



# Decision-Making Models for Healthcare Supply Chain Disruptions: Review and Insights for Post-pandemic Era

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## Abstract

The black swan event caused by the novel coronavirus (COVID-19) has majorly exposed the vulnerabilities of the supply chain of many of the firms. However, healthcare sector is one of the significant areas which majorly got disrupted during this pandemic event. The majority of the studies focus on the reviews on supply chain disruption modelling to analyse the risk and their effect on supply chains. This study provides a systemic literature review of various supply chain disruption models in the healthcare sector, analyses them based on different parameters identified from the literature. Some of our key findings include (1) analysis of quantitative and analytical modelling approaches used for dealing with disruption in healthcare sector; (2) managerial implications that derive potential future research avenues and insights for practitioners in the domain of healthcare supply chain disruption in post-pandemic era to improve international competitiveness and operational excellence.

**Keywords** Healthcare sector · Supply chain disruption · COVID-19 · Risk management · Quantitative modelling · Analytical modelling · Supply chain competitiveness

## Introduction

Supply chain disruption are viewed as a mix of unexpected setting of occasions and the subsequent results which risk the progression of material and ordinary business exercises significantly (Wagner & Bode, 2006). There are several risks associated with Supply Chain. They are classified into operational and disruption risk (Tang, 2006; Xu et al., 2020). Operational risks refer to day-to-day disruptions in Supply Chain operations, such as fluctuation time and lead time, whereas Disruption Risks belong to low-frequency high-impact events (Ivanov et al., 2017). Disruption risks can be categorized into natural (earthquake, flood, fire, COVID-19, etc.) and man-made (terrorist, accident, the bankruptcy

of supplier, etc.) (Fahimnia et al., 2015). These risks have an immediate impact on the Supply Chain network since links of Supply Chain are temporarily disturbed and unavailable. There are several disruption events that have been well documented. Some of them are the COVID-19, 09/11 terrorist attack, Hurricane Mitch, Earthquake in Taiwan (1999), Eruption of Volcano in Iceland (2010), Flood of Thailand (2011), Tsunami in Japan (2011), Explosion at BASF factory in Germany (2016), etc. (Dolgui & Ivanov, 2021; Fahimnia et al., 2015). In 2015, a series of the explosion at a container warehouse for toxic chemicals at Tianjin Port caused significant environmental changes like Water cyanide level exceeded from accepted limit, destruction of 8000 newly produced car and shutdown of 2 manufacturing plants of Toyota (Bugert & Lasch, 2018). According to report by EY 2020, almost all the industries like Automobile, Electronics Manufacturing, Food Processing, Gems and Jewelry, IT, Leather, Medical devices and Equipment, Metals, Minerals, Pharmaceuticals, Plastics and Packaging, Real Estate and Construction, Retail and e-commerce, Textile and Apparel and, Tourism and Hospitality are affected by COVID-19 pandemic as well (EY 2020; Deshmukh & Haleem, 2020). Furthermore, black swan events like Influenza pandemic, and COVID-19 pandemic has badly affected the Healthcare

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Supply Chain (Francis, 2020; Govindan et al., 2020; Hovav & Tsadikovich, 2015).

Disruption has played a crucial role in Healthcare Supply Chain (HSC). Healthcare supply chain management is defined as the regulation of the flow of medical and essential goods and services from manufacturer to patient. In Healthcare, supply chain management is typically a very complex and fragmented process (Saviano et al., 2014). Regardless of the severity of the disruption events, organizations need to take unprecedented measures for preventing or mitigating the risk caused by disruption events.

Although Supply Chain Disruption Modelling is widely studied in the last decade, its application in the Healthcare sector is prolonged because disruptions are not so frequent. Substantial amount of literature is available in Supply Chain disruption domain. However, there is scarcity of studies that focuses on the quantitative modelling approaches used for dealing with disruption in Healthcare Industry. To the best knowledge of author's this, a systemic literature review in the arena of quantitative modelling used in healthcare industry has not been conducted previously. This work bridges the gap by systematically analysing the all the quantitative models used in healthcare sector Supply chain disruption.

Specifically, we have defined three research questions to specify the goals of this literature review:

- (a) Which modelling techniques are used for supply chain disruption modelling in healthcare?
- (b) How well the identified models and modelling techniques take the identified risk-specific modelling characteristic into account?
- (c) What are the open questions and future research directions in the area of supply chain disruption modelling in healthcare sector post-pandemic?

