



Impact analysis of COVID-19 outbreak on cold supply chains of perishable products using a SWARA based MULTIMOORA approach

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Abstract

The present study aims to analyze the impact of the COVID-19 outbreak resulting in Cold Supply Chain (CSC) disruptions and shed new light on the potential opportunities yielded from the pandemic. In addition, the work also aims to explore the most appropriate strategies to minimize CSC disruption due to the COVID-19 outbreak and to repurpose to create conditions as they were before the pandemic. The impact of the COVID-19 outbreak on CSCs has been analyzed theoretically and empirically, considering seven broader assessment criteria. To diminish the disruption due to COVID-19, eight of the most appropriate remedial strategies have been proposed in this study. A new hierarchical model was developed to articulate the analysis and consolidate various issues pertinent to CSC disruption caused by COVID-19 in one frame. The developed model was analyzed using a hybrid approach of SWARA-based MULTIMOORA methods. The SWARA method has been used to analyze the significance of considered assessment criteria, while the MULTIMOORA method has been used to analyze the mutual importance of proposed strategies. The findings of this paper show that ‘structural impact’ and ‘business and financial impact’ are the two most affected traits of CSC during the COVID-19 pandemic throughout the world. Meanwhile, the strategies ‘development of safe and healthier work scenario for partners of the cold chain’ and ‘successful monitoring and implementation of COVID-19 protocols’ are the two most important proposed strategies that might help management to mitigate the influence of the COVID-19 outbreak on CSCs. Findings of this research enable CSC managers and policy-makers to develop potential and robust plans for their operations to respond to disruptive situations like COVID-19 and turn them into opportunities for organizational growth and improving the health of society.

Keywords COVID-19 pandemic · Food products · Pharmaceutical products · Cold Supply Chain · SWARA method · MULTIMOORA method

Abbreviations

COVID-19 Coronavirus disease 2019
SARS-CoV-2 Severe Acute Respiratory Syndrome
 Coronavirus 2

CSC Cold Supply Chain
WHO World Health Organization
GHG Greenhouse gas
JIT Just in Time
GCCA Global Cold Chain Alliance
PPE Personal Protective Equipment
CAGR Compound Annual Growth Rate
SWARA Stepwise Weight Assessment Ratio
 Analysis
MULTIMOORA Multi-Objective Optimization by Ratio
 Analysis plus the Full Multiplicative
 From
 B_j Relative importance score for criterion
 j
 \bar{B}_j Average relative importance score for
 criterion j
 E Number of experts’ groups

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G_j	Comparative importance score for criterion j
K_j	Coefficient value for the relative importance of criterion j over the other
G'_j	Corrective weight for the criterion j
W_j	Final weights for criterion j
A	Direct decision matrix for the proposed strategies
a_{ij}	The relative score for ith strategy relative to jth criteria
a^*_{ij}	The normalized relative score for ith strategy relative to jth criteria
V_{ij}	Weighted normalized decision matrix
W_j	Weight of jth criterion
Y_i	Utility for ratio analysis system
U_i	Utility for full multiplicative MOORA approach
Z_i	Reference point approach
l	Number of beneficial criteria
$n-l$	Number of non-beneficial criteria
t_j	Maximal objective reference point for criterion 'j'
D_{ij}	Weighted distance of ith alternative (strategy) from t_j
$IMB(AV)$	Improved borda assessment value
m	Number of alternatives (strategies)
n	Number of criteria
$r(Y_i), r(Z_i), r(U_i)$	Preference order/ ranking obtained from ratio analysis, reference point approach and full multiplicative form respectively
R	The final order of preference for the proposed strategies
FCSC	Food Cold Supply Chain

1 Introduction and background

COVID-19, also termed SARS-CoV-2, is an infectious disease caused by the most recently discovered member of the coronavirus family. Coronavirus was first found by Arthur Schalk and M.C. Hawn in the 1930s in North Dakota when severe infections in the respiratory system of chickens were observed and characterized as infectious bronchitis virus (IBV) (Lai et al. 2020; Estola 1970). On 31st December 2019, the first case of SARS-CoV-2 was reported at the WHO office in Wuhan, China (Shi et al. 2020; Lal et al. 2020). However, on 30th January 2020, the World Health Organization (World Health Organisation Report 2020) declared it an international public health emergency (Lal et al. 2020). At the time of the current research work, the United States of America (U.S.A.), India, Brazil, France and the United Kingdom (U.K.), are the five most affected

countries due to COVID-19. At the same time, more than 482 million COVID-19 confirmed cases and the loss of more than 4.9 million human lives had been reported worldwide (Worldometer 2022). Still, the cases of coronavirus continue to increase. Yet, no approved vaccine has been discovered that eliminates the possibility of coronavirus spreading. Phase-wise lockdowns, bulk quarantine, travel bans, the prohibition of transportation and social distancing were imposed by the majority of governments in their respective countries to control the spread of the COVID-19 pandemic.

In the current scenario of the COVID-19 outbreak, the most critical challenge for governments and policymakers is to provide healthy food and healthcare security for the people (Shanker et al. 2021; Marques da Rosa et al. 2021). In the wake of the novel COVID-19 pandemic, people have become more aware and health-conscious. As a virtue, people have stressed the quality of the product rather than its cost (Lu et al. 2020), resulting in an increase in demand for healthy and hygienic foodstuffs and other perishables on a large scale. Perishables are those products that have short life cycles, are sensitive to environmental parameters (such as temperature, pressure, humidity and light), and are fragile (Joshi et al. 2011). Therefore, when these products are exposed to temperatures outside a sustainable range, chemical reactions start, and a microbial decay in their quality, integrity and potency occurs (Ali et al. 2018; Joshi et al. 2009). Therefore, they require a temperature-controlled environment (such as refrigeration and smart packaging system) for production, storage and movement (Masudin and Safitri 2020).

Due to the capability to maintain the quality and hygiene levels of the product, CSC operations have been viewed as the veins of a healthy society and the country (Qin et al. 2021; Gligor et al. 2018). A CSC is an unbroken process combining various facilities that can maintain a permissible sustainable temperature range of perishable products from the point of origin to final consumption (Joshi et al. 2012). During the pandemic outbreak, with most countries imposing lockdowns and social distancing to mitigate the spread of coronavirus, CSCs were still working 24 h a day to ensure the quality and hygienic standards of delivered products. Despite various significant advantages, the cold supply chains of perishable products face various glitches in their processes due to the COVID-19 pandemic.

Due to the outbreak, considering the effects of COVID-19, food and pharmaceutical supply chains are the two sectors most affected. Despite the severity of the pandemic on the global supply chain, millions of lives have been lost due to the disruptions to proper food and health facilities. Most supply chain linkages were interrupted due to shutdowns and scarcity of labor. So far, literature examining the impact of the COVID-19 outbreak on the perishable products' supply chain has discussed only the adverse

effects over a specific dimension, such as the economic, environmental or societal impact. For instance, in a study performed to analyze the impact of the COVID-19 outbreak on the food supply chain, focus was given to the socio-economic aspect (Abdul et al. 2021). A similar study has aimed to explore the role of management initiative in up-taking the traceability system during the COVID-19 pandemic in the context of the Indonesian FCSC (Masudin et al. 2021). The importance of technological practices has been presented as one of the top requirements to cope with problems in the flow of food in FCSCs during the pandemic (Chitrakar et al. 2021; Masudin et al. 2021). Owing to the importance of CSCs in the health and food security of every society and country, it has become essential to analyze the impact of the COVID-19 outbreak on the CSCs of perishable products.

Unpredicted lockdowns and seizing operations have disrupted the global supply chain market of perishable products and put at risk the food and health security of the world (Sharma et al. 2021a; Barbieri et al. 2020). The COVID-19 pandemic has not only caused the loss of millions of human lives but has also severely affected the socio-economic structure of the globe (Yu et al. 2021). Although the COVID-19 pandemic has brought the whole world to its knees, the conditions have been even worse in developing countries like India. India is the second-largest populated country and the second-worst affected country due to the COVID-19 pandemic (to the date of writing). As the government of India imposed a lockdown and social distancing norms, numerous instances had been noticed where a large number of perishables (fresh fruits, vegetables, grains and pharmaceuticals) went to waste due to unavailability of labor and the inability of producers to access a cold storage facility (Sharma et al. 2021a; Sinha et al. 2021). In India, due to the COVID-19 pandemic, the unemployment rate reached a maximum level and reduced the country's economic growth by 23.9% (Barbate et al. 2021). More than 80,000 crore INR losses have been incurred in the Indian food sector (Sharma et al. 2021a). In agriculture, around 20–30% of fresh agricultural produce went to waste due to the disruption in its supply chain structure amid the adversities of COVID-19 lockdowns (The Hindu 2021). Although the Indian context has been selected for study due to its capability to carry out an analysis with regard to COVID-19 restrictions within a real-time market scenario, the orientation of the study has been shifted towards realizing the effect of the COVID-19 outbreak on CSCs in a global context.

Therefore, to repurpose the strength of CSC utilization to a level as it was before the pandemic, it becomes necessary to analyze the impact of the COVID-19 outbreak on perishable products' CSCs by consolidating various perspectives associated with the disruption due to the pandemic. Further,

to improve CSC performance and be able to withstand such adversities, it is necessary to explore learning opportunities from the COVID-19 pandemic. Therefore, this study is structured to address the following research questions (RQs):

RQ 1: What are the broader areas of perishable products' CSCs affected by the COVID-19 pandemic ?

RQ 2: How has the COVID-19 outbreak affected the performance of perishable CSCs?

RQ 3: What strategies can be adopted to mitigate the impact of the outbreak on perishable products' CSCs and convert adversities into opportunities?

Insights of the research will expose the comprehensive value of both theoretical and empirical investigation in the subject domain. The research carries out an in-depth literature analysis of previous work in the realm of the effects of the COVID-19 pandemic on the cold supply chain. In addition, the presented work also aims to provide management and academia with a healthier basis for understanding the severity of the COVID-19 outbreak by considering some real-life examples and facts. At the same time, relative importance scores of the suggested strategies to fight against such adverse situations are proposed. The proposed work has been carried out to assess the impact of the COVID-19 outbreak on the cold supply chain and possible remedial strategies both theoretically and empirically. A preference rating approach has been used for the mutual importance assessment of the strategies suggested to overcome the effects of COVID-19 on CSCs.

