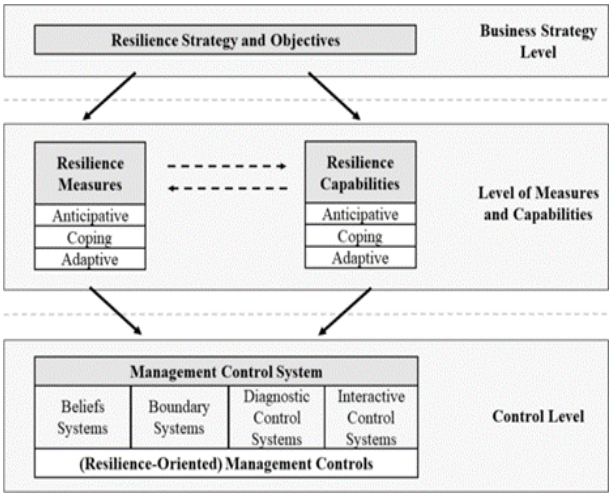

Fig. 1. Conceptual organisational resilience/ management control system framework [20]

2.1 Search Strategy

Information search was conducted in various databases, such as Scopus, Web of Science, ScienceDirect and Google Scholar. These databases were chosen due to their extensive coverage of peer-reviewed articles and conference proceedings related to operations management, logistics and industrial engineering. Boolean operators were used to identify and combine specific keywords and search terms, such as ‘supply chain resilience’, ‘resilient supply chain’, ‘production planning’, ‘production control’, ‘resilience strategies in manufacturing’ and ‘disruption management in supply chains’. Only relevant articles were selected for the study.

2.2 Classification of Articles

The articles were classified according to the research methodology and resilience strategy proposed. This classification provided a clear structure for identifying key themes, understanding the current state of research and recognising gaps or underexplored areas in the literature.

3. Analysis and Discussion

The analysis was based on 39 selected articles from the literature on SCR in the context of PPC. Key themes that emerged include definitions and conceptual frameworks, causes of disruptions, the integration of resilience into planning systems, resilience measures, applications in industry, and gaps in existing knowledge.

3.1 Definitions of Supply Chain Resilience

In today's fluctuating and risky business environment, organisations are increasingly faced with disruptive events, such as pandemics, natural catastrophes, cyber-attacks and geopolitical tensions [19]. These disruptions pose serious challenges for global supply chains, making resilience an issue of extreme priority.

Based on the literature, many authors define SCR as the ability of a system to anticipate, absorb, adapt to and recover from disruptive events [8]. This general definition concludes that foresight, robustness, flexibility and recovery are the essential qualities organisations must cultivate in their supply chains to ensure continuity and competitiveness.

Simply put, SCR is the strategy of planning ahead for unexpected problems through prior design and planning of the supply chain [21]. It is the capacity to adapt quickly to disruptions and retain control over operations. A resilient supply chain not only recovers but comes out even stronger after a disruption, making the business more competitive than others.

3.2. Drivers of Supply Chain Disruptions

Supply chain disruptions are driven by several key factors. Global transportation bottlenecks, particularly in maritime shipping, have a significant impact, as 80% of international trade depends on sea transport [22]. One of the best-known disruptions is the Ever Given case, a gigantic container ship that ran aground and blocked the Suez Canal in March 2021 for six days. This event highlighted the manner in which a single disruption at a chokepoint can lead to extensive ripple effects throughout global supply chains, resulting in delayed deliveries and total losses amounting to USD 88.79 million [2].

Commodity price shocks caused by abrupt increases in the prices of crude oil, natural gas, coal, fertilisers and metals are also major contributors [23]. An example of geopolitical events like Russia's invasion of Ukraine add to these disruptions by increasing the prices of energy and essential goods and causing logistics bottlenecks, especially for countries that rely on Russian energy [1].

Moreover, the COVID-19 pandemic intensified existing supply chain vulnerabilities and created new challenges, particularly through widespread lockdowns and labour shortages. These were especially severe in critical areas in the global logistics network [18]. Consequently, backlogs occurred due to ships waiting longer to dock and unload. These effects spread throughout the supply chain, resulting in inventory shortages, increased shipping costs and interrupted production in various industries.

3.3 Cybersecurity in Supply Chain

Robust cybersecurity measures are necessary due to the increasing cyber threats arising from the digitisation of supply chains [16]. The complex interdependencies in supply chains make them vulnerable to common threats, such as ransomware, phishing and insider attacks. These threats can expose sensitive information and disrupt operations [24]. To overcome these problems, comprehensive cybersecurity frameworks, enhanced inter-organisational cooperation and real-time threat detection systems must be implemented [24]. Global sourcing, diverse legal jurisdictions and reliance on third-party services have further complicated the realisation of supply chain cyber-resilience [15]. Protecting against cyber-physical system attacks requires the integration of cyber and physical security as a holistic approach for cybersecurity. According to Ibiyemi and Olutimehin [24], effectively safeguarding supply chains in the digital age necessitates preventive measures, detection and response strategies and recovery planning. Achieving these goals requires policy and regulatory compliance.

Cyber threats are seen as critical and increasingly damaging sources of disruption in supply chain risks. Cyber attacks have caused disruptions in supply chain operations across industries in several high-profile cases. Among them was the NotPetya malware attack in 2017, which caused over USD 10 billion loss in a single cyber event [24]. Another case was the 2020 SolarWinds Orion breach, which involved a supply chain attack on thousands of organisations, including several U.S. government agencies. The most recent event was the ransomware attack on JBS SA in 2021, which resulted in operational shutdowns across North America and Australia,

highlighting the ability of cyber threats to cause immediate production halts and supply delays.

These cases show the urgent need to incorporate cybersecurity risk assessment for creating SCR.

3.4 Complex Interdependencies

The significant impact of COVID-19 on global supply chains signalled the need for their resilience and flexibility [3]. Complex associations in modern supply chains have caused fatal effects during disruptions in various sectors [25], including transportation disruptions, manufacturing slowdowns, supply-demand imbalances and operational inefficiencies [26]. SCR can be enhanced by focusing on digital-intensive business models, collaborative network designs and sustainability [26]. The risks can be mitigated by employing strategies such as redundancy, flexibility and localisation [3]. Effective decision-making must be able to capture complex interdependencies between supply chain disruptions, mitigation strategies and firm performance [27]. The dependencies and vulnerabilities of the global supply chain can be assessed using network analysis tools [25]. In general, developing more resilient and adaptable supply chains in the future is crucial to overcome unexpected situations such as the COVID-19 pandemic.

3.4.1 Cross-Sector Supply Chain Integration During Crisis

The COVID-19 pandemic not only stressed individual supply chains but also catalysed unprecedented cross-sector collaborations, exemplifying how industries can dynamically reconfigure under extreme pressure. A notable case is the intertwining of the automotive and medical device supply networks to rapidly scale the production of ventilators, a critical medical resource during the height of the crisis. Automotive manufacturers, equipped with robust production systems, advanced logistics networks and precision engineering capabilities, collaborated with medical device firms to meet the surging demand. This emergent partnership showcases the adaptive capacity of supply chains to transcend sectoral boundaries when confronted with urgent societal needs [7].

This case also exemplifies the concept of complex interdependencies, where agility and openness to cross-industry integration became essential features of resilience. Rather than being confined to traditional roles, supply chains displayed fluidity—repurposing tooling lines, reallocating resources and merging knowledge systems in real-time. It also highlights the importance of modular design, interoperable systems and multi-use capabilities in future supply chain planning. For PPC, this case emphasises the need for flexible planning frameworks that allow organisations to shift focus, reprioritise outputs and collaborate across industry boundaries without compromising efficiency or compliance [7].

3.4.2 Corporate Case Studies

A study that examined corporate case studies revealed that the leading firms enhanced their SCR through flexibility, rapid response and proactive planning. Rice and Sheffi [28] examined how giant companies such as Land Rover, Aisin Seiki Co., United Parcel Service (UPS), Dell, Baxter International, DHL and Nokia embedded agility into their supply chain operations in order to understand how they adapted to supply chain disruptions. The stated companies faced various disruptions, including natural disasters, supplier problems and geopolitical risks, but successfully overcame those through structural and strategic flexibility. The success was achieved through pre-emptive investments in supply chain agility. For example, Dell leveraged built-to-order models and real-time information, and DHL and UPS capitalised on network redundancy and visibility tools to reroute operations during crises.

These examples collectively show that resilience is not merely a reactive capability but a designed-in feature enabled by flexible procurement contracts, diversified supplier bases, IT infrastructure and empowered response teams. The ability to detect, interpret and act on disruption signals early—while maintaining service levels—positions such companies to not only recover but also to gain a competitive advantage in turbulent environments [28].

3.5 Lean Manufacturing Limitations

Recent research highlights the limitations of lean manufacturing and just-in-time inventory systems in the face of disruptions. While these practices enhance efficiency under normal conditions, they can exacerbate the impact of disruptions due to minimal buffer stocks and reliance on precise timing [4][29]. The COVID-19 pandemic exposed the lack of resilience in supply chains, prompting a reevaluation of these practices [30]. More resilient approaches are needed that balance efficiency with risk mitigation. Solutions proposed include

integrating resilience principles into lean manufacturing systems, implementing the SCRAM framework to assess and manage supply chain vulnerabilities [4] and adopting a dynamic mix of lean and legacy supply chain practices through coordinated demand-driven production [31]. These solutions aim to create flexible and resilient production systems that can respond effectively to disruptions while maintaining efficiency.

3.6 Resilience in Production Planning and Control

The integration of advanced technologies to strengthen SCR and production planning was highlighted recently. In complex manufacturing environments, digital twins, which leverage machine learning and real-time data, are key elements that enable proactive risk management and adaptive decision-making [10][13]. These technologies facilitate end-to-end visibility, allowing organisations to anticipate and respond to disruptions effectively [10]. Demand forecasting and risk assessment capabilities across the supply chain are improved by utilising predictive analytics and data-driven strategies, incorporating IoT and cloud computing [32]. Machine learning algorithms can be combined with production system data to implement intelligent digital twins for adaptive PPC [11]. These approaches offer significant potential for enhancing SCR and operational efficiency due to increasing market volatility and disruptions.

Recent research on SCR metrics emphasises the importance of resilience by evaluating its strategies. Hosseini et al. [33] proposed a Bayesian network approach that balances vulnerability and recoverability to measure SCR. Meanwhile, a new resilience measure based on the ratio of system performance after disruption to normal state performance was introduced by Li et al. [34]. Ribeiro & Barbosa-Póvoa [9] developed a responsiveness metric incorporating economic and customer impact objectives for resilient supply chain design and planning. Additionally, existing SCR metrics were reviewed by Behzadi et al. [6], who proposed a new measure called the net present value of the loss of profit (NPV-LP).

Table 1 shows the comparative table of SCR metrics.

Table 1.
Comparative Table of SCR Metrics

Metric	Approach	Focus	Strengths	Limitations	Best Use Case
Bayesian Network [29]	Probabilistic graphical model	Vulnerability and recoverability	Handles uncertainty, models complex interdependencies	High data/expert input demand	Strategic risk analysis, scenario planning
Performance Ratio [30]	Ratio-based performance measure	Post-disruption performance vs. normal	Simple, intuitive, fast to apply	Ignores long-term effects, oversimplifies dynamics	Quick diagnostics, comparative benchmarking
Responsiveness Metric [9]	Multi-objective optimisation	Economic + Customer impact	Holistic, aligned with planning goals	Computationally intensive	Design and policy optimisation
NPV-LP [6]	Economic loss quantification	Financial impact (Profit loss)	Financial rigor, supports ROI evaluation	Data-intensive, excludes qualitative factors	Investment justification, cost-benefit analysis

These studies help to identify the need for comprehensive metrics that consider multiple factors, including recovery time, system performance, economic impact and customer responsiveness. This enables for better effective decision-making in supply chain management and enhances overall resilience to disruptions.

3.7 Applications in Industry

The importance of AI in enhancing SCR across industries continues to grow, as highlighted by recent research. In manufacturing, AI applications contribute significantly to predictive maintenance, risk mitigation and quality control, with machine learning and deep learning being the predominant technologies [12]. The healthcare sector has leveraged AI, blockchain and big data analytics to manage disruptions during the COVID-19 pandemic, although practical applications remain limited [35]. AI's potential to improve SCR is further emphasised through early risk identification, operation optimisation and enhanced decision-making [36]. In the USA, companies are

increasingly adopting technologies such as AI, blockchain and IoT to predict disruptions, optimise operations and respond swiftly to challenges, demonstrating the critical role of continuous innovation in maintaining operational continuity [37].

3.8 Gaps in Existing Knowledge

Recent research highlights significant gaps in SCR and sustainability. Standardised metrics for measuring resilience are lacking, making benchmarking challenging across industries [5][17]. In addition, the relationship between sustainability and resilience remains unclear, with conflicting perspectives on whether they are separate concepts, components of each other or synonymous [14]. This ambiguity extends to implementation methods and performance measurements [17]. Exploring how emerging technologies impact SCR is necessary as well. Research streams have developed divergent definitions and theories of resilience, limiting the potential for generalisable principles [5]. Future research should focus on integrating existing knowledge, developing standardised frameworks and investigating the intersection of sustainability and resilience strategies to address these gaps [14][17].

3.8.1 Future Recommendations

Integration of Digital Twins and Predictive Analytics

Future research should explore how digital twins, enhanced by machine learning and real-time analytics, can be systematically embedded into PPC systems to simulate disruption scenarios and design proactive response strategies [10]. These tools can improve visibility, reduce lead times and support decision-making during uncertainty.

Hybrid Resilience-Efficiency Models

There is an urgent need to develop hybrid models that integrate resilience with the efficiency of lean systems. This approach may include the incorporation of selective redundancies, dynamic safety stocks and risk-based segmentation in inventory and supplier strategies.

Cyber-Resilience Frameworks in PPC

With digital transformation accelerating, future research should prioritise cybersecurity in PPC environments. Interdisciplinary studies can bridge the gap between supply chain operations and information security, contributing to more secure and resilient digital ecosystems [38].

Cross-Sector Resilience Strategies

Real-world case studies from the COVID-19 pandemic illustrate the potential of cross-sector collaboration in enhancing agility and modular adaptability. Investigating frameworks for inter-industry cooperation, such as shared production capacities and interchangeable components, can support systemic resilience [10].

Resilience Metrics and Decision-Support Tools

The development of standardised resilience metrics and decision-support dashboards, which include real-time monitoring and scenario modeling, can significantly enhance risk visibility and responsiveness across production systems [35].

Policy and Governance Implications

Scholars should examine the impact of policy, trade regulation and public-private partnerships in supporting resilience investments. Effective institutional governance can create incentives for firms to adopt long-term resilience strategies [39].

4. Conclusions

This systematic review underscores the growing need for embedding resilience within supply chain management, particularly in PPC. As global supply chains face increasingly frequent and severe disruptions, ranging from natural disasters and pandemics to cyber-attacks and geopolitical conflicts, resilience has become a strategic imperative rather than a supplementary feature. The literature reveals several recurring themes: the foundational constructs of SCR, sources and types of disruption, the integration of digital technologies such as digital twins, growing cybersecurity vulnerabilities and the inherent limitations of traditional lean paradigms in turbulent environments.

While lean systems optimise cost-efficiency and process flow, they often fail to provide the necessary buffers for disruption absorption, highlighting the trade-off between efficiency and robustness. Moreover, the growing complexity of global networks necessitates data-driven, adaptive and decentralised planning frameworks that respond dynamically to uncertainty. The integration of cybersecurity into SCR is also critical, as digital interconnectivity exposes PPC systems to cyber risks that can paralyse operations.

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مرونة سلاسل التوريد في سياق الإنتاج والخدمات اللوجستية العالمية

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المستخلص

يقدم هذا البحث مراجعة عميقة لموضوع مرونة سلسلة التوريد (SCR) في سياق الإنتاج والخدمات اللوجستية العالمية، مع مراعاة الحاجة الملحة لأنظمة متكيفة وقوية في ظل تنامي حالة الضبابية العالمية. يهدف البحث إلى دراسة احتياجات واستراتيجيات مرونة سلاسل التوريد في الإنتاج والخدمات اللوجستية العالمية. تم اختيار ٣٩ بحثًا" تناولت مرونة سلاسل التوريد في سياق الإنتاج والخدمات اللوجستية العالمية. صُنفت البحوث وفقاً لاستراتيجية المرونة التي اقترحها المؤلفون. من بين الأعمال المختارة المنشورة، تم تسليط الضوء على مواضيع رئيسية مثل تعريفات المرونة، ومحركات الاضطراب، ودمج التقنيات الرقمية مثل التوائم الرقمية، والأهمية القصوى للأمن السيبراني. كما ناقش البحث عيوب التصنيع الرشيق، ومقاييس المرونة، وتطبيقاته الصناعية خلال الكوارث الكبرى مثل جائحة كوفيد-١٩. اظهرت النتائج أنه على الرغم من أن تطبيقات التكنولوجيا، مثل الذكاء الاصطناعي والتحليلات التنبؤية، قد عززت مرونة تخطيط الإنتاج والتحكم فيه (PPC)، إلا أن العديد من القضايا لا تزال بحاجة الى معالجة فيما يتعلق بتوحيد المقاييس وتنسيق الاستدامة مع المرونة. قدم البحث بعض التوصيات التي تدعم نماذج المرونة والكفاءة الهجينة، وأطر المرونة السيبرانية، واستراتيجيات الصناعات المتعددة، بما يُتيح لسلاسل التوريد مواجهة الاضطرابات المستقبلية.