Supply Chain Management in Pandemics

Subjects: Business | Engineering, Industrial | Computer Science, Artificial Intelligence

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Pandemics cause chaotic situations in supply chains (SC) around the globe, which can lead towards survivability challenges. The ongoing COVID-19 pandemic is an unprecedented humanitarian crisis that has severely affected global business dynamics. Similar vulnerabilities have been caused by other outbreaks in the past. In these terms, prevention strategies against propagating disruptions require vigilant goal conceptualization and roadmaps. In this respect, there is a need to explore supply chain operation management strategies to overcome the challenges that emerge due to COVID-19-like situations.

supply chain management survivability epidemic outbreaks influenza COVID-19 sustainability viability resilience industry 4.0 review manufacturing

1. Introduction

Disruptions to business operations and global supply chains (SC) caused by disasters have led the practitioners and researchers to focus on survivability, which is the most concerning topic these days [1]. There have been several threats, such as climate changes leading to natural disasters, man-made circumstances (in terms of terrorism), and several other potential risks. Consequently, companies look for ways to survive in tough times and sustain their positions after such events. A potential roadmap for ensuring both objectives is to transform their operations and SC activities into transparent, agile, and reliable cyber–physical systems. Many industrial tycoons have started the journey towards digitalization [2].

Moreover, to survive during disasters, the focus on improving market-share, ecological consciousness, and differentiation through technology leadership, along with a reliable and sustainable SC network requires a workable framework. However, approaches such as being lean, green, and resilient, and ensuring sustainability are established, and practiced supporting emerging market requirements. In terms of sustainability, if an SC gets disturbed because of a disaster, the parallel node to the affected location is identified and connected to minimize the disruptions in supplies and demands [3]. Among different types of disasters categorized by the World Health Organization (WHO), epidemic outbreaks have proven to be destructive to human lives as well as economies. The manufacturing setups, which are considered the backbone of any country's economy, often face full or partial closure in such circumstances. The economic effects surpass territorial boundaries through a globally connected network. At the micro-level, many industrial sectors experience absenteeism of the workforce because many are affected or taking care of affected ones at their residences. This leads to a significant drop in operations and production levels, and sustainable performance gets disturbed [4]. The world has been challenged several times by extraordinary pandemics, which left long-term effects on society, businesses, operations, and SCs [5]. Among these ripple effects, 20 to 50 million people died due to the Spanish Influenza outbreak in 1918–1919. Similarly, the Ebola virus also had unmatched effects on all dimensions. These large-scale losses urged the upgrade of disease risk, prevention, and outbreak management facilities, despite the unavailability of cures [6][7]. Notable outbreaks such as SARS, MERS, AIDS, cholera, and malaria have affected society, as well as the economy, having accumulated effects in the billions of US dollars [8]. Moreover, a lot of waste and environment damages are caused every year [9].

In recent years, the frequency and severity of these disasters have been becoming worse due to several factors. World Health Organization [10] has categorized various types of disasters. The potential types which potentially lead to epidemic outbreaks are classified in Figure 1. The emergencies' consequence is pandemics, causing unprecedented losses. All SCs, at a local and global level, get affected and face challenges in ensuring logistic and manufacturing operations continuity [11]. Therefore, it is important to address the diseases under a unanimous framework in the current timeline. A few studies have reported that these epidemics are the consequence of climate change and patterns [12]. Businesses are already experiencing disasters. Recently, they have been hit by the highly contagious, unprecedented, and infectious outbreak termed as COVID-19. It is a novel outbreak causing disturbances to human lives and the circular economy [13].

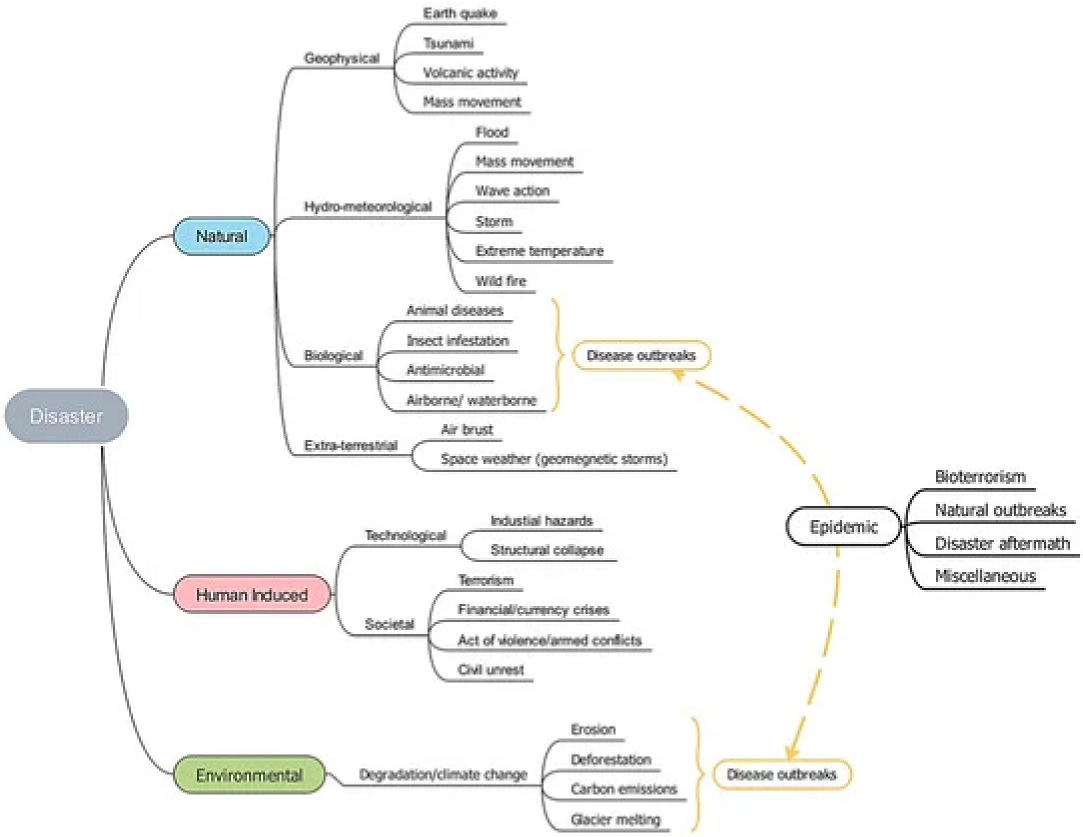

Figure 1. Disaster classification which poses serious threats to global supply chains (SCs). (Source: authors).

2. Discussion on the Findings

2.1. Categorization of Previous Epidemic/Disease Outbreaks and SC Implications

To get an understanding of the impacts of previous outbreaks, a rigorous literature review is summarized in Table 1, categorizing the available research on different epidemics' effects on the performance of SCs. The content analysis was carried out by focusing on the epidemic and objectives studied in those publications, the problem-solving approaches, and the related implications recommended and proposed in those pandemic situations.

Table 1. Pandemics and the objectives to resolve their impacts on SC.

Ref	Pandemic	Objectives	Problem-Solving Approaches	Developments/Implications
[14] [15] [16] [17] [18] [19] [20] [21] [22] [23] [24] [25] [26] [27]	Influenza	• Resource allocation during the outbreak. o deterministic model. o logistics model especially for medical resources. o contractual model for vaccine procurement and distribution under an inefficient system. • Investigations on transportation infrastructure and logistics policies for	• Qualitative analysis of yearly published reports, WHO announcements, recommendations, documents of disease control departments. • Brainstorming and devising a conceptual roadmap. • Game theory and/or optimization. • Case study. • Mathematical modelling/exact method approach. • Optimization heuristics and/or case study. • Agent-based simulations and/or	• An integrated model for suppliers and retailers was recommended to make use of cutting-edge technology. Moreover, traceability measures can improve logistics performance. • To combat the epidemic, adequate involvement of policymakers and government officials is required to develop logistics, operations, and SC capabilities. • A rigorous focus is retained on the coordination of influencers to combat vaccine shortfalls and to reduce social costs by distributing them to several partners. • However, logistics activities play a vital role in outbreak control through necessary medication and preventive essentials. Based on this, the

Ref	Pandemic	Objectives	Problem-Solving Approaches	Developments/Implications
		medicine distribution. • Drug distribution model and redistribution of resources during a pandemic. • Epidemic logistics model to control the disease. • Food distribution planning. • Optimization of patient and resource allocation. • Vaccine distribution to selected groups with a minimum distance coverage focus. • Logistics challenges to public health care response through international support.	mixed-integer linear programming. • Non-linear programming. • Simulation and/or case study. • Secondary data analysis.	response to outbreak control through international coordination is possible. • The outbreak elimination is also dependent on public health care officials' decisions to disseminate vaccine through effective network design. • To address the capacity issues, voluntarily quarantine helped industries such as food industries, which were running at half capacity. Furthermore, the proceedings to take control of the outbreak dynamically were carried out while taking logistics factors and disease propagation into account. Management of dispersed resources and logistics infrastructure plays a vital role in managing the outbreak.