The presented work aims to bridge the gaps of previous studies and ground the various aspects of the influence of the COVID-19 outbreak depicting diverse subjective and empirical perspectives associated with CSCs of perishable products. Thus, it enables CSC managers and decision-makers to develop potential and robust plans for their operations to respond to situations like COVID-19 and turn them into opportunities for organizational growth and positive change. To the best of the author's knowledge, this is the first paper that consolidates various areas of perishable CSCs affected by the COVID-19 outbreak into one frame through a theoretical and empirical analysis. The conceptual model and analysis of this paper might help CSC authorities, practitioners and researchers to improve CSC performance and grasp the opportunities arising from the COVID-19 outbreak. In addition, it also provides an opportunity to re-examine their CSC operations and check systems for the insurance of food security and a better public healthcare system.

The study has been organized in the following way. In Sect. 2, the literature review of the studies published in the domain of CSC and COVID-19 pandemic has been elucidated. The theoretical conception of the effect of the COVID-19 outbreak on CSCs has been discussed in the sub-sections of Sect. 2. Section 3 provides a methodological

overview of the proposed methodology. Sub-Sects. 3.1, 3.2 and 3.3 discuss the motivation for using the proposed methodologies, SWARA method and MULTIMOORA method, respectively. Section 4 has been elucidated to discuss the empirical assessment of criteria and proposed remedial strategies. In Sect. 5, a discussion on achieved research results is presented. Section 6 sets out the conclusions of the study; sub-Sects. 6.1 and 6.2 discuss the theoretical and managerial implications followed by limitations and future avenues of the work, respectively.

2 Literature review

In the current situation, COVID-19 has worsened the conditions of global CSCs of perishable products in respect of business, cost, priorities and future opportunities (Barbieri et al. 2020). Besides this, several pros and cons have been observed in the global CSC structure and its performance during this global health emergency due to COVID-19. Therefore, it is necessary to evaluate and analyze the impact of the COVID-19 pandemic and its social effects on perishable products' CSCs during this outbreak and find some appropriate strategies that might help to tackle such situations in future (Kumar et al. 2020b).

Nowadays, with the whole world facing global health and economic emergencies, the average rise in global temperature creates a very critical situation for us all. The average temperature for the spring season of 2020 (March to May 2020) is the second-highest average global temperature rise (1.905 °F) in the twentieth and twenty-first centuries after the year 2016, when the average was recorded as 1.995 °F (Global Climate Report 2020). Due to the rise in global temperature and lockdown periods during the COVID-19 pandemic, many perishables and temperature-sensitive products (such as fresh fruits, vegetables, meat and seafood) went to waste; these could have been used as a source of food.

From production to end consumption, perishables such as food and pharmaceuticals are often transported for long distances and under time constraints (Hall and Johnson-Hall 2021). Due to a shorter life cycle and perishable nature, these products face a higher risk of being wasted (Kumar et al. 2021a, b; Kumar et al. 2022). Due to lockdown and restrictions on travel during the COVID-19 outbreak, most farmers, whether in a rural or urban area, found themselves unable to transport their agro produce to market. As a result, a considerable amount of agro produce went to waste due to the unavailability of refrigerated transportation facilities and cold stores to keep them fresh. The COVID-19 pandemic has severely affected the food and beverage supply chain (Chowdhury et al. 2020). To ensure food and healthcare security, there should be a sufficient volume of cold storage

facilities so that farmers and other people can quickly access these services. It will not only ensure food and healthcare security for the general population but also improve the welfare of farmers (Sim and Wiwanitkit 2021).

Although the outbreak has disrupted the global supply chain structure of all logistics, the disruption in the food and pharmaceuticals supply chain has brought the whole world to its knees; these are basic needs for human beings to survive. Various authors have presented food waste in the processing and supply chain stages as the world's central problem (Batista et al. 2021; Read et al. 2020). More than 40% of the total food produced worldwide went to waste only because of insufficient cold storage facilities, lack of proper training for handling staff, old packaging trends, lack of temperature monitoring and inefficient refrigeration technology (Food and Agriculture Organization 2013). This not only results in more than \$750 billion annual losses to the global economy but also creates a problem of food security for the future (Department of Commerce 2016).

A decline in economic growth has been observed in most countries (Barbate et al. 2021). Amid the COVID-19 catastrophe, a significant decline in the first and second-quarter revenues of the CSC has been observed, while the monthly operational cost has increased by 1–1.5% (GCCA 2020). It has been estimated that the coronavirus pandemic might cost more than \$2 trillion to the global economy by the end of 2020 (UNCTAD 2020). However, the cost of the COVID-19 pandemic might reach \$8.8 trillion in global economic losses by the end of 2020 (ADB, as reported by BBC News, dated 15 May 2020). In such hostile situations with the decline in economic growth, people are cutting back on purchasing things; consequently, a drop in the economic growth rate of CSCs has been experienced.

Another broader aspect of CSCs of perishable products during the COVID-19 outbreak is the effect of consumer behavior in demand for frozen and chilled products. During the century's most fatal disease, a drastic shift in consumer behavior related to chilled and frozen products has been observed (Sharma et al. 2021b). Previous studies on coronavirus transmission have shown a strong relationship between the coronavirus spread and environmental conditions such as temperature and humidity. Past analysis shows that the most favorable conditions for the survival of coronavirus are 4 °C surrounding temperature (Casanova et al. 2010). It has also been observed that a strong relationship is present between the spread of COVID-19 and environmental conditions with around 90% of COVID-19 cases seen in countries where temperature and relative humidity range from 3–17 °C and 3–9 g m⁻³ respectively (Sharma et al. 2021a). To cope with these circumstances, people are cutting back on purchasing chilled and frozen products; this has significantly influenced the CSC market globally.

To analyze the impact of the COVID-19 outbreak on the perishable products' CSC, an extensive literature review of articles published in national and international journals, newspapers, reports and websites related to CSC disruption during the COVID-19 pandemic has been performed. The findings of the literature analysis were discussed with relevant professionals having field and academic backgrounds. Based on this, seven broader criteria have been recognized and selected for impact analysis. These broader criteria are structural impact (C1), social impact during the pandemic outbreak (C2), current cold chain market strategies and trends (C3), consumer behavior and purchasing habits (C4), business and financial impact (C5), impact of governmental response (C6) and impact on quality and security of product (C7). Figure 1 demonstrates the broader criteria of disruption analysis due to the COVID-19 outbreak on the performance of the CSC.

In addition to the above, this research has also proposed best-suited strategies that may help management and decision-makers to mitigate the adverse impacts of the COVID-19 outbreak on the CSC and society in general. Based on the existing literature review, time-to-time analysis of the recommendations of the WHO and governments and dis-

cussion with relevant professionals, eight best-suited strategies have been selected. The strategies are shortening and simplifying the long cold chain links (S1), integration of all parties in the link (S2), facilitating the ease of access to personal protective equipment (PPE) and COVID-19 testing for workers and employees (S3), successful monitoring and implementation of COVID-19 protocols (S4), development of short to medium term strategies and plans for unprecedented situations like COVID-19 (S5), development of a safe and healthier work scenario for partners in the cold chain (S6), providing sufficient training of workers to handle products in scenarios like COVID-19 (S7) and planning and understanding the demand and supply uncertainty (S8).

To consolidate the various issues pertinent to CSC due to COVID-19, a hierarchy-based model considering proposed strategies was structured, as shown in Fig. 2.

The current research proposed the SWARA method to analyze the severity of considered criteria based on their relative weights. However, mutual importance assessment of the proposed strategies has been acquired using the MULTIMOORA approach. The following sub-section explains the detailed analysis of the COVID-19 outbreak impacts on CSC.

Fig. 1 Broader criteria of disruption analysis due to COVID-19 outbreak on the performance of cold supply chain. (Modified from Sharma et al. 2021a, b)