The organization of this paper is as follows. The next section describes the paper's research methodology followed by the significant problems associated with healthcare supply chain disruption, then the evaluation criteria with respect to the existing modelling approaches for healthcare supply chain disruption are explained. After interpreting the results of the evaluation, the last section summarizes the findings from the reviewed literature and offers a general look at future research in the field of the study.

## Research Methodology

The literature regarding supply chain disruption modelling in healthcare sector is limited. To attain the objective of this paper, we have reviewed the papers related to supply chain disruption modelling in the Healthcare Sector. In the first stage, we performed the search to identify the related papers

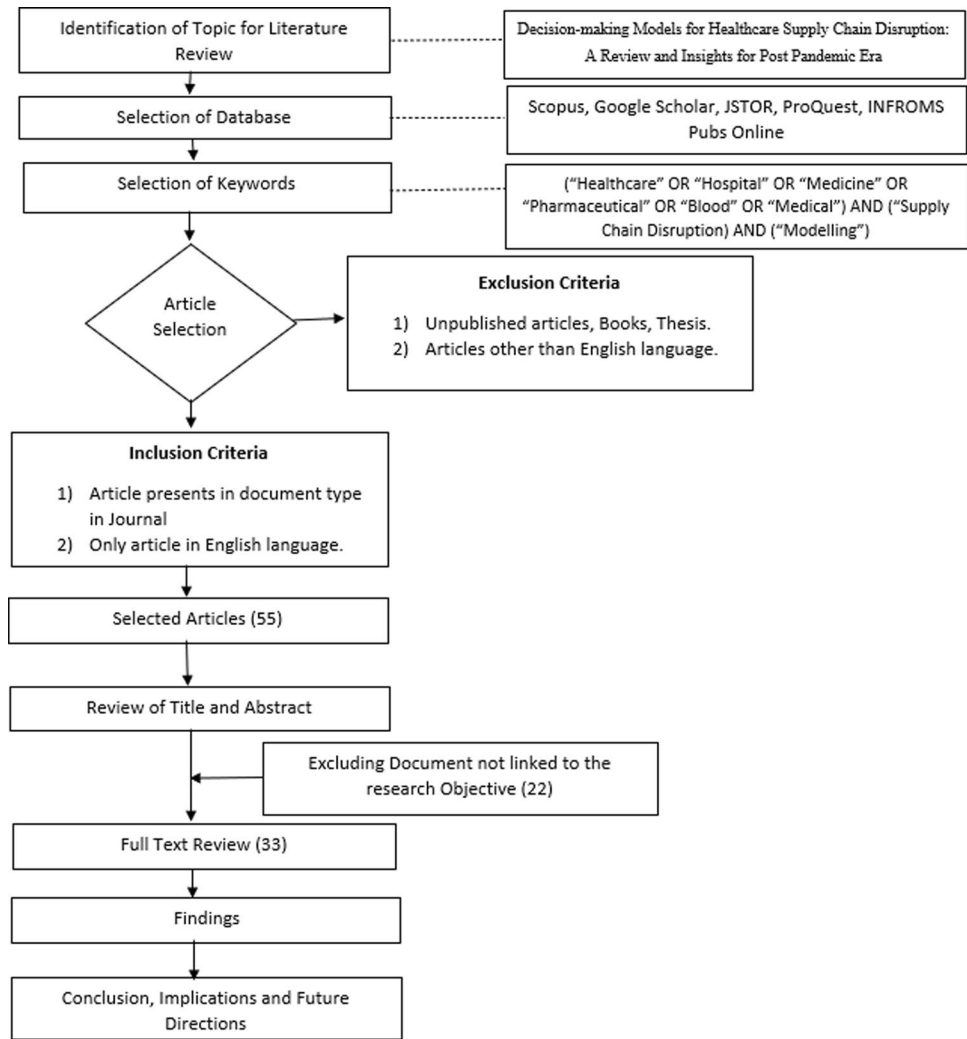
from various databases like Scopus, Google Scholar, JSTOR archive, ProQuest, INFORMS Pubs Online using keywords, such as 'healthcare', 'hospital', 'medicine', 'pharmaceutical', 'blood', 'medical' in combination with 'supply chain disruption' and 'modelling'. In the first phase, 60 journal articles were obtained. Out of those 60 research articles, 55 were taken into consideration after the removal of duplicated article. In the next step, we consider only those papers which met our research criteria i.e., we have excluded the unpublished articles, book chapters and thesis. In the same line, we have also excluded the articles not present in English Language and considered only 33 articles for final review purpose. In the last stage, we analysed the main findings from the analysis of the papers. This study presents a critical analysis on relevant and existing literature on Healthcare Supply Chain Disruption Modelling for a way forward to cope up with the risks post-pandemic as is presented in Fig. 1.