Ref	Pandemic	Objectives	Problem-Solving Approaches	Developments/Implications
		• Stating the effects of the disease on SC, logistics, vaccine procurement, distribution, and related challenges. • Food distribution and risk of propagation of disease.		
[28] [29] [30]	Ebola	• Logistics modelling for resources distribution to control the epidemic outbreak. • Disease promotion through air-travel and defining the role of aviation infrastructure. • Configuring treatment places and comparing	• Mixed-integer linear programming/case study. • Secondary data analysis • Heuristics. • Dynamic programming	• Epidemic logistics model, including dealing with the constraints of treatment centers such as geographical variables, the changing aspects of infected locations, and the effect of resource allocation. • Efficient developments in passenger screening were devised against limited airport infrastructure to avoid disease propagation. The resource allocation approach should depend on the dynamic evaluation of the complete system and disease propagation status backed through a strong logistics control system.

Ref	Pandemic	Objectives	Problem-Solving Approaches	Developments/Implications
		strategies for affected ones		
[31] [32] [33] [34]	Cholera	• Response to the epidemic outbreak. control policies and the emergence of health facilities • newly developed Haddon matrix model • data-driven model • model based on the distance for facility location decisions in the context of humanitarian response. • model based on resource constraints such as facilities location, staff, size and so on	• Haddon matrix • Secondary data analysis • Centralized planner model/network congestion model • Mixed-integer linear programming	• Through a Haddon matrix, a framework provides comprehension on logistics during multiple phases of a disaster, such as pre-, during, and post-event for humanitarian purposes. The focus was shifted towards empowering medical staff as a part of SC to make resource allocation in emergency stages more effective. • Individual's behavior to make logistics more effective is important in humanitarian SCs. The effective resource allocation of limited SC supplies and response to the epidemic, multiple types of resources, and their consecutive demand should be assessed.
[35]	Malaria	• Drug distribution strategy under	• Markov decision approach	• Effective transportation planning can reduce costs and shortages in medicine

Ref	Pandemic	Objectives	Problem-Solving Approaches	Developments/Implications
		strategic and tactical aspects		and vaccine procurement and distribution. • Several challenges are identified during implementation phases, such as inadequate communication, fragile implementation efforts and engagement by government and other authorities, and poor infrastructure of transportation (logistics).
[36]	Smallpox	• Response to the disaster through SC emergency for large scale vaccination	• Operations research/linear programming	• The emergency network design influences on disease control and management in socio-economical activities. The research contributed to outbreak propagation control and resource distribution model assisting in epidemic control and management.
[5] [37] [38] [39]	COVID-19	• Investigation of SC resilience and robustness strategies • Analysis of intertwined SC networks for survivability: the perspective of digital SC • Prediction of impacts ranging	• Simulation/case study • Game theory • Secondary data analysis based on industrial newsletters and, health and economic forums	• Unmatchable disruptions to SCs are reported. Different developments to accurately predict the effects on various SCs, ranging across several time zones, to support the performance and for mitigation. • The disruption is pushing industrial leaders to test different resilience strategies to combat the effects. For

Ref	Pandemic	Objectives	Problem-Solving Approaches	Developments/Implications
		from operations disturbance to economic activity.		this, analysis of interconnected and resilient networks also assures survivability and sustainability in COVID-19-like disruptions over a long-term tenure.
[40] [41] [42] [43] [44] [45] [46] [47] [48]	General epidemic management/control	• Development of a model to enhance vaccine procurement and reduce associated social costs. • Vehicle trip network structure development concerning passenger density. • Vaccine distribution model in high constraints of logistics. • Experts view on efficient response to an epidemic outbreak. • Emergency model for SC	• Artificial intelligence algorithms such as machine learning, genetic algorithms. • Monte-Carlo simulation. • Exploratory modelling analysis. • A multi-objective stochastic programming model. • Panel discussion/focus group. • Susceptible-Infectious-Recovered (SIR) model. • Secondary data analysis	• The option contract model was proposed to assist suppliers through demand optimization to reduce procurement and social costs. A model to identify infectious vehicles to support logistics and SC, and to avoid risky trips, was developed. Whereas, distance for optimized logistics protocols remains a challenge for effective resource allocation. • Emergency medicine distribution and long periods of delay also contribute to increasing uncertainty. • An effective way to resolve these issues is proposed through an integrated model employed in SCs to minimize shortages, an adequate flow of medicines and other resources in an integrated manner. Moreover, effective identification of an infectious public system can help to

4. Rabenasolo, B.; Zeng, X. A Risk-Based Multi-criteria Decision Support System for Sustainable Development in the Textile Supply Chain. In Handbook on Decision Making: Vol 2: Risk Management in Decision Making; Lu, J., Jain, L.C., Zhang, G., Eds.; Intelligent Systems

Ref	Pandemic	Objectives	Problem-Solving Approaches	Developments/Implications
		networks to address fluctuations in demand during the pandemic. • Policies to eradicate effects of pandemic under uncertain conditions.		modify resource distribution plans with disease propagation.

9. Peretti, U.; Tatham, P.; Wu, Y.; Sgarbossa, F. Reverse logistics in humanitarian operations: Challenges and opportunities. J. Humanit. Logist. Supply Chain Manag. 2015, 5, 253–274.
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2.2. Multiple Correspondence Analysis

To analyze and establish a conceptual map on the selected domains based on the dataset, multiple correspondence analysis was carried out, and displayed in Figure 2. It is an effective technique for reducing contents and developing a conceptual map [49]. It is a two-dimensional technique that constructs a graphical map of the distribution of word similarities in the data set. These words were acquired from "keywords" and "titles" of the references considered for analysis. The frequency of the words used in the publications determines the size of the circle and text, whereas the color represents different clusters. The keywords "sustainability", "disasters", "supply chains", "supply chain management" and "resilience" were easily identifiable and confirmed the research trends in particular areas. However, other words were displayed as emerging research areas in the SC field.

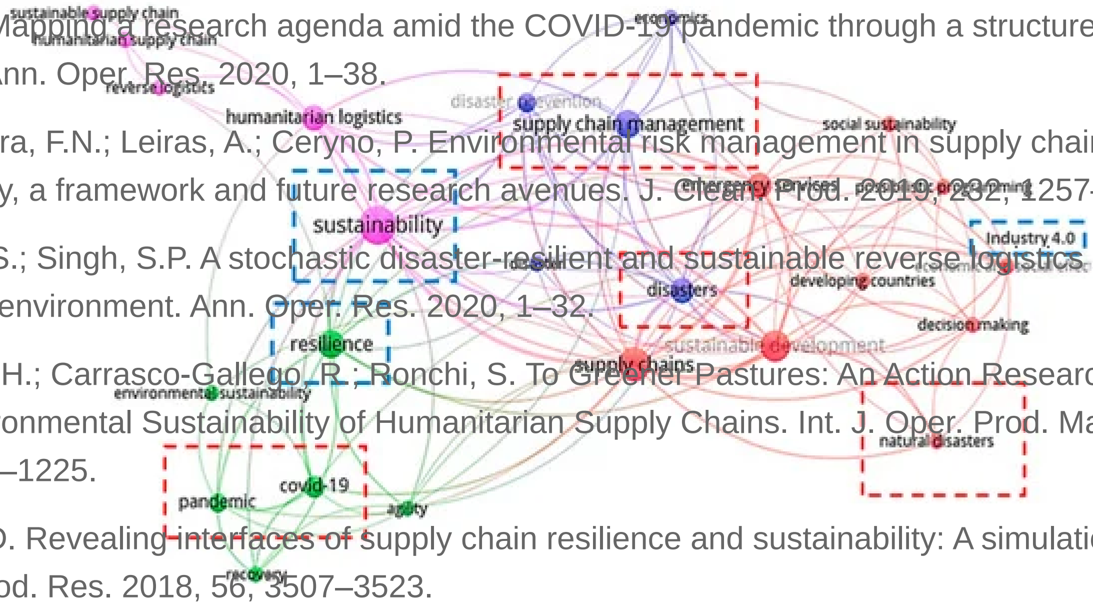

Figure 2. Conceptual map generated through correspondence analysis.

Moreover, “COVID-19”, “pandemic”, “recovery”, “natural disasters”, “humanitarian supply chain”, and “humanitarian logistics” were also interesting topics for recent scenarios. As represented by the correspondence analysis, “emergency services” recommends areas of effective and efficient resource allocation and logistics planning. As a consequent “resilience”, “disasters”, and “decision making” indicated emerging themes of the research. In this research study, “sustainability”, “pandemics”, “disasters”, “supply chain”, and “emergency services” were visible as impact themes, and were focused to gather the answers to the research questions from the scarce literature. Our study advocates the use of these themes to evaluate the impacts of epidemics and their effects on SCs. From Figure 3, a multiple co-occurrence analysis of the countries of authors affiliation was carried out. The countries “France”, “Germany”, “United States”, “China”, “Iran”, and “India” contributed more to the research on the selected domain. The size of the circle and text represents the frequency of repetition of the countries in the articles.

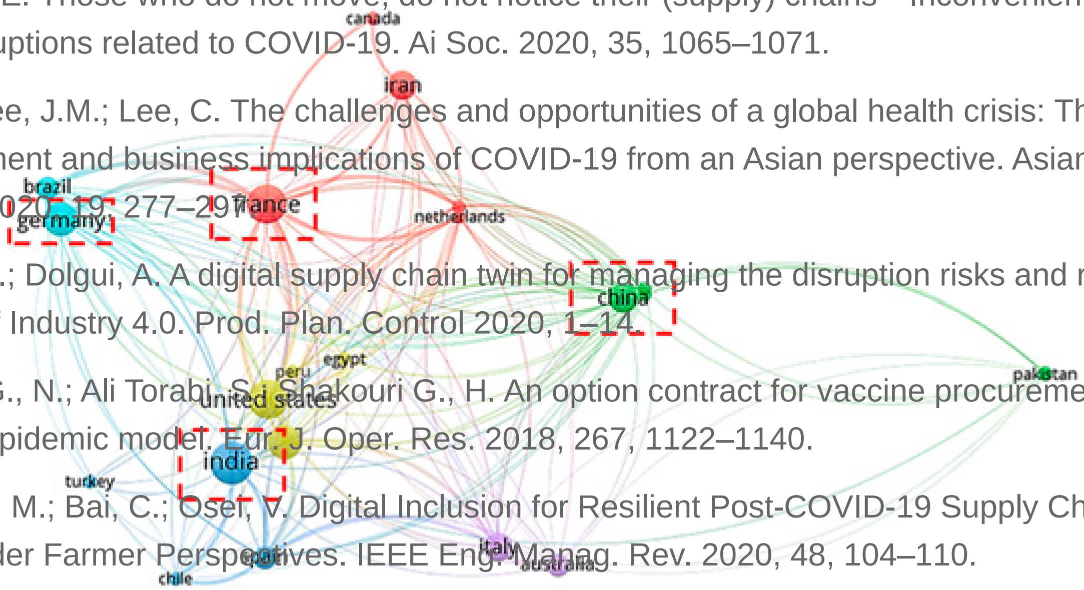

Figure 3. Multiple co-occurrence analysis of the main countries contributing to the selected research area.

3. Future Research Avenues

3.1. Sustainability/Survivability Preparedness

To prepare SCs for greater reliability and survival during deeply uncertain environments, first a focus on the preparedness aspect (for survivability) was highlighted by our SLR on the effects of epidemic outbreaks on SCs. On the path of sustainability, these key areas are highlighted more during content analyses, such as cost efficiency, agility, flexibility, resource efficiency, environmental footprint, and reliability. Moreover, there are not only opportunities in the domain of mathematical optimization and simulation, but also with other approaches, for example queuing theory, system dynamics, effective scheduling and forecasting, and knowledge-based systems

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can be explored [50][40]. This indicates that decision-makers should employ a universal integrated approach to improving SC survivability and sustainability perspective [51][52][53]. Moreover, simulation-based approaches are commonly used [54] to evaluate different decisions during an epidemic for better response to SC operation disruptions [5][38][55][56]. Simulation is used as a predictive tool to test decisions, massive disruptions, and performance capacities. In addition to this, consideration of SC ecosystems, viability analysis, intertwined network analysis, and humanitarian logistics also play a key role in SC sustainability. However, inter-domain areas overlapping with resilience and robustness include risk mitigation learning, pre-allocation of resources, emergency distribution planning, and product diversification and substitution. Our study sheds more light on the management and allocation of resources, as evident from previous approaches mentioned in Table 1.

Additionally, sustainability itself, as a focus of our SLR is discussed through considering SC ecosystems, and the viability of the system, operations, and network, as well as novel and severe disruptions to SCs and how a circular economy can help to sustain production capacities, and deal with insufficient supply and demand conditions, to ensure short-term and long-term SC sustainability and survivability [8][57]. Moreover, the feedback in SC ecosystems, both positive (cycle of natural resources) or negative (cycle of emissions as a contributor to climate change), and the interactions of SC stakeholders, such as society, organization was also considered. Similarly, workforce development, technological innovations are positive interactions, whereas strikes (SC disruptions and organization-based resilience level), global disruptions (pandemics or epidemic outbreaks causing SC disruptions at sustainability level) are negative interactions. Attempts to mitigate these negative implications are made through a focus on the overlap of sustainability/survivability with industry 4.0/digitalization. "Disruption recovery planning", "disruption pattern recognition", and "disruption identification" in highly interconnected digitally assisted SCs can bring integrity through intertwined networks. This requires incorporating all the stakeholder at all levels, such as society, organizations, system, and processes [39]. Moreover, humanitarian logistics and crises regarding SC sustainability are also vital areas to explore further in the field [58][59][60].

3.2. Digital/Industry 4.0 Vigilance

There is an urgent need to evaluate the current technological readiness level for industry 4.0 transformation to firmly combat COVID-19-like future disruptions. Earlier, cutting-edge technologies such as blockchain, additive manufacturing, and artificial intelligence (AI) were not available to industries, but in this epoch, these technologies provide high-end traceability, robustness, and resilience to SCs. First, the analysis of an epidemic outbreak's effects on SCs can be carried out, followed by an assessment of the current technology level [61], and lastly a framework for developed, under-developed, and developing countries (as dynamics are different in every community) to roadmap the transformation journey. These technologies (artificial intelligence, Industry 4.0) could play a crucial role in SC resilience and robustness against ripple effects [62][63]. In terms of visibility and digital manufacturing networks, we can foresee a viable option for assuring workability during a crisis and the coordination of recovery from future pandemics [58][64]. "Digital twins", "digital analytics and AI", and "smart and digital manufacturing" are remarkably good ways forward to ensure robust SCs. Whereas the overlap of this focus with resilience and robustness of SCs was also identified by our SLR. The collaboration of "Industry

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4.0/digitalization”, with “resilience/robustness” offers a way toward through firm reliance, in terms of resource configuration and risk management infrastructure [62][65][66].

3.3. Resilience/Robustness Readiness

The next focus of SCs is their readiness to respond to the impacts of remarkably high and unexplored ripple effects. Companies and economies are facing a great depression due to the COVID-19 pandemic [67][68][69]. This is an important aspect of understanding the implications of ripple effects and pandemic stress on SCs, and the possibilities of collapse due to disease and disruption propagation through networks. Though multiple aspects of ripple effects have been simulated and studied in various dimensions they deserve to be explored more [4][56][65]. The journey for resilience and robustness of SCs starts from evaluating ripple effects, then the adaptation of new terms, leading towards the recovery phase. Several tensions in SCs were reported from previous pandemics, as mentioned in Table 1, and several operation management approaches have been used to address resource allocation. Practitioners, decision makers, managers, and experts continuously try to monitor SCs performance, to rigorously evaluate the disruptions, and to make a recovery plan covering all aspects and leaving nothing unexamined. To ensure the recovery plan is successful certain key roles need to be addressed, such as “risk mitigation inventory”, “redundant capacity”, and “backup facilities and channels”. These are the significant areas which are needed to make SCs robust, as well as resilient against such pandemics.

To summarize, SCs must operate with the assistance of operations management approaches and the aspects mentioned in Figure 4, from a resilience and survivability perspective, to avoid supply shortages, and delivering an optimized, responsive, and dynamic decision support model for different stages of disaster, pandemics, and outbreaks through taking aid from simulations, mathematical optimization, and network and complexity theories.

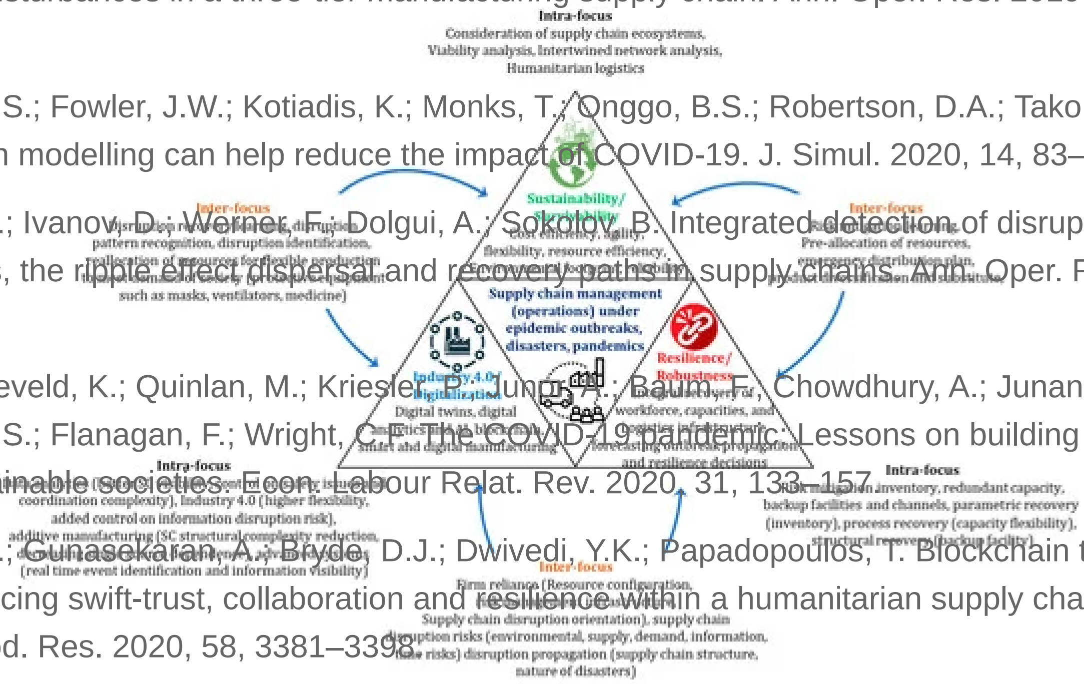

Figure 4. Framework for the readiness of SCs to combat pandemics.

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3.4. A Conclusive Insight

This research study covers the main aspects by classifying different epidemic outbreaks and SC resilience objectives addressed from the view of local as well as global pandemics. The overall insight of our SLR analysis orientates the traditional SCs towards risk, resilience, and sustainable understanding, to tackle severe, destructive, unmatched global disruptions and disasters. Hence, multiple approaches were found significant to address issues during a pandemic [4][70][58][66]. Therefore, there is always a continuous need, as per the understanding from the analysis of a SLR, to explore existing approaches [61], extend them, or propose new [38][71] ones, to deal with new challenges, and we urge experts to explore the areas mentioned in Table 2 with novel approaches or hybrid techniques.

Table 2. Proposed research extension opportunities and agenda for investigating and effectively responding to an epidemic's effects on SCs.

Ref	Literature Gap	Open Questions and Opportunities for Future Research	Potential Solution Approaches
[72] [73] [74] [75]	Optimized and novel models for sustainable operations in disturbed SCs during epidemic/disasters, for resource allocation in a dynamic environment, and for the development of sustainable SCs and smart production systems in smart cities	How can optimized and novel models help in responding to vulnerable SCs and show robust behavior with SC effects such as shortages, delays, and overhead costs? How new facilities can be developed to cater to the requirements of dynamic disruptive situations? How smart cities can help to support epidemic epicenters?	Robust optimization; Stochastic programming; Mixed-integer linear programming; Game theory; Dynamic capability
[76] [77] [78] [79] [80]	Optimized response to humanitarian logistics (forward and reverse), supply chains, and operations	How can the local and global SCs plan to respond to disasters at a local as well as global scale in terms of humanitarian relief? How to prepare a flexible humanitarian response, to plan for an epidemic anywhere? How parallel operations can help in sustaining reliable and quick humanitarian relief response through digitally supported SCs?	System dynamics Mixed-integer linear programming Socio-technical systems
[4][8] [23] [29]	Novel and severe disruptions to SCs and how a circular economy can help to sustain production capacities and	What are the scenarios that lead to severe ripple effect intensification? Do they cause	System dynamics Complexity theory Agent-based simulation

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Ref	Literature Gap	Open Questions and Opportunities for Future Research	Potential Solution Approaches
[47] [76]	manage insufficient supply and demand conditions	long-term unremitting bullwhip effects? How can a circular and digitally supported economy help to reduce global shortages and mitigate the effects on production and global supply?	Discrete event simulation Informational processing theory
[53] [72] [81] [82]	Severe effects on the ecology of epidemic outbreaks in SCs	How to restore and take benefit from severely impacted SCs in a societal and organizational context? How can the focus on environmental sustainability be intensified, such as carbon emission reduction, pollution reduction etc.	Agent-based simulation Discrete event simulation Knowledge-based systems Mixed-integer linear programming
[83] [84] [85] [86]	Drastic reduction in the sales of multiple industrial business and global SCs, and coping with the shortages of medical supplies; building resilient capabilities to repurpose operations during disruptions	How can disruptions to global SCs sales affect short- and long-term goals? How can resilience strategies help in this situation? How can immediate transition and repurposing of factories make it possible to meet novel demands?	System dynamics Discrete event simulation Contingency theory Digital twinning
[30] [87] [88] [89]	Delocalization of manufacturing facilities and reducing the dependence on others	How to reduce dependence and build inhouse capabilities for manufacturing effectively? What are the potential effects on economies because of relocating major manufacturing facilities?	System dynamics Discrete event simulation Contingency theory
[44] [90] [91] [92]	Blockchain as an aid to reduce disruption effects through effective information flow	How blockchain technologies, such as traceability through visibility and security can help to reduce the shortages? How can this help in quickly responding to the disruption?	Complexity theory Reliability theory Dynamic capabilities Convex programming Mixed-integer linear programming
[22] [43] [93] [94] [74]	Artificial intelligence and additive manufacturing to support SCs during epidemic outbreaks	How artificial intelligence can help industries through digital manufacturing and other assistive technologies in the epoch of epidemics?	System dynamics Discrete event simulation Organizational resilience Complexity theory

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Ref	Literature Gap	Open Questions and Opportunities for Future Research	Potential Solution Approaches
[95] [96] [97] [98]		How can artificial intelligence help in making responsive models, and by providing an optimized strategy through heuristics? How to make an assessment of technological readiness, and roadmap the transformation journey to combat future disruptions? How additive manufacturing assistance with artificial intelligence can repurpose manufacturing demand through digital as well as social media data analytics? How can additive manufacturing contribute to meet urgent demand, such as surgical masks, protective equipment, and so on?	Heuristics Machine/Deep learning-based models

Initially, the categorization of major epidemic outbreaks which disturbed SCs significantly was carried out. The potential research objectives which were addressed are displayed in Table 1, and the possible solution methodologies were extracted to make a roadmap for the journey of the COVID-19 pandemic. Therefore, different SC survivability aspects were explored from previous practices in the context of pandemic disruptions, and making resilience a goal for the whole SC network, system, organization, and process, as reported from Table 1. To make SCs ready for future disruptions certain critical components of SCs were extracted, such as resilience and robustness, sustainability and survivability, digitalization, and industry 4.0. All these components play a crucial role during pandemics and are interrelated, such as in the aspects of readiness, vigilance, responsiveness, and preparedness for effective recovery from the disruptions caused by epidemics.

Various governments have been establishing uncommon collaborative activities with manufacturing firms and specific suppliers for the reconfiguration, adaption, and ramping-up of production to provide medical facilities to ensure resilience and flexibility in systems [99][100][101]; this may partially be achieved through digitalization [100][101][102][103][104][105][106][107][108]. Moreover, numerous global societies need to tackle the mismatch between supply and demand in distinct ways, providing social distancing and other cautionary measures [109]. In addition to this, the use of collaborative robots for reconfiguration of existing production setups can be foreseen to enhance the flexibility of a system; for instance, adapting automotive industry for the production of ventilators [99][101]. This could be a future research and development direction to deal with pandemics and large-scale disasters [109]. An exponential growth in research and development in this direction could be seen in the near future [109].