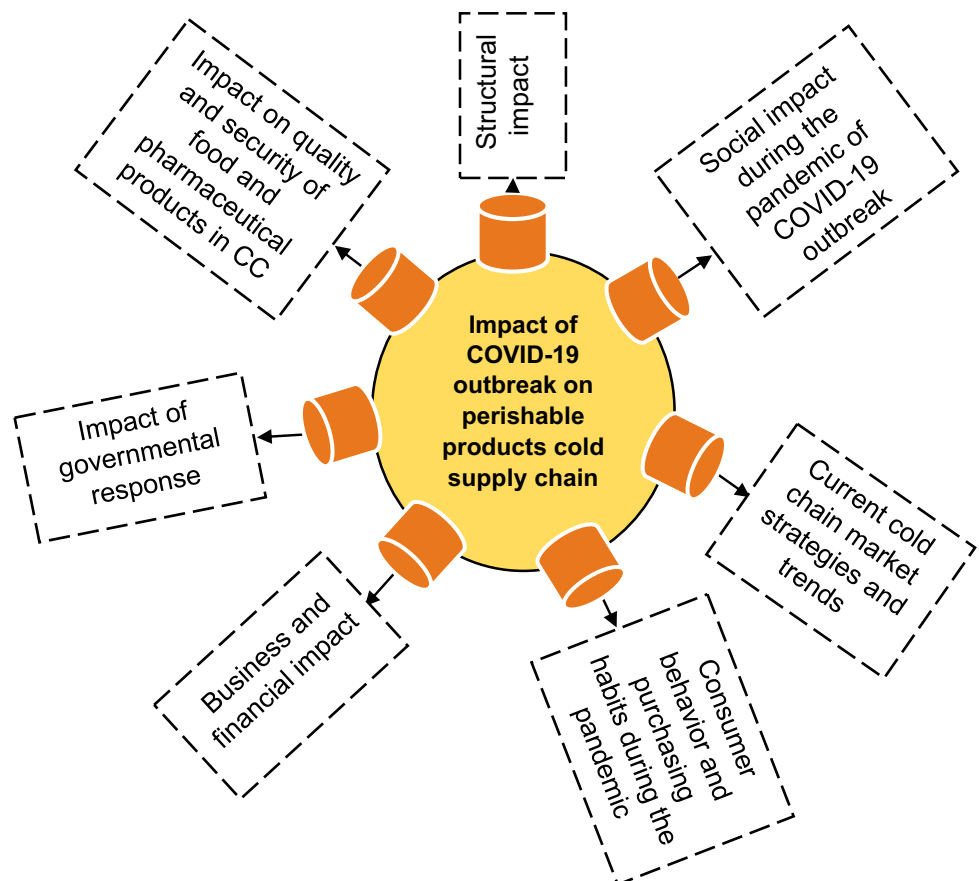
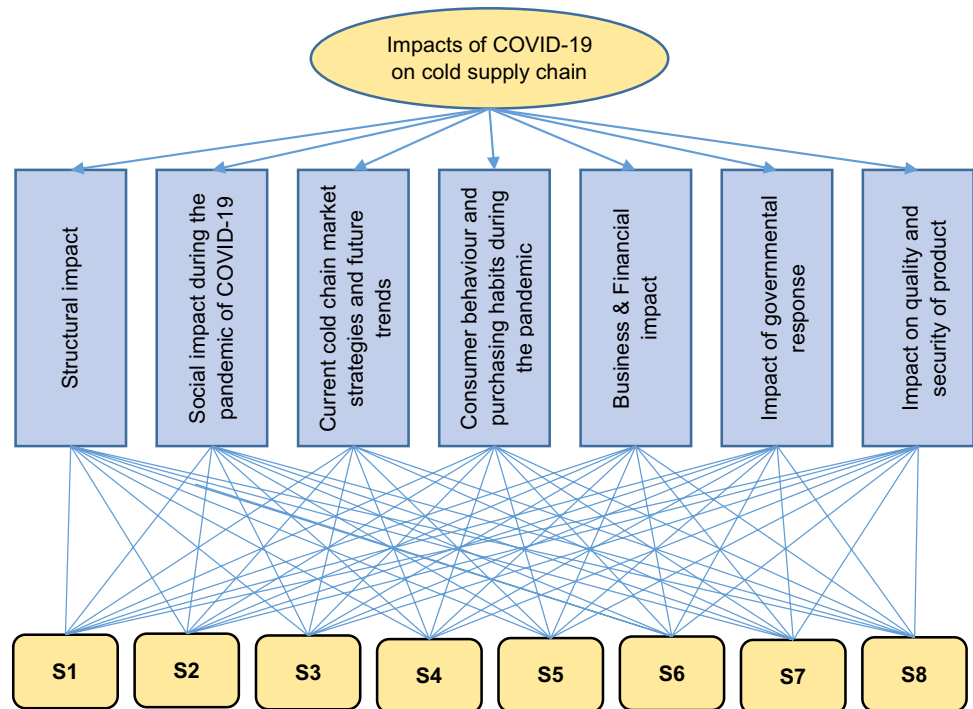


Fig. 2 A hierarchical model for selecting the best strategies to mitigate the COVID-19 disruptions in the cold supply chain



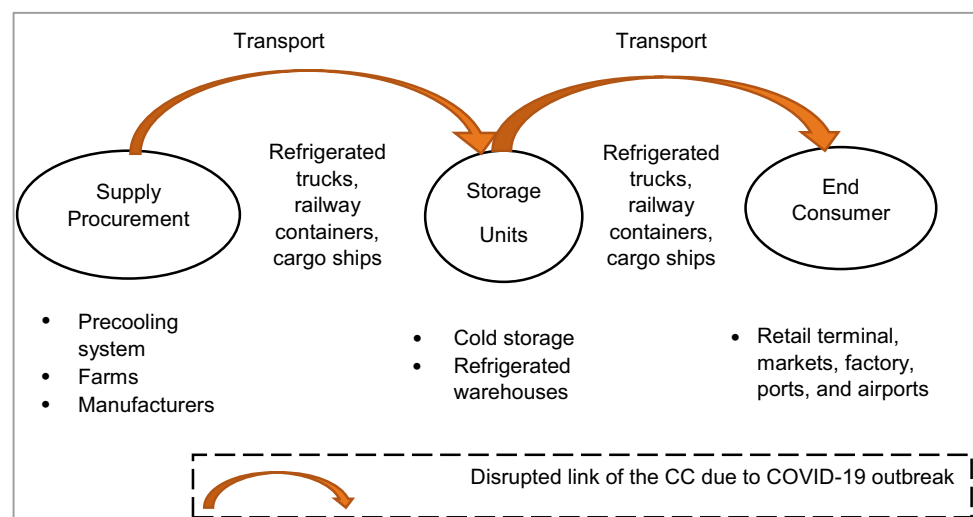
2.1 Structural impact

During the COVID-19 outbreak, with the world struggling to control the spread of coronavirus and save human lives, the global supply chain structure (including forecasting, procurement and distribution strategies) has been abruptly disrupted (Sharma et al. 2021b). A generalized structure of a CSC comprises suppliers, transport units, refrigerated storage, warehouses and end consumers. A CSC infrastructure includes temperature-controlled storage and transportation of products, ensuring optimum quality for consumers (Phore 2020). A significant disruption in the CSC structure

has been experienced due to the measures adopted to control the spread of the COVID-19 pandemic. Figure 3 demonstrates the disruptions in the interlinks of the CSC owing to the COVID-19 outbreak.

Human resources are the primary requisite for the success or failure of any organization (Kumar et al. 2020a). The closing of crucial links of the CSC (such as ports, airports and terminals) due to the unavailability of human resources and travel prohibition have clogged the export and import arrangements of industries operating on refrigerated shipments of their products. In addition, measures to control the coronavirus spread (such as segmented lockdowns, social

Fig. 3 A typical structure of a cold supply chain (Modified from Brzozowska et al. 2016)



distancing and restricted transportation) have resulted in a shortage of handling staff, unavailability of raw material and inadequate CSC structure; this has created food loss and disruption to ongoing immunization programs. The damage to the structure of CSCs has slowed down immunization programs with other diseases going unchecked due to the shortage of medicines and other pharmaceuticals (Kumar et al. 2021b). Despite lockdown and social distancing issues, farmers could not reach markets to store their products in refrigerated warehouses (cold stores). It has been observed that more than one-third of the total food produced becomes waste due to insufficient CSC structure; this costs \$8.3 billion annually (Blakeney 2019). CSCs of food products and pharmaceuticals are the two sectors most affected by the COVID-19 pandemic.

Financial and product flows are two critical factors with a high relationship (King and Venturini 2005). The interruption of one flow results in the blockage of the other. During the COVID-19 pandemic, both flows have been significantly interrupted, throwing up a critical challenge (Mahajan and Tomar 2021; Sid et al. 2021). A massive amount of food waste and disruption of immunization programs during the most disastrous disease of the century have forced decision-makers and policymakers to re-examine their CSC strategies.

2.2 Social impact during the pandemic of COVID-19

In one respect, while the global pandemic COVID-19 has caused the whole world to struggle to save lives and absorb a considerable amount of global economic loss, it creates opportunities for humans to re-evaluate and look at things afresh (Bashir et al. 2020). To control coronavirus spread during the COVID-19 pandemic, governments have imposed phase-wise lockdowns and social distancing norms. Therefore, people stay at home and keep themselves away from any genetic activity. Consequently, a significant influence has been observed on the quality of the environment worldwide. Freight transportation has been noted as one of the primary causes of degradation of environmental quality (Kumar and Anbanandam 2020). Lockdowns and prohibition of unnecessary travel during the COVID-19 outbreak provide a lamp in dark clouds for the global environment. A significant reduction in atmospheric contaminants such as nitrogen dioxide (NO₂), carbon monoxide (CO) and aerosol optical depth has been observed during the outbreak (Lal et al. 2020). China, the largest contributor to global GHG emissions, observed a reduction in its carbon emissions of 25 percent during lockdown periods (Myllyvirta 2020). Worldwide carbon dioxide emissions due to transportation and travel activities have been reduced by 8 percent (Lombrana and Warren 2020).

Previous studies show a strong relationship between environmental status and the performance of the CSC (Saif and

Elhedhli 2016; Kumar et al. 2021a; Wu et al. 2019). As the percentage volume of GHG emissions increases, the global average temperature rises significantly. In a study performed to establish the trade-off between the environment and CSC performance, it has been shown that an increase in global temperature lowers the performance of CSC (Wu et al. 2019; Choudhary et al. 2020). A CSC, one of the major emitters of GHG, emits around 1 percent of the total GHG worldwide (Heard and Miller 2019). In some developed countries, this data accounts for 3 to 3.5 percent of the total output (Garnett 2007). In the wake of the COVID-19 pandemic and norms to reduce coronavirus infection, people are moving away from refrigerated products such as cold drinks and alcohol (Hald and Coslugeanu 2021). This significantly reduces the load on CSCs, consequently lowering the GHG emission rate from refrigerated supply chain activities.

It can be inferred from the above discussion that the consecutive lockdowns and prohibition of travel during the COVID-19 outbreak have had a positive effect and have created hope for better environmental conditions. Green ecological conditions arising from lockdowns during the outbreak provide a safeguard for a resilient and low carbon footprint CSC with improved performance.

2.3 Current cold chain market strategies and trends

The severe impacts of the catastrophic circumstances of the COVID-19 outbreak have been felt and realized on current CSC market strategies resulting in demand and supply upheaval (Seetharaman 2020). Restricted access to raw materials, human resources and other critical elements of the production process has raised the cost of products (Grinberg-Zalite et al. 2021). It has mounted massive pressure on the players and policymakers operating in CSC industries. During the COVID-19 outbreak, there has been a negative impact on some CSC performing sectors, while for others, it has created an opportunity (Aday and Aday 2020). Imports of seafood products (perishable and temperature-sensitive) that shared more than \$1.26 million in 2018 have been influenced significantly due to the COVID-19 pandemic outbreak (Meharoo et al. 2020). Other CSC market sectors, such as soft drinks and alcohols, frozen meat, frozen food and dairy products (such as ice cream), have also been influenced by the novel COVID-19 pandemic. On the one hand, while a significant decline in demand for some products was noticed during the pandemic, on the other hand, the demand for others was amplified. For example, during the first phase of the pandemic, the demand for milk and its substitutes increased by more than 300 percent in US dollars (Nielsen 2020). To overcome the demand and supply shocks in the supply chain, the concept of supply chain 4.0 can be adopted, integrating industry 4.0 and the supply chain of a product (Frederico et al. 2020). This can create a vast future scope and opportunities for supply chains, espe-

cially those handling products such as food and milk based goods (Sharma et al. 2020).