## Problems Associated with the Healthcare Supply Chain

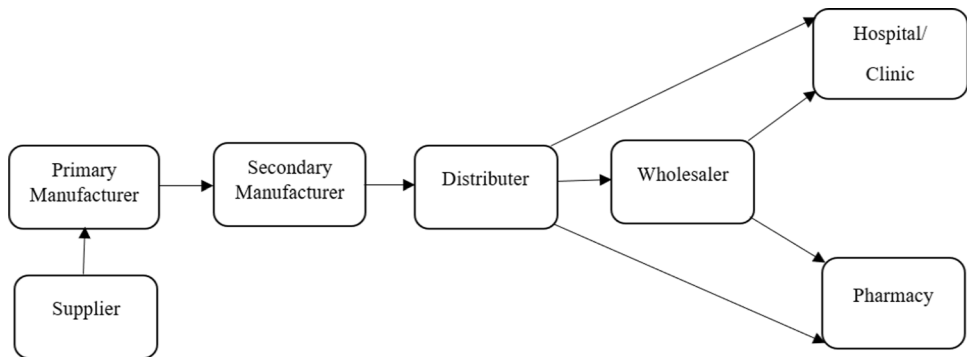
HSCs are different from the standard supply chain due to its complex nature, the presence of high-value medical materials, and, most importantly, the fact that they deal with human lives. According to Kitsiou et al. (2007), a typical HSC consists of focal entities (hospitals), backward entities (Manufactures), and forward entities (private and public payers) as presented in Fig. 2. Mathew et al. (2013) defined another version of HSC. According to him, the chain starts with the flow of different products, and it involves several stakeholders. In addition to this, HSC also requires the participation of government institutions, regulatory agencies, and insurance companies (System et al., 2005). Rivard-Royer et al., (2002) identified two chains that are mainly associated with HSC: the first one is related to storage within the hospital, etc., whereas the second one is related to distributors and manufacturers, etc.

There are several problems associated with HSC like variability and unpredictability of patient profile and high demand of care, integrated planning systems between patient flows and different health service organization, reduction of waste, unnecessary cost elimination while improving the quality (Bourlakis et al., 2011; de Vries & Huijsman, 2011; Wieser, 2011; Battini et al., 2014). Usually, HSCs maintain high levels of stock to provide 100% service level. The drug demand is highly unpredictable. Some drugs have very less shelf-life; some are used in more amount some used in less amount. With rising in a turbulent environment, Hospital organizations need to be flexible so that they can manage

**Fig. 1** Step-wise research methodology for SLR



**Fig. 2** Typical healthcare supply chain



uncertainties and helps in risk mitigation strategies (Bag et al., 2018; Sushil, 2017).

Other specific issues are cited as follows:

- The health care supply chain is very complex in comparison to the standard supply chain because of the presence

of essential and nonessential medical items. In addition to this, human lives are associated with HSCM (Aldri-ghetti et al., 2019).

- Harmful waste is associated with HSC. There is a need for a reduction in waste. Healthcare systems have a pressure to reduce the cost for the elimination of waste mate-

rial without hampering the quality of care provided to patients (Battini et al., 2013).

- HSC needs to maintain high levels of stock to provide a 100% service level. This leads to an increase in cost (Neve & Schmidt, 2021). During the COVID-19 outbreak, the demand for drugs became highly unpredictable, which further leads hospitals to overstock and sometimes understock.
- Requirements of patients and their expectations are changing with time leads to difficulty in managing the HSC (Kumar et al., 2018).
- HSC needs to be flexible so that it can quickly adapt to external changes (Dubey et al., 2019).
- HSC needs to increase the responsiveness and to mitigate the risk (Dubey et al., 2019).

Furthermore, healthcare sector is continuously facing several operational challenges during and beyond COVID-19 pandemic in several ways like low bed capacity, lack of medical resources, vaccines, PPE kits and equipment”, staff shortage in healthcare industry”, mismatch between demand and supply of essential, and uncertainty in demand with each upcoming wave, etc. (Burgess & Radnor, 2013; Leung et al., 2020; Leite et al., 2020). Therefore, proper contingency plan need to be in place for mitigation of such risks.

## Evaluation Criteria for Healthcare Supply Chain Disruption Models

To the best of our knowledge, this paper is the first one where we will discuss modelling approaches related to supply chain disruption in Healthcare Sector. Table 1 shows all the criteria with their measurable indicators.

Understanding of propagation helps to form the mitigation strategies and reduction of risks in the supply chain.

**Table 1** Derived evaluation criteria for healthcare supply chain disruption modelling

Evaluation criteria	Indicators
Number of considered risks	(One, two, three or more than three)
Consideration of risk propagation	Yes/no
Duration of risk	Short term (ST)/long term (LT)
Risk identification	Yes/no
Risk assessment	Yes/no
Risk mitigation	Yes/no
Risk optimization	Yes/no

According to Qazi et al., (2015), risk propagation is a trendy topic for future research. In our review, if propagation is considered in the modelling approach, then it satisfies our criteria. We have also checked the duration of risk in modelling approaches that either the effect on supply Chain is for Short term or Long term. Supply chain models have a specific objective of reducing the vulnerability of the supply chain or increases the resilience of supply chain. Appropriate strategies can optimize these things if the future risk situation of the supply chain can be predicted well. In our review, if any mitigation strategy is involved in the modelling approach, then it satisfies our criteria. According to Chopra and Sodhi (2004), there are no simple strategies for prevention or completely reduce the impact of disruption. Mitigation Strategies are defined as actions taken by a firm to lessen the risk of disruption. Mitigation strategies are categorized into 4 different parts: elimination of risk, reduce the frequency and consequence of risk, acceptance of risk, and transfer the risk by sharing (Zsidisin & Richie, 2009).

Our work is focused on risk-related criteria and leaves out other general points like the flexibility of modelling approaches and the complexity of modelling approaches.

## Evaluation of Identified Healthcare Supply Chain Disruption Modelling

The identified literature can be broadly classified according to the use of modelling techniques since different modelling approaches have their characteristic features with some pros and cons.

### Optimization Methods

Optimization is a relatively new approach to optimization of uncertainty affected issues. In has already been proven that this is one of the most potent techniques for tackling real-life problems that mostly deals with uncertain events (Aharaon et al., 2009). This technique can be used with both a single objective optimization problem as well as a multi-objective optimization problem. It provides a solution that has an acceptable performance under most of the uncertain events. Peng et al. (2011), Pishvae et al. (2011) have used robust optimization in a single objective context. In the bi-objective context, robust optimization is used by Fahimnia et al. (2017), Diabat et al. (2019).

Metz and Zabinsky (2010) presents a Stochastic optimization approach for storage and distribution of medical supplies in disaster condition. To prepare against disaster, the Stochastic programming model has been developed for the selection of storing locations of medical supplies and inventory levels for each medical supply. Jabbarzadeh et al. (2014) develop a dynamic, Robust stochastic optimization

model for designing the supply of blood during and after the disaster. This model can assist in blood facility location and allocation decisions for multiple post-disaster periods. Hamdan and Diabat (2020) developed a multi-stage optimization model for the blood supply chain. In this model, robust optimization two-stage stochastic optimization was used for the mitigation of the effect of disasters, optimization of total costs and consideration of delivery time of blood to the hospitals.

## Game Theory

Game theory helps to decide the best possible option in the conflicting decision. It simply provides the general rule of logic but does not give the winning strategy. In real-life scenarios, there is much uncertainty that has not been considered in the Game theory approach. Delaurentis et al. (2008) develop a Game theory approach for solving the problem of medical stockpiling in preparation for a flu pandemic. This paper aims to develop an analytical approach for determining the appropriate stockpile levels of critical medical items (excluding vaccines) under various flu pandemic scenarios. This paper focuses on group decision making for a community of hospitals. It has been found out in the study that the hospital's decision on how much stockpile of one item needed depends not only on uncertainties but also on its mutual aid relationship with other hospitals. Adida et al. (2011) use the Game Theory approach for joint inventory stockpiling of medical supplies for a certain group of hospitals before the disaster. During the disaster, demand is uncertain. That is why there is a need for stockpiling of medical supplies. The objective of this paper is to estimate the amount of stockpile in a decentralized setting by minimizing the total cost of Stockpiling. The model is also compared with the centralized setting. Mamani et al., (2013) proposes a game theory model to contract the coordination mechanism for influenza vaccine.

## Queuing Theory Model

Queuing theory is used for modelling of those processes which involve problems related to waiting lines. Basically, it is used for the mathematical study of formation, function, and congestion of waiting for lines (McManus et al., 2004). Many health researchers and health care managers have been using queuing theory since 1950 to describe and analyse the hospital system (Baily, 1952; Green & Nguyen, 2006; Worthington, 2009). Over the years, a number of theoretical, analytical queue models were developed for the analysis and enhancement of the performance of hospitals and their sub-systems. The performance metrics usually calculated using calculations formulas developed in queuing theory include

time-waiting for measures, congestion measures, idle time measures, and the use of the server. Hui. (2010) constructed a model for analysing and interpreting time-optimal control of the distribution of antibiotics in case of the bioterrorist attack in a metropolitan queuing network which has been considered in this paper. Mainly, antibiotic distribution is considered in various stages of the disease.

## Simulation

A simulation of the supply chain shows the behaviour over time of the logistics network. A model shows the logical network of the supply chain, and it is then executed over time to dynamic the simulation. Lee (2008) develops a simulation model for evaluating the effectiveness of alternative dispersiveness plans for emergency medical supplies (vaccine and antibiotics) in the event of bioterrorism in US. In this paper, the author assesses and analyses logistics and supply chain plans for distributing vaccines in smallpox attack. Azghandi et al. (2018) use a mathematical simulation model to examine the effect product recalls considering different disruption scenarios like propagation in time and space, interactions of decision-makers on drug shortages to ascertain how these shortages can be mitigated by changing decision policies related to inventory. Aldrighetti et al. (2019) have used a simulation approach to analyse the effect of disruption and mitigation strategies. Haghjoo et al. (2020) develop a Dynamic robust allocation model for designing a blood supply chain under facility disruption risks and uncertainty in a disaster situation. It has been considered that the effect of disruption in facilities depends on the initial investment level, which is affected by the allocation budget. Paul et al. (2020) proposed a Bayesian Network Model for transportation risk associated with pharmaceutical supply chain disruption in Bangladesh context.

Discrete event simulation (DES) is a way to simulate the dynamic behaviour and performance of a real-life scenario. DES concept models have modelled a wide range of supply chain planning issues, including supply chain design, inventory planning, production scheduling, and supplier selection (Tako & Robinson, 2012). Simulation only allows "what if" analysis whereas enables decision-makers to test and better understand possible ways to meet a new strategy.

Elleuch et al. (2014) describe the supply chain risk approach to assist decision-makers to risk identification, assessment and management. The approach combines for several techniques like Failure mode, effects, and critical analysis (FMECA) to identify the risk and its current location, Design of experiment (DOE) to design risk mitigation and action scenarios, Discrete event simulation to assess risk mitigation scenarios and Analytic hierarchy process (AHP) method to evaluate the risk management scenarios.

## Mathematical Modelling

Compartmental models are used to perform the mathematical Modelling of infectious diseases. In this method, the population is divided into compartments with different labels like susceptible, infectious, and recovered. The origin of this model is from the work of Kermack et al. (1927). Arinaminpathy and Mclean (2008) use Mathematical Modelling (differential modelling and compartmental Modelling) for stockpiling of antiviral drug Tamiflu. Liu (2007) develops a mathematical model that can be used for deriving necessary stockpiling level for the vaccine to meet the urgent need in the natural outbreak of epidemic disease. It has been considered in the paper that there is a shortage of vaccines due to high demand, but production is normal. The goal is to minimize the shortage, given a fixed total cost (both waste and inventory holding cost). Firstly, an oversimplified model has been developed. In the next step, a more realistic model has been developed. Kamp et al. (2010) use mathematical models and computer simulations to find the availability of blood products during Influenza epidemic. The spread of Influenza disease is modelled by the compartmental susceptible–infected–recovered model (SIR model). Sha and Huang (2012) propose a multi-period location model for scheduling of blood in an emergency after an earthquake in Beijing. Govindan et al. (2020) used the Fuzzy interface system in healthcare system for reducing stress in the community, breaking the propagation of COVID-19 and mitigating the epidemic outbreak for healthcare supply chain disruption. Chick et al., (2008) design a cost sharing contract for influenza vaccine supply chain.

## Mixed Integer Linear Programming

Mixed-integer linear programming is developed for the design of the high dimensional and nonlinear system. It is used for system analysis and optimization as it presents a flexible and robust method for solving a large and complex problem. Shishebori and Yousefi Babadi (2015) use a mixed-integer linear programming model for designing a robust and reliable medical service (MS) centre location network design. It considers uncertain parameters, system disruptions, and investment budget into account. The model is based on a robust optimization approach. Hasani and Khosrojerdi (2016) created mixed integer-linear model for designing a robust global supply chain network for a medical device manufacturer under uncertainty to maximize the total after-tax profit. Liu and Zhang (2016) developed the FPEA model for the study of the dynamic allocation of medical resources in the control of an epidemic diffusion. This model is used for logistics planning for satisfying forecasted demand and minimizes the total cost. Lückner and Seifert

(2017) use it to analyse optimal risk mitigation strategies for a single firm that is affected by supply chain disruption risk. The paper focuses on Risk mitigation inventory (RMI) and process flexibility decisions for a pharmaceutical firm. Timajchi et al. (2019) proposed a bi-objective mixed integer mathematical programming for the inventory routing problem of hazardous and deteriorating pharmaceutical items in a healthcare network.

## System Approach

System dynamics is a very abstract modelling method. It ignores the fine details of the system, such as individual properties of individuals, products, or events and generates a general representation of a complex system. Brailsford et al. (2004) used a system dynamics approach for reviewing emergency and on-demand healthcare in Nottingham, England. Parvin et al. (2018) develop a solution methodology that integrates strategic-level and tactical level models for managing the distribution of malaria medications, such as Artemisinin combination therapies in three-tier centralized health system. A two-stage stochastic programming model was constructed at a strategic level for addressing the demand uncertainty problem. For the tactical level, the Markov decision approach was used for determining the optimal periodic transshipment policies.

## Agent-Based Model Approaches

Agent-based Modelling is a modelling and simulation method in which multi-agent systems represent social, economic, and ecological systems, etc. (Salamon, 2011). An agent is an independent, self-oriented and human agency that can act independently from other agents. It interacts with and reacts to other agents and their environment by having a simple collection of rules of it and then or by integrating complex techniques of artificial intelligence into its behaviour (Taylor, 2014). Wang et al. (2012) describe agent-based simulation for an emergency response to a mass causality incident in an urban area. The model is developed with the help of geographic information system (GIS) data and resource information which facilitates building of an model for area where both GIS and resource data are available. In last, simulation models are used for evaluation of provided options which may help policy makers.

## Hybrid Model

Anagnostou et al. (2013) developed an integrated model of Discrete event simulation (DES) and agent-based simulation (ABS) for emergency medical services. The DES was used to model the workflow of the EMS for the identification

of system bottlenecks. Whereas ABS integrated geographic information system for modelling ambulance movements and their interaction with the operation centre. Fakhimi et al. (2015) presented an integrated model of DES and ABS for the analysis of sustainable planning strategies for EMS. ABS paradigm was used for Modelling of ambulance services (emergency call centre, vehicles and crews) while considering environmental, social and financial factors for sustainability modelling. At the same time, DES paradigm was used for the analysis of resulting data of ABS paradigm. Shamsi et al. (2018) constructed a specific option contract for proactively provisioning required vaccine from two suppliers (main supplier and a backup supplier). This model goal is to minimize procurement and social cost. A hybrid solution was proposed to find the optimal solution in which optimal control, Stackelberg game model and nonlinear programming approach are included. It has found from the study that policy-making decisions influenced by the season in which disease occurs. The transmission rate of disease, natural recovery rate and natural deaths are variables that plays major role in decision-making process of epidemic diseases. Fahimnia et al. (2017) use a Stochastic bi-objective model for efficient and effective blood supplies in disasters. The blood supply network consists of Blood donors, mobile blood facilities, local and regional blood centres, and demand points.

Table 2 briefly describes all the modelling approaches used in supply chain disruption in healthcare industry.

## Results and Discussion

Currently the world is fighting with COVID-19 pandemic, which affects almost all the sectors whether it is Hospitality, Aviation, Tourism, Manufacturing, E-commerce, Retailers (Business News, 2021). But it has severely caused disruption in Healthcare Sector in terms of demand uncertainty for PPE kits, Vaccines, Medical devices, and Pharmaceuticals (DeSalvo et al., 2019). There have been several quantitative modelling approaches used in different disruption events and during pandemics like Robust Optimization, Simulation, Mathematical programming, Game Theory and Queuing Theory. Only Govindan et al., (2020) has proposed fuzzy modelling in case of COVID-19 but still there has been a lot of scope for applying mathematical programming, game theory, optimization approaches, and simulation for risk identification, assessment and risk mitigation caused by COVID-19 pandemic (Gupta & Soni, 2021). As has been highlighted in Table 2, very few of the articles have considered multiple risks in their methodology. Moreover, risk optimization is also not being undertaken by many of them. This is one of the major research gap which needs to be addressed. In

order to benchmark the best healthcare practices during such pandemic; demand and supply management, collaboration between public and private partners, collaboration between the primary and secondary healthcare, employee-and-patient centric resources are required to be facilitated for further functioning of the healthcare systems and address the critical issues. Optimization of risks is also crucial not only for addressing the shortages in healthcare staffs, PPEs, equipment, etc. but also to rather prepare a robust disaster plan while implementing lean practices along with Industry 4.0 technologies for a sustainable healthcare system in place. It is, therefore, essential to make a resilient supply chain to assess decision-making in times of epidemic outbreaks (Dolgui & Ivanov, 2021; Ivanov, 2020). Several researchers have published articles regarding supply chain disruption modelling (Cui et al., 2016; Hou et al., 2018; Ivanov, 2017; Torabi et al., 2015; Wilson, 2007; Zhang et al., 2015). Moreover, there are several opportunities to improve International Competitiveness (IC) of the healthcare industry from Indian perspective also.

## Managerial Implications

Competitiveness plays an important role in improving the efficiency, productivity of any firm while building a sustainable ecosystem. The emerging economies, like India may reap huge benefit due to ample number of existing opportunities. The findings of the study clearly state the critical need for the modelling approaches in order to mitigate the various risks generated in a healthcare supply chain, particularly during and post-pandemic. The results of the study help the practitioners and healthcare managers to use the various models for facilitating the resources across the supply chain and therefore plan accordingly in future for a resilient and sustainable healthcare supply chain. Moreover, this brings on advantages and opportunities for promoting medical tourism and use of emerging technologies for building various dimensions of competitiveness and sustainability (Chauhan et al., 2021; Mishra & Sharma, 2021; Momaya, 2020).

## Conclusion, Limitations and Agenda for Future Research

This review has identified all the existing modelling approaches related to supply chain disruption modelling, with respect to risk-specific criteria from the literature. The analysis indicates that modelling approaches fulfil a great number of risk-specific requirements, but still a lot of progress needs to be made. Especially, on the main network

**Table 2** Modelling approach to model healthcare supply chain disruption

Author	Number of risks	Risk propagation	Duration of risk	Risk identification	Risk assessment	Mitigation of risk	Risk optimization	Modeling approaches
Brailsford et al. (2004)	1	No	ND	Yes	Yes	Yes	No	System Dynamics
Liu (2007)	2	No	LT	Yes	Yes	No	Yes	Mathematical Programming
Arinaminpathy and Mclean (2008)	2	Yes	LT	Yes	Yes	Yes	No	Mathematical Modelling (differential equation and compartmental Modelling)
Chick et al. (2008)	1	No	N	No	No	No	No	Mathematical Model
Delaurentis et al. (2008)	2	Yes	LT	Yes	Yes	No	No	Game Theory
Lee (2008)	3	No	LT	Yes	Yes	No	No	Simulation
Lee et al. (2009)	1	No	ND	Yes	Yes	No	Yes	Mathematical modelling
Kamp et al. (2010)	2	Yes	LT	Yes	No	No	No	SIR mathematical model,
Hui (2010)	1	No	LT	Yes	Yes	No	Yes	Queuing Theory
Mete and Zabinsky (2010)	3	No	ST	Yes	Yes	No	No	Two Stage Stochastic Optimization
Adida et al. (2011)	2	No	LT	Yes	Yes	No	No	Game Theory
Sha and Huang (2012)	3	No	ST	Yes	Yes	Yes	No	Lagrangean Relaxation, Mathematical Programming Formulation
Wang et al. (2012)	1	No	ND	Yes	Yes	No	No	Agent-Based Modelling
Anagnostou et al. (2013)	4	No	ND	Yes	Yes	No	No	Hybrid Modelling (Discrete Event Simulation and Agent-based simulation)
Mamani et al. (2013)	1	Yes	ND	Yes	No	No	No	Game Theory
Allen et al. (2014)	1	No	ND	Yes	Yes	No	Yes	Discrete Event Simulation
Elleuch et al. (2014)	3	Yes	ND	Yes	Yes	Yes	No	Discrete Event Simulation, AHP
Jabbarzadeh et al. (2014)	4	No	ST	Yes	Yes	No	Yes	Robust Optimization Model
Fakhimi et al. (2015)	1	No	ND	Yes	Yes	No	No	Hybrid Modelling (Discrete Event Simulation and Agent-based simulation)
Shishebori and Yousefi Babadi (2015)	2	No	ND	Yes	Yes	No	Yes	Mixed-integer linear programming model
Hasani and Khosrojerdi (2016)	2	No	ST	No	No	Yes	No	Mixed-integer linear programming model
Liu and Zhang (2016)	2	Yes	LT	Yes	Yes	Yes	No	FPEA Model
Lücker and Seifert (2017)	1	No	LT & ST	Yes	Yes	Yes	Yes	Mathematical model
Fahimnia et al. (2017)	5	No	ST	Yes	Yes	No	No	Stochastic bi-objective Supply Chain model, Hybrid solution approach, combining e- constraint and Lagrangean relaxation method
Parvin et al. (2018)	3	No	ST	Yes	Yes	Yes	Yes	System Dynamics
Shamsi et al. (2018)	2	Yes	LT	Yes	Yes	No	Yes	Hybrid Modelling (Stackelberg Game Model and Nonlinear Programming Model)
Aldrighetti et al. (2019)	1	Yes	LT & ST	Yes	Yes	Yes	No	Simulation
Timajchi et al. (2019)	2	No	ND	Yes	Yes	No	Yes	Mixed-integer linear programming model
Haghjoo et al. (2020)	2	No	ST	Yes	Yes	No	Yes	Meta heuristic model, Monte-Carlo simulation
Paul et al. (2020)	1	No	ND	Yes	No	Yes	No	Bayesian Belief Network
Govindan et al. (2020)	1	Yes	LT	Yes	Yes	Yes	No	Fuzzy Modelling



**Table 2** (continued)

Author	Number of risks	Risk propagation	Duration of risk	Risk identification	Risk assessment	Mitigation of risk	Risk optimization	Modeling approaches
Hamdan and Diabat (2020)	4	No	ST	Yes	Yes	Yes	Yes	Two Stage Stochastic Optimization Model, Lagrangean Relaxation

ST short term, LT long term, ND not defined

level, risk characteristics, namely risk propagation, risk mitigation should be given more emphasis by future research efforts. In addition to this, data basis of all the approaches could be given a more central role to increase the validity of models.

This systematic literature review used the keywords based on several number of trials so that it can cover most of the articles. Although there can be a possibility that some modelling approaches has not been covered because specified modelling approach was not the search criteria, instead of this a general keyword for modelling has been used. Secondly, the articles from business and management domain are only considered. There is a possibility that some articles exist in other subject areas. Future research studies can develop some methodology to deal with these limitations.

Most of the studies has been done for short-term disruption. In future, suitable modelling techniques for medium-term disruption and long-term disruption in healthcare supply chain are required to be explored. Furthermore, the use of Multi-Criteria Decision-Making, Stochastic Programming, Input–Output modelling approach may be used to deal with supply chain disruption in healthcare sector. In addition to that, prospective models should put more emphasis on resilience and risk control in HSCM. It is, therefore, expected that the research field to grow further, expand, and play a more decisive role for academics and practitioners from competitiveness point of view.

## Key Questions Reflecting Applicability in Real Life

1. What are the critical barriers/challenges in healthcare supply chain for achieving resiliency and sustainability?
2. How to address the ethical issues in a healthcare industry?
3. What are the key factors that drive digital health business post-pandemic in improving the competitiveness of healthcare industry?
4. What dimensions facilitate patient's safety and mental health post-and-beyond pandemic?

5. What are the major challenges for the implementation of lean six sigma in Indian hospitals?

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**Code availability** Not applicable.

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**Conflict of interest** The authors declare there is no conflict of interest.

**Data transparency** All authors ensure that all data as well as software application and support the published claims and comply with field standards.

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