Pharmaceutical industries, which are dependent on a cryogenic CSC for storage and transportation of vaccines, blood units and samples and other cellular samples, have been a focus of policymakers and researchers. Due to the COVID-19 pandemic, there may arise an enormous demand for better CSCs from industries like the pharmaceutical and food sectors in the near future. Therefore, to overcome the challenges arising from the COVID-19 outbreak, it becomes necessary to revise current forecasting, procurement and distribution strategies of CSCs. In order to achieve a demand and supply balance in such a scenario, the JIT (just in time) principle might be adopted by pharmaceutical industries (Kaswan et al. 2021). To ensure a decrease in food waste and provide health security in such unprecedented situations (COVID-19), it is necessary to promote and expand the CSC infrastructure under next-generation supply chain strategies. In integration with industry 4.0, the adoption of advanced digital technologies such as cloud-warehouse management system (WMS), radio frequency identification (RFID), sensor tags such as wireless sensing network (WSN), automated guided vehicles (AGVs), internet of things (IoT) and slice racking systems for storage may provide a safe environment and future opportunities for CSCs (Frederico 2021; Masudin et al. 2021). In a similar study, it has been observed that the integration of IoT in the subsequent stages of the supply chain standardizes the rate of information sharing between supply chain players and improves the performance of the cold chain (Al-Talib et al. 2020).

2.4 Consumer behavior and purchasing habits during the pandemic

The results obtained from experimental work and previous research demonstrate that the spread of coronavirus mostly takes place in low-temperature conditions (Demongeot et al. 2020; Sajadi et al. 2020). To reduce the spread rate and avoid coronavirus infection, governmental and public healthcare organizations have made some suggestions and implemented regulations. For example, to boost the immunity of the body during COVID-19, India's Ministry of AYUSH (2020) has advised people to take hot food and warm beverages e.g. taking Chyavanprash and hot Kadha, which can be taken as herbal tea prepared from Basil (*Tulsi*), Cinnamon (*Dalchini*), Black pepper (*kalimirch*), Dry Ginger (*Shunthi*) and Raisin (*Munakka*). Governmental regulations to improve the body's immunity and avoid infection from coronavirus make people frightened of using frozen foods and beverages. As a result, they have changed their tastes and preferences in choosing food. The three significant impacts of consumer behavior on the CSC during the pandemic are:

1. A decline in the demand for frozen and refrigerated products.
2. The mismatch between demand and supply estimates.
3. Shortage of cold chain links to provide home delivery of products.

A paradigm shift in customers' habits has been observed during the COVID-19 outbreak; tastes and preferences have shifted from chilled and cold foods to warm foods and beverages (Sheth 2020). A sharp decline in demand has been observed for products during COVID-19, reducing the global market share of CSCs. In addition, many manufacturers now prefer to trade online, prompting a change in customers' buying habits (Soleimani et al. 2019). Rather than going to a market and standing in long queues, people are now willing to have products delivered to their homes. A lack of understanding of the customer's requirements and the practices of market competitors leads to a demand and supply mismatch and loss of organizational value (Tyagi et al. 2017). To avoid stock-outs of products, most essentials have been stored as safety stock during lockdown periods. This has created a problem of demand and supply mismatch in the CSC. To handle the situation of stock-out and uncertainty in demand within the supply chain, emphasis should be given to the manufacturer and retailer relationship, considering the cost influence on market demand (Pundhir et al. 2019).

Therefore, to cope with consumer requirement and to make a CSC resilient, it is necessary for management and decision-makers to revise their strategies and policies. They also need to learn and revise their processes and technology so that a CSC may be able to shift from one state to another to address the challenges of the COVID-19 pandemic.

2.5 Business and financial impact

With the whole world struggling to save lives, the most disastrous global pandemic has hit the economies of nearly every country very hard. As a result, most of the world's leading economies (such as the U.S.A, China and India) have suffered economic crises during the pandemic (Meharroof et al. 2020). The current pandemic has created a catastrophic situation that realized the biggest recession in the global economy after the great recession of 2008–2009 (Bagchi et al. 2020). Consequently, severe disruptions due to the COVID-19 outbreak were witnessed in the business and financial sectors of the global CSC as well. It has been observed that millions of tons of fresh perishables and temperature-sensitive products (such as ago-produce, meat and seafood) have been wasted due to lockdown and restricted transportation during the COVID-19 pandemic (Tanvir et al. 2021; Mishra et al. 2021). The seafood import and export market (having more than \$1.26

million shares in the global market), which has huge reliance on CSCs, has almost been brought to a halt due to the pandemic outbreak (Meharroof et al. 2020).

The effect of COVID-19 has also been observed on the global meat CSC. India, one of the top exporters of bovine produce and beef in the world, has seen a drastic decline in the export market (having more than \$3.59 billion in global market value), during the COVID-19 pandemic period (Coluccia et al. 2021; Peel 2021; Hobbs 2021). Due to the pandemic outbreak, from the start of April 2020, the meat supply chain shut down or cancelled almost all of its operations (Richards and Vassalos 2020). A significant impact has also been observed on the global dairy market. Due to public health regulations and restrictions on travel and international transportation related to the COVID-19 pandemic, the export of dairy products has been prohibited in many countries. As a result, the CSCs of milk processing industries have experienced severe, negative impacts (World Dairy Expo Executive Committee 2020). Due to lockdowns, the demand for liquid milk from hotels, restaurants and schools has stopped. The major CSC business and financial impacts of COVID-19 (GCCA 2020) are.

1. Due to the extended storage period, the quality and potency of CSC products have declined and inventory costs have increased.
2. There is a significant decline in revenue in the first and second quarters of 2020.
3. There is increased cost in reverse logistics due to the higher rate of return of cold products.
4. There is a decline in overall profit and sometimes loss of product value.
5. There is a higher cost of operating the CSC business due to employee transportation, accessing PPE, sanitization and extra incentives.

Despite the severe business and financial impacts of the COVID-19 outbreak on the CSC, it creates several opportu-

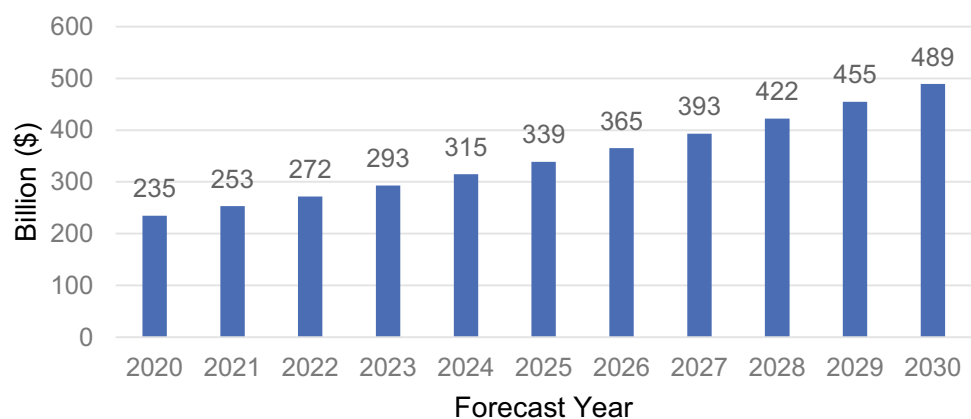
nities. During this period, significant growth in the demand for food products such as milk, butter and cream has been observed. It has been reported that demand for the dairy products mentioned increased by 279% during this pandemic (Research and Market report 2020). An increase in the demand for dairy products and other perishables, such as vaccines and hygienic food, during the pandemic has attracted the attention of decision-makers and investors to scale up the CSC infrastructure so that demand and supply could be met. Reports on the cold chain market (2018) had forecast a CSC growth at a CAGR of 7.6% from 2018 to 2023. Figure 4 refers to the forecast for the growth of the CSC industry from 2020 to 2030.

It has been forecast that the value of the pharmaceutical industry will rise by \$9.48 billion from 2020 to 2024 at a CAGR of 10% (Business Wire 2020). Since the outbreak of the COVID-19 pandemic, scientists and researchers have been working to develop a permanent treatment for coronavirus. As food and pharmaceuticals are temperature sensitive with shorter shelf lives, special care will be required to deliver such products. Therefore, to avoid vaccine and food waste, the management of such supply chains should be given special attention (Mouneer et al. 2021). Managers should plan an efficient and effective CSC to minimize the loss of vaccines and the uninterrupted flow of vaccination programs (Georgiadis and Georgiadis 2021). Researchers have started working to find a potential CSC structure so that a vaccine for COVID-19 is easily accessible to everyone around the globe.

2.6 Impact of governmental response

Governmental responses toward the mitigation of the spread of coronavirus in the wake of COVID-19 have significantly affected CSC performance and its share in the global market. Literature analysis has explored the effect of governmental responses on the quality and safety of perishable products and the overall gain for the supply chain (Mangla

Fig. 4 Forecast for the growth of the cold chain industry from 2020–2030 (Extended analysis of markets and market report on cold chain market 2018)



et al. 2021). To mitigate the spread of the virus, governments have implemented phase-wise lockdowns, the prohibition of unnecessary travel and COVID-19 protocols that slow down the flow of products and operation of CSCs (Mishra et al. 2021; Aday and Aday 2020). Government responses towards facilitating access to PPE and financial support to enable CSCs to operate have played a key role during COVID-19. Governmental financial support and the level of ease of COVID-19 testing for CSC workers also influence CSC operations (Global Cold Chain Alliance 2020). The report suggests that to promote the CSC business and the country's growth, the above factors should be priorities for consideration of any government.

2.7 Impact on quality and security of food and pharmaceutical products in the cold chain

Perishable products such as cooked and baked foods, vaccines and pharmaceuticals are temperature sensitive. Any slight fluctuation in the sustainable temperature range starts chemical reactions and biological decay of the products; they become waste after some time. Previous studies have suggested that in the CSC of perishable products, such as food items and pharmaceuticals, the assurance of quality and security of the goods are the two major challenges that the world has faced due to the COVID-19 pandemic (Masudin and Safitri 2020). In the wake of the pandemic, as the number of COVID-19 positive cases increases, it creates a severe challenge for the CSC industry to eliminate the spread of the virus in the product or packaging. A product may have to travel a long distance to reach the end consumer in a CSC. Safety and hygiene issues appear as primary concerns within the supply chain during the pandemic. In between storage and transportation, there is a risk of spreading the virus into the product. Many circumstances have been recorded where an infected supplier has caused the spread of infection to food purchasers and the consumer. The major consequences of COVID-19 impacting on the quality and security of products in the CSC are.

1. Risk to human health.
2. Reduced willingness to purchase by the customer
3. Loss of value that might be earned after the product's sale.

3 Research methodology

The aim of the study is to analyze the impact of the COVID-19 outbreak on CSC both theoretically and empirically. In addition, the study also aims to explore the most suitable remedial strategies and propose a preference rating for the same to overcome the effects of the pandemic. Based on a

literature review and discussion with relevant professionals, seven assessment criteria for impact analysis and eight of the most suitable remedial strategies have been explored. Afterwards, to facilitate a one view visualization of the criteria and strategies, a hierarchical model was developed as shown in Fig. 2. A hybrid approach of SWARA and MULTIMOORA techniques has been used to analyze the developed model empirically. The SWARA method has been used to obtain the severity weights for the impacts imparted; simultaneously, the MULTIMOORA method is used to determine the priorities to visualize the importance of the proposed strategies. Sub-Sect. 3.1 now discusses the motivation to assimilate SWARA and MULTIMOORA methods to achieve the objective of the study.

3.1 The enthusiasm behind assimilating the SWARA and MULTIMOORA methods

In order to analyze the severity of the chosen criteria for impact analysis of the COVID-19 outbreak and propose a significant order for the recommended strategies, the case in hand has been regarded as a multi-criteria decision-making (MCDM) problem. To determine the relative severity weights of criteria/attributes, there are various MCDM methods such as AHP, ANP, DEMATEL, SWARA, WASPAS, and BWM available to solve such problems (Agarwal et al. 2021; Tyagi et al. 2015, 2018; Yazdi et al. 2020; Zhou and Lei 2020). This study has selected the SWARA method for weight determination. The key advantages of using the SWARA method are that it is an expert-oriented technique; secondly, it offers flexibility for decision-makers to provide priorities based on the evidence; thirdly, it requires less manual work. Apart from this, a significant contribution of the SWARA technique is that it can be used for both minimization and maximization types of criteria and offers more precise results than others (Yücenur et al. 2020).

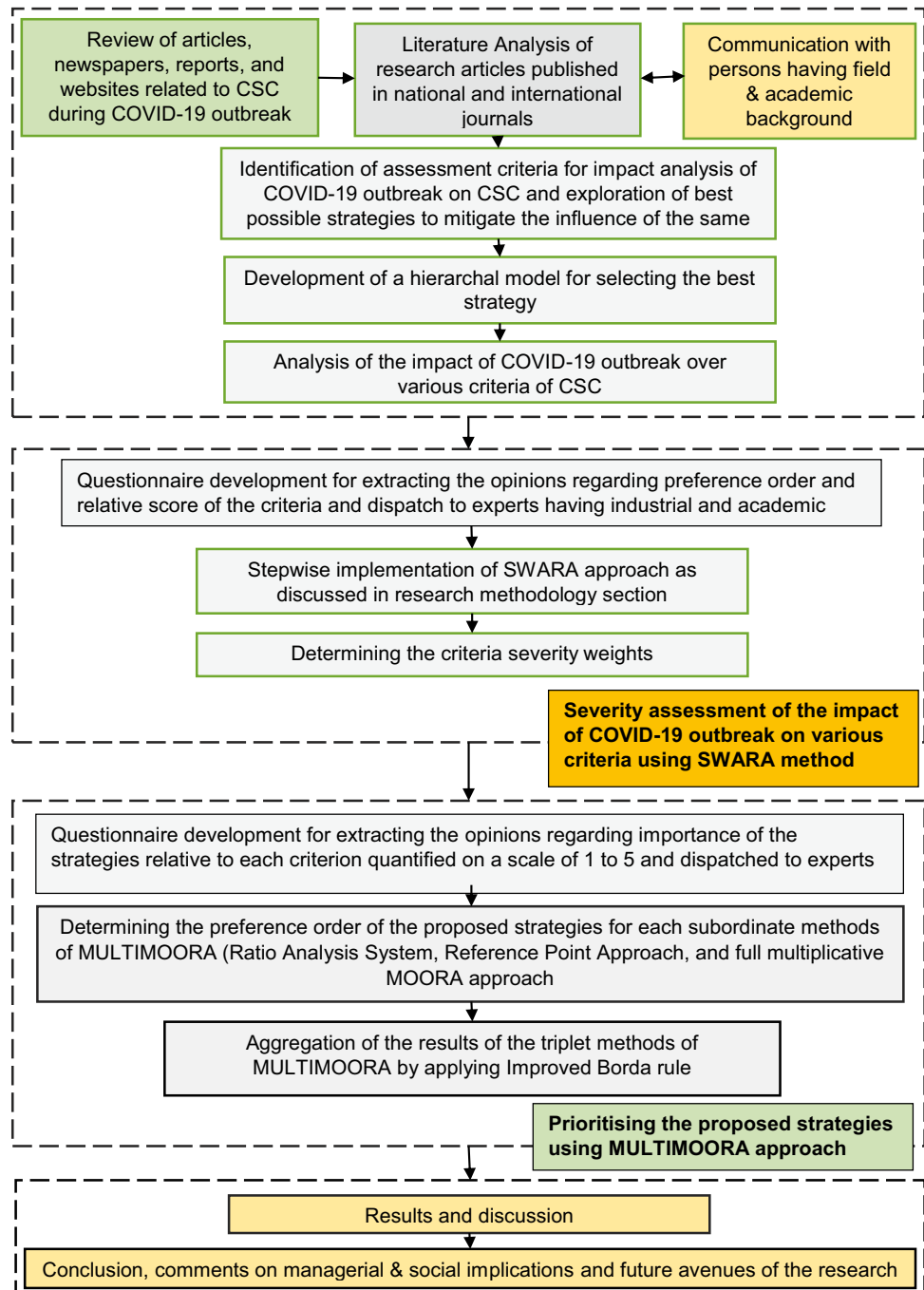
In order to acquire the order of preference for the alternatives (strategies), MCDM approaches such as AHP, TOPSIS, DEMATEL, PROMETHEE, MULTIMOORA, WASPAS etc. can be used. The MULTIMOORA is a more robust method than the above-discussed ranking methods based on the subjective weight judgments received from the decision-makers. The MULTIMOORA method has wide applications due to its' inherent advantages over others (Hafezalkotob et al. 2019; Keršulienė et al. 2010):

- Ability to solve the problem while having independent and dependent alternatives.
- It provides a conservative side to decision-makers as it utilizes a min–max approach that suggests the best choice, while not harming the criteria.

- Ability to combine the triplet subordinate features of MCDM in a single tool.
- Provides flexibility to overcome the chances of selecting bad alternatives in one subordinate method (as it utilizes the triplet subordinate method to reach a final decision).
- It offers results that are more robust when ordinal measures have to be undertaken as it utilizes quantitative numbers to reach a confident decision.
- All the objectives and alternatives can be inter-related and taken into account at one time.

From the above discussion, it can be concluded that the MULTIMOORA method has various significant advantages over others. Therefore, from the above motivation, the current research work proposed a hybrid approach of SWARA and MULTIMOORA methods. The study is structured in such a way that the output weights obtained from the SWARA method are further fed to the MULTIMOORA approach to determine the preference order of the proposed strategies. The procedural flowchart for the proposed research methodology used in the current work has been

Fig. 5 Procedural flow chart for research methodology used in the current work



shown in Fig. 5. The stepwise procedure for the enactment of the proposed methodology has been discussed as follows.

3.2 SWARA method

Stepwise Weight Assessment Ratio Analysis (SWARA) is a multi-criteria decision-making tool that is used to calculate the weights for the criteria or attributes for the problem under consideration. The SWARA approach was first proposed to solve the problem of method selection (Keršulienė et al. 2010). The weight assessment and prioritization of criteria in SWARA analysis depends upon expert experience, knowledge, information and historic upbringings about the problem. The SWARA technique has been extensively used for the weight assessment of criteria or attributes in various engineering and social applications. In integration with the COPRAS (COmplex PROportional ASsessment) method, the SWARA technique has been used to obtain priority weights of criteria for selecting alternatives in renewable energy production (Yücenur et al. 2020). In the pharmaceutical industry, the SWARA method has previously been proposed to obtain criteria weights (Eghbali-Zarch et al. 2018).

In this research, the SWARA method has been used to obtain the severity order of the criteria of impact analysis of COVID-19 disruption of CSCs. To acquire the intended objective, at first, a hierarchal model containing criteria of disruption analysis and proposed strategies was developed. Thereafter, to collect the experts' opinions regarding the relative severity of the criteria, three groups of relevant professionals were formed, each group having three to five field professionals. Relevant professionals were selected from food processing and healthcare industries located in the Ludhiana and Jalandhar regions and academic institutions in Punjab, India. Table 1 shows brief demographic characteristics of the selected relevant professionals for severity analysis of criteria. In order to obtain the experts' opinions, a questionnaire was structured and dispatched to concerned relevant professionals to achieve the initial importance ranking for the identified criteria based on their experience and perceptions. In the same questionnaire, the experts were also requested to provide a relative score for

the importance of each criterion on a scale of 0 to 1.0 in a division of five (Yücenur et al. 2020). For example, the highest-ranked criterion was provided with a relative score of 1 and the same for other remaining criteria between 0 and 1. Simultaneously, brainstorming sessions have also been conducted to filter out the doubts orienting toward the analysis side.

The steps involved to obtain the priority weights using the SWARA method (Yücenur et al. 2020; Eghbali-Zarch et al. 2018) are.

Step 1: The group of selected experts is asked to arrange the criteria in descending order of importance. Based on the importance order of the criteria, this produces the ranking for the identified criteria from the experts based on their experience, knowledge, information and perceptions.

Step 2: Obtain the relative score (B_j) for the importance of each criterion on a scale of 0 to 1.0 in a division of five. [$0 \leq b_j \leq 1$].

Step 3: Determine the average relative importance score (\bar{B}_j) for the criteria.

$$\bar{B}_j = \frac{\sum_{j=1}^n B_j}{E} \quad (1)$$

where E is the number of experts.

Step 4: After obtaining the average relative importance score, the criteria are arranged in descending order of their (\bar{B}_j) value.

Step 5: Then comparative importance (G_j) is obtained for each criterion.

Step 6: The coefficient value (K_j) for the relative importance of one criterion over the second is obtained by using the following equation.

$$K_j = G_j + 1 \quad ; \quad j = 1, 2, \dots, n \quad (2)$$

$K_j = 1$, for the criteria with a maximum average relative importance score.

Step 7: Obtain the corrective weights (G'_j) for the criteria by using Eq. (3). For the criteria with maximum average relative importance score; $W'_j = 1$

Table 1 Brief demographic characteristics of the experts for severity analysis of criteria

Respondent profile for the severity of criteria (n=23)				
Field of expertise	Job position	Number of experts	Year of experience	Percentage
Food processing industry	Production Managers	5	> 10	21.73
	Restaurants owners	3	> 15	13.04
Healthcare industry	Sales and marketing managers	3	> 8	13.04
	Pharmacists	4	> 15	17.23
Academicians	Professors	5	> 12	21.74
	Academic practitioners	3	> 12	13.04

$$W'_{j+1} = \frac{G'_j}{K_{j+1}} \quad (3)$$

The normalized value of corrective weights gives the final weights for the criteria.

Step 8: Finally, criteria weights are calculated by using Eq. (4).

$$W_j = \frac{W'_j}{\sum_{j=1}^n W'_j} \quad (4)$$

3.3 MULTIMOORA method

Multi Objective Optimization on the basis of Ratio Analysis (MOORA) is an extensively used method in multi-criteria decision making to acquire the ranking of each alternative, attribute, approach or a method. It was first introduced by Brauers and Zavadskas in 2006. MULTIMOORA is an improved form of the MOORA method introduced by its originator that provides a triple ranking for alternatives based on ratio analysis and full multiplicative form (Brauers and Zavadskas 2010). The final order from the MULTIMOORA analysis is based on the aggregation of the rankings obtained from the triplet MOORA methods. In the current research, the ratio analysis method in integration with full multiplicative form and reference point approach, has been used to achieve the objective. The study is designed in such a way that the output of the SWARA method is further fed to the MULTIMOORA methodology to evaluate the importance of the proposed strategies and tier them according to their capability to counter the influence of the criteria. To aggregate the rankings obtained from the three methods of the MOORA technique, the 'improved Borda' rule has been used.

To obtain the preference order/ranking using MULTIMOORA analysis, the first step is to construct the pairwise direct decision matrix for the strategies or alternatives. To get the rating for alternative relative importance concerning criteria, a questionnaire was structured using a five-point Likert scale (as given in Table 3) and dispatched to 176 relevant professionals; 59 responses were received, accumulating a total response rate of 33.52 percent; this is appropriate to proceed the analysis (Malhotra and Grover 1998). The selected relevant professionals for data collection have backgrounds in the healthcare sector, food processing industries and academia of Punjab, India. During the relevancy check, six responses were discarded due to incomplete information. Therefore, 53 pertinent responses were selected to make the analysis. Table 2 shows a brief demographic of the experts who analyzed the relative importance of the proposed strategies.

Table 2 Brief demographic of experts for analyzing the relative importance of the proposed strategies

Experts profile for analyzing the relative importance of the proposed strategies (n = 53)			
Job position	Number of experts	Year of experience	Percentage
Logistics provider	8	> 12	15.09
General managers	6	> 8	11.32
Production managers	17	> 12	17
Quality assurance manager	5	> 10	32.07
Academicians	13	> 15	24.53
Physicians	4	> 8	7.54

The stepwise methodology for implementing the MULTIMOORA method is given in the following sub-sections.

3.3.1 Ratio analysis system

This method is generally used to evaluate the ranking when the attributes or criteria of the problem are independent of each other's performance. It is a fully compensatory method; it determines the order of alternatives using the degree of compensation over each other. The steps involved in the implementation of the ratio analysis system are as given below.

Step 1: Construction of the direct decision matrix.

A questionnaire was structured to construct the decision matrix for alternatives (proposed strategies) containing the degree of importance of alternatives to mitigate the criteria impact using a five-point scale of 0 to 5, as given in Table 3.

If there are 'm' number of alternatives and 'n' number of criteria, then the direct decision matrix is constructed as.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \quad (5)$$

Table 3 Scale for the relative importance of the alternative concerning criteria

Explanation	Importance scale/value
Absolutely not preferred	0
Equally preferred	1
Weakly preferred	2
Moderately preferred	3
strongly preferred	4
Absolutely preferred	5

$[C_1 \dots C_n]$

$W = [w_1 \dots w_n]$

Step 2: Normalization of the direct decision matrix.

The normalization of the direct-decision matrix has been calculated by using the following equation.

$$a^*_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=m}^n (a_{ij})^2}} \tag{6}$$

Step 3: Construction of weighted normalized decision matrix.

The following equation has been used to construct the weighted normalized decision matrix.

$$V_{ij} = W_j \times a^*_{ij} \tag{7}$$

Step 4: Calculation of the utility (Y_i) for each alternative/strategy by using the following equation.

$$Y_i = \left[\sum_{j=1}^l W_j \times a^*_{ij} - \sum_{j=l+1}^n W_j \times a^*_{ij} \right] \tag{8}$$

where; ‘ l ’ is the number of beneficial criteria and ‘ $n - l$ ’ is the number of non-beneficial criteria.

The ranking for the alternative in the ratio analysis system depends on its utility value. The option that forms the highest utility is given rank one, while the same with the minimum is given the least rank.

3.3.2 Full multiplicative MOORA approach

The ratio analysis system's first, second and third steps are the same while calculating the utility in the full multiplicative MOORA approach. The utility of this system can be obtained by using the following equation.

$$U_i = \frac{\prod_{j=1}^l (V_{ij})}{\prod_{j=l+1}^n (V_{ij})} \tag{9}$$

The alternative, which attains the highest utility, is given the highest priority of preference; the same with the lowest value of U_i is preferred as last.

3.3.3 Reference point approach

The ratio analysis system and full multiplicative MOORA depict the best choice, which is superior in all respects of the criteria. On the other hand, in the reference point approach, the best alternative is the one that has the worst performance relative to each measure i.e. the alternative with the lowest utility is the best alternative. The procedure to achieve the utility in the reference point approach follows these steps.

Step 1 and **Step 2** are the same as those used in the ratio analysis rule.

Step 3: Define the maximal objective reference point using Eq. (10).

$$t_j = \{ \max_i V_{ij}, j \leq l; \min_i V_{ij}, j > l \} \tag{10}$$

Step 4: Calculate the weighted distance of each alternative from t_j by using Eq. (11).

$$D_{ij} = |w_j * t_j - w_j * a_{ij}| \tag{11}$$

Step 5: Calculate the utility for the approach, using Eq. (12).

$$Z_i = \max_j D_{ij} \tag{12}$$

The ranking of the alternatives is provided in ascending order of the utility. The choice with the lowest utility is given rank one, whereas the same with the highest forms the least rank.

3.3.4 Aggregation of the ranks (preference order)

There are many methods available to aggregate the ranking obtained from MULTIMOORA techniques. These include the dominance theory method (Souzangarzadeh et al. 2017; Kracka et al. 2010; Wang et al. 2018; Fattahi and Khalilzadeh 2018), rank position method (Altuntas et al. 2015), precise order preference technique (Dorfeshan et al. 2018), ORESTO technique (Liao et al. 2019), Borda rule (Hafezalkotob et al. 2019) and improved Borda rule (Hafezalkotob et al. 2019; Wu et al. 2018). In the current analysis, to obtain the aggregate preference order for the strategies obtained from the three tools of MOORA, ‘improved Borda rule’ (IMB) has been used. The advantage of using the improved Borda rule over the other tools is that it includes both the factors of the MUTIMOORA method (utility and rank) to calculate the final ranking. This is lacking in other rank aggregation tools. The utilities obtained from the three methods of the MOORA technique are normalized to get the final preference order of alternatives from the improved Borda rule (as presented by Hafezalkotob et al. 2019); the assessment value (AV) for each approach is calculated by using Eq. (13).

$$IMB(AV) = Y^*_i \frac{m - r(y_i) + 1}{m(m + 1)/2} - Z^*_i \frac{m - r(z_i) + 1}{\frac{m(m+1)}{2}} + U^*_i \frac{m - r(u_i) + 1}{m(m + 1)/2} \tag{13}$$

where Y^*_i , Z^*_i , and U^*_i are the normalized utilities for the ratio analysis system, full multiplicative form and reference point approach, respectively.

Table 4 Preference order and relative importance score for criteria as provided by the experts

Criteria	Group 1		Group 2		Group 3		Averaged Importance score \bar{B}_j
	Preference order	Importance score (B_{j1})	Preference order	Importance score (B_{j2})	Preference order	Importance score (B_{j3})	
C1	1	1	2	0.9	1	1	0.9667
C2	6	0.25	6	0.5	7	0.7	0.4833
C3	5	0.4	3	0.8	4	0.85	0.6833
C4	3	0.7	4	0.7	3	0.9	0.7667
C5	2	0.85	1	1	2	0.95	0.9333
C6	7	0.1	7	0.4	6	0.75	0.4167
C7	4	0.55	5	0.6	5	0.8	0.6500

The aggregate preference order for the alternatives depends upon the 'improved Borda rule assessment value' [IMB (AV)]. The alternative with the highest IMB (AV) value is given the highest priority of preference, and the one with the lowest value is preferred last.

4 Numerical illustration

The current research aims to identify and analyze the impacts of the COVID-19 pandemic on the CSC and propose best-suited strategies to mitigate the effects of the outbreak. Seven assessment criteria have been finalized to investigate COVID-19 disruptions on CSCs. In addition, the eight most suitable strategies have been proposed to mitigate the effect of COVID-19 disruption on CSCs. The present research has proposed a SWARA-based MULTIMOORA approach to analyze the severity order of the criteria and preference order of the proposed strategies empirically. Then, a stepwise procedure of the SWARA and MULTIMOORA methods has been followed to achieve the desired objective as discussed in the research methodology section. Table 4 shows the ranking and relative importance score for criteria provided by the experts.

Based on the averaged importance score, the sequence of criteria severity can be presented as $C1 > C5 > C4 > C3 > C7 > C2 > C6$.

The averaged importance score based on judgments provided by experts offers an initial visualization of the severity order of the criteria under consideration. To better understand the severity order, further analysis has been performed considering averaged importance score as the basis to obtain the final severity weights. Table 5 represents the summary of results obtained from the SWARA analysis.

The findings of the SWARA method demonstrate that criterion C1 (structural impact) is the most stringent criteria of CSC influenced by the COVID-19 outbreak. At the same time, criterion C6 (impact of governmental response) is least affected by the pandemic outbreak. Therefore, the management and decision-makers of organizations operating CSCs must focus on establishing a robust CSC structure that can perform efficiently in unfavorable situations.

After obtaining the severity weights of the criteria for COVID-19 outbreak impact analysis on CSC disruption, the MULTIMOORA method is applied to visualize the mutual importance of proposed strategies concerning each criterion. The study is designed in such a way that the severity weights

Table 5 Summary of the results obtained from SWARA analysis

Criteria	\bar{B}_j	Comparative importance score (G_j)	Coefficient value (K_j)	Corrective weight (G'_j)	Final weights for criteria (W_j)
C1	0.9667	0.0000	1.0000	1.0000	0.1807
C5	0.9333	0.0333	1.0333	0.9677	0.1749
C4	0.7667	0.1667	1.1667	0.8295	0.1499
C3	0.6833	0.0833	1.0833	0.7657	0.1383
C7	0.6500	0.0333	1.0333	0.7410	0.1339
C2	0.4833	0.1667	1.1667	0.6351	0.1148
C6	0.4167	0.0667	1.0667	0.5954	0.1076

Table 6 Averaged pairwise direct decision matrix for the strategies relative to the criteria

	C1	C2	C3	C4	C5	C6	C7
S1	5	3	4	5	4	2	5
S2	4	2	4	3	4	3	3
S3	2	4	3	2	3	4	4
S4	3	5	2	2	2	3	5
S5	2	3	5	3	5	3	3
S6	3	4	4	3	2	2	2
S7	4	3	3	2	4	4	4
S8	2	5	4	4	5	1	3

Table 7 Weighted normalized decision matrix and utility for ratio analysis system

V_{ij}	C1	C2	C3	C4	C5	C6	C7	utility (Yi)	Preference order r (Yi)
S1	0.0969	0.0324	0.0525	0.0838	0.0652	0.0261	0.0630	-0.4198	8
S2	0.0775	0.0216	0.0525	0.0503	0.0652	0.0391	0.0378	-0.3440	4
S3	0.0387	0.0432	0.0394	0.0335	0.0489	0.0522	0.0504	-0.3063	2
S4	0.0581	0.0540	0.0263	0.0335	0.0326	0.0391	0.0630	-0.3066	3
S5	0.0387	0.0324	0.0657	0.0503	0.0815	0.0391	0.0378	-0.3455	6
S6	0.0581	0.0432	0.0525	0.0503	0.0326	0.0261	0.0252	-0.2880	1
S7	0.0775	0.0324	0.0394	0.0335	0.0652	0.0522	0.0504	-0.3506	7
S8	0.0387	0.0540	0.0525	0.0670	0.0815	0.0130	0.0378	-0.3446	5

of criteria obtained from the SWARA method provide the basis for the MULTIMOORA method. For the same, the whole analysis is performed using three steps of the MULTIMOORA method as discussed below.

Firstly, the ratio analysis was performed to obtain the preference order. Then, the multiplicative MOORA approach is used to calculate the preference order of the proposed strategies. After that, the reference point approach is used to obtain the order for the same. Finally, the preference orders obtained from triplet methods are aggregated to get the final ranking. By using the responses received from the experts for the relative importance of the proposed strategies, an averaged pairwise direct decision matrix has been constructed, as given in Table 6.

After establishing the direct decision matrix, the normalization of the direct decision matrix has been performed, with the weighted direct decision matrix obtained by using Eqs. (6) and (7). Table 7 shows the weighted normalized direct decision matrix. The ratio analysis system's utility is calculated using Eq. (8) and shown in Table 5.

The ratio analysis approach of MULTIMOORA suggests that strategy S6 (development of safe and healthier work scenario for partners of the CSC) is most preferred. In contrast, S1 (shortening and simplifying the long CSC links) is the least effective strategy to overcome the negative impact of the COVID-19 outbreak. The full multiplicative MOORA approach and reference point approach have been carried out

to provide a healthier platform for the relative importance of proposed strategies.

The utility (U_i) for the full multiplicative MOORA approach is obtained using Eq. (9). The results achieved from implementing the full multiplicative MOORA approach are summarised in Table 8.

The maximal objective reference point (t_j) for each criterion is calculated firstly to find the utility of the reference point approach using Eq. (10). Then the weighted distance from t_j is obtained using Eq. (11). Next, the utility for the reference point approach is calculated using Eq. (12). Tables 9 and 10 summarize the results obtained from the reference point approach, the outline of the utility and ranks as obtained from the three methods of the MOORA technique, respectively.

Table 8 Summary of the results obtained from the full multiplicative MOORA approach

Approach	Utility (U_i)	Preference order r(U_i)
S1	2.4715	8
S2	2.9832	6
S3	3.3875	3
S4	3.4879	2
S5	3.0097	5
S6	3.6130	1
S7	2.9375	7
S8	3.1555	5

Table 9 Summary of the results as obtained from the reference point approach

Ai								Utility (Zi)	Preference order r (Zi)
	C1	C2	C3	C4	C5	C6	C7		
S1	0.0581	0.0108	0.0263	0.0503	0.0326	0.0130	0.0378	0.0581	8
S2	0.0387	0.0000	0.0263	0.0168	0.0326	0.0261	0.0126	0.0387	3
S3	0.0000	0.0216	0.0131	0.0000	0.0163	0.0391	0.0252	0.0391	4
S4	0.0194	0.0324	0.0000	0.0000	0.0000	0.0261	0.0378	0.0378	2
S5	0.0000	0.0108	0.0394	0.0168	0.0489	0.0261	0.0126	0.0489	6
S6	0.0194	0.0216	0.0263	0.0168	0.0000	0.0130	0.0000	0.0263	1
S7	0.0387	0.0108	0.0131	0.0000	0.0326	0.0391	0.0252	0.0391	4
S8	0.0000	0.0324	0.0263	0.0335	0.0489	0.0000	0.0126	0.0489	6

Table 10 Summary of the utility and ranks as obtained from the three methods of MOORA technique

Approach	Ratio analysis		Reference point approach		Full multiplicative form	
	utility (Yi)	Rank r(Yi)	Utility (Zi)	Rank r(Zi)	Utility (Ui)	Preference order r(Ui)
S1	-0.4198	8	0.0581	8	2.4715	8
S2	-0.3440	4	0.0387	3	2.9832	6
S3	-0.3063	2	0.0391	4	3.3875	3
S4	-0.3066	3	0.0378	2	3.4879	2
S5	-0.3455	6	0.0489	6	3.0097	5
S6	-0.2880	1	0.0263	1	3.6130	1
S7	-0.3506	7	0.0391	4	2.9375	7
S8	-0.3446	5	0.0489	6	3.1555	5

The final preference order for the proposed strategies depends upon the aggregation of the rankings obtained from the triplets of the MOORA method. An ‘improved Borda rule’ has been used in the current analysis to achieve the final preference/importance order for the proposed strategies.

For the aggregation of results obtained from the triplet methods of the MOORA approach, Eq. (13) has been used. At first, normalized utilities for each form of MOORA were calculated as discussed in the research methodology section of the improved Borda rule. The final preference

Table 11 Assessment value and final preference order for the strategies based on improved Borda rule

Approach	IMB (AV)	The final order of preference (R)
S1	-0.1104	8
S2	-0.0482	5
S3	-0.0342	3
S4	0.0058	2
S5	-0.0593	7
S6	0.0177	1
S7	-0.0376	4
S8	-0.0575	6

order for the proposed strategies using the improved Borda rule depends upon the assessed IMB (AV) values. The approach with the highest assessment value is ranked first while the same with the least assessment value has the last rank (8th). The summary of results obtained from the improved Borda rule is shown in Table 11.

From Table 11, it can be seen that from all the proposed strategies, S6 (*development of a safe and healthier work scenario for partners of the cold chain*) is the most effective strategy to reduce the impact of COVID-19 disruptions on CSCs. Similarly, S4 (*Successful monitoring and implementation of COVID-19 protocols*) is the second most suitable strategy that can be taken up by CSC decision-makers to mitigate the disruption caused due to the COVID-19 pandemic.

5 Results and discussion

The study primarily focuses on measuring the impact of the COVID-19 outbreak on the cold supply chain of perishable products. In addition, the work also aims to explore the most suitable remedial strategies and their preference rating index for mitigating the effects of the pandemic outbreak on CSCs. The study analyzes and discourses the impact of the COVID-

19 pandemic on seven broader assessment criteria. The study also identifies the eight most suitable remedial strategies that can help CSC management to reduce the impact of COVID-19 and repurpose the CSC to where it was before the pandemic. To analyze the mutual importance of the proposed strategies relative to the assessment criteria, a hierarchical model was developed and analyzed using a hybrid approach of SWARA and MULTIMOORA methods. The empirical assessment of the impact of the COVID-19 outbreak on CSCs was analyzed by computing the severity weights of the assessment criteria using the SWARA method, while the mutual importance of proposed strategies was performed, determining the importance scores for each individual using the MULTIMOORA method.

To visualize the severity order of the criteria in one view, Figs. 6 and 7 have been constructed. These show the bar chart for the criteria weights and pie chart for the percentage criteria contribution in the COVID-19 impact analysis on the CSC.

Our literature findings of the current work found that the COVID-19 outbreak has severely affected multiple areas of CSCs of perishable products. To provide a healthier understanding of the severity and complexity of the impact of COVID-19 on the various criteria of disruption analysis, severity weights of the same have been formed by using the SWARA method, the results of which are summarised in Table 5. The findings of the study show that the COVID-19 outbreak has affected all areas of the CSC, including socio-economic and environmental aspects. The results demonstrate that the *structural impact* of the COVID-19 outbreak on the cold supply chain has maximum severity (having the highest severity weight, $W_1 = 0.1807$). The key findings of the work support the notions of the work of Qin et al. 2021. They examined the severe impacts of the COVID-19 outbreak observed on the global supply chain of the health-care system. On the other hand, the *impact of governmental response* on CSC disruption appears as the least impacted criteria due to the COVID-19 outbreak.

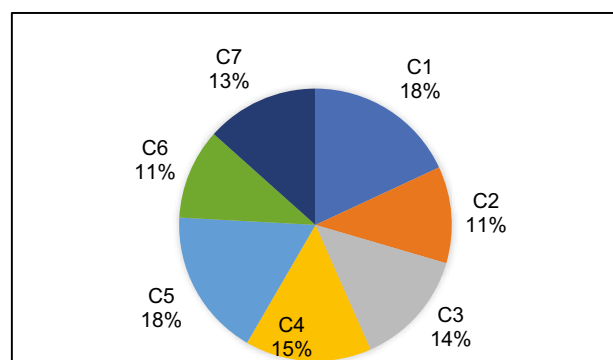
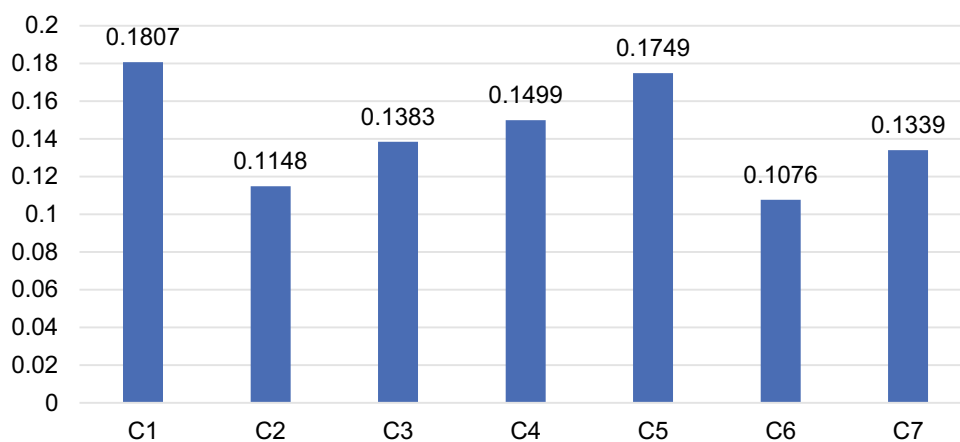


Fig. 7 Pie chart for the percentage criteria contribution in the COVID-19 impact analysis on cold supply chain

From the literature analysis, it has been observed that governmental norms related to lockdown, social distancing and travel prohibition have all but closed down CSC operations, disrupting the entire structure. Various links of the CSC have broken down due to unavailability of raw materials, refrigerated transportation facilities, shortage of workforce, farm disruption, the closing of markets and disrupted channels of information sharing. The key findings of this study are in agreement with the results of previous work (Sharma et al. 2021a; Golan et al. 2021; Mishra et al. 2021), in which the structural impact of the COVID-19 outbreak has been observed as the most disruptive layer of the supply chain. It has forced decision-makers and policymakers to re-examine their CSC strategies and policies. They need to adapt the design of the CSC structure to provide robustness to the chain in unfavorable conditions, for example if the period of lockdowns or prohibition of travel and transport are extended. In addition, due to the increasing number of COVID-19 vaccine doses required as per the guidelines, there is a need for a resilient vaccine supply chain strategy for their production and distribution (Golan et al. 2021). Hence, to repurpose CSC systems to levels in operation

Fig. 6 Bar chart for the severity weights of COVID-19 disruption on criteria of analysis



before the COVID-19 pandemic, the focus must be given to providing a resilient supply chain structure.

The results of the analysis also show that criterion C5 (*business and financial impact*) has second-highest severity weight ($W_5 = 0.1749$) after criterion C1 (structural impact). Thus, following the *structural impact*, the *business and financial impact* aspect of CSC is seen as the second most affected layer due to the COVID-19 outbreak. This finding of the study supports the notions of Mukhamedjanova 2020, who concluded that the COVID-19 pandemic has crippled the global economy and created an unprecedented economic crisis for the worldwide supply chain. During the lockdown periods, the closing of markets, supermarkets, schools, restaurants and hotels have badly hit the CSCs' economic share of the global market. In addition, the misinterpretation or misinformation on social media websites about perishable products such as meat, chicken and seafood and the possible spread of coronavirus due to consumption of these products, has also slowed down the economic growth of CSCs.

Following the severity assessment of criteria '*structural impact*' and '*business and financial impact*' of disruption analysis of CSC layers due to the COVID-19 outbreak, the same for other criteria has also been performed. The results of the study demonstrate that the other criteria '*societal impact*'; '*current cold chain market strategies and trends*'; '*consumer behavior and purchasing habits*'; '*impact of governmental response*' and '*impact on quality and security of product*' have severity weights of 0.1148, 0.1383, 0.1499 and 0.1339 respectively. Therefore, after emphasizing the criteria '*structural impact*' and '*business and financial impact*', other criteria must be addressed in descending order of their severity weights.

From Fig. 6, it can be seen that the order of severity of the criteria of disruption analysis due to the COVID-19 outbreak on CSCs is $C1 > C5 > C4 > C3 > C7 > C2 > C6$.

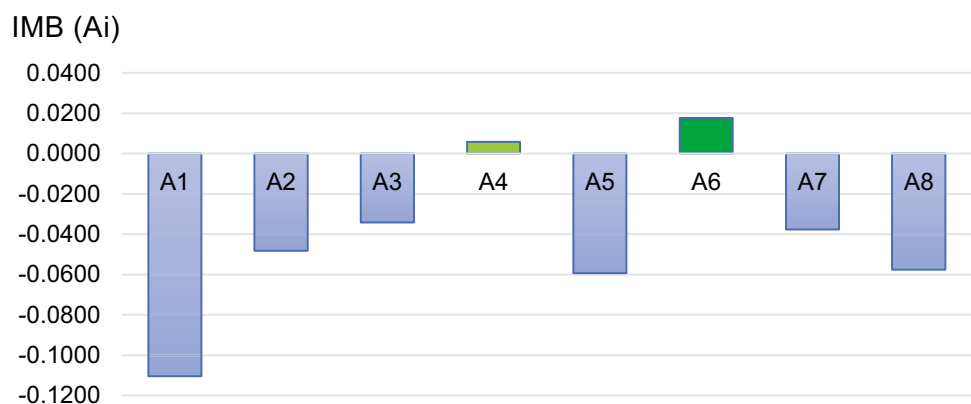
The selection of proposed strategies was based on the real-time analysis of the recommendations passed by the WHO and governments, literature analysis relevant to CSC and experts' opinions based on their experience. Further, the rela-

tive importance of the proposed strategies has been assessed using the MULTIMOORA (triplet MOORA) method. To aggregate the orders of preference for the recommended strategies obtained from the triplet MOORA method, an improved Borda rule has been used. The preference order of the strategy using the improved Borda rule depends upon the improved Borda assessment value. Figure 8 has been constructed to better visualize the improved Borda assessment values for the proposed strategies.

The summary of results for preference order of the proposed strategies is given in Table 11. From the analysis of all proposed strategies relative to the considered criteria, it has been found that the *development of a safe and healthier work scenario for partners of the cold chain* (having a maximum IMB assessment value of 0.0177) is the most effective strategy to mitigate the impact of COVID-19 on CSCs. It will require a healthier communication network among CSC partners, including suppliers, distributors, retailers and consumers. Therefore, management and planners must focus on analyzing those areas where the risk of the safety of partners exists. Creating safe and healthier work scenarios for CC partners provides security to crucial elements of CSCs and increases confidence in customers and co-partners towards refrigerated products (Masudin et al. 2021).

The strategy '*Successful monitoring and implementation of COVID-19 protocols*' (having the second-highest IMB assessment value of 0.0058) is the second most important strategy to overcome the influence of the COVID-19 outbreak. During the catastrophic situation of COVID-19, the principal challenge for CSC management and policymakers is to integrate their existing systems with current standings to maximize their organizational performance. It requires a systematic procedure to record COVID-19 spread response activities. To control the spread of coronavirus, some protocols (such as frequent hand sanitization and washing, keeping 6 feet distance among workers, providing workers with PPE and necessary COVID-19 vaccination for members of the CSC) have been imposed by the WHO and governments in their respective countries. Successful monitoring and

Fig. 8 Clustered column chart showing improved Borda assessment values for the proposed strategies



implementation of these protocols might help management to formulate plans and strategies to respond to situations such as COVID-19. Their aim is to repurpose their CSCs to pre-pandemic levels of operating.

Followed by the strategy ‘development of safe and healthier work scenario for partners of the cold chain’ and ‘successful monitoring and implementation of COVID-19 protocols’, ‘facilitating the ease to access PPE and COVID-19 testing for workers and employees (having third highest IMB assessment value -0.0342)’ is the third most significant strategy to mitigate the influence of the COVID-19 outbreak on CSCs.

The remaining strategies form their preference order based on their respective IMB assessment values. The strategies ‘shortening and simplifying the long cold chain links’, ‘integration of all parties in the link’, ‘development of short to medium term strategies and plans for unprecedented situations like COVID-19’, ‘providing sufficient training of workers to handle the products in a scenario like COVID-19’ and ‘planning and understanding the demand and supply uncertainty’ acquired the IMB assessment values of -0.1104, -0.0482, -0.0593, -0.0376 and -0.0575 respectively; therefore, these were the eighth, fifth, seventh, fourth and sixth order in priority. In order to mitigate the impact of COVID-19 outbreak disruption on CSC, the proposed strategies can be adopted in the sequence as $S_6 > S_4 > S_3 > S_7 > S_2 > S_8 > S_5 > S_1$.

The results obtained from the MULTIMOORA analysis show that approach S_6 (development of safe and healthier work scenario for partners of the cold chain, rank one) and S_4 (successful monitoring and implementation of COVID-19 protocols, rank two) are the two most important strategies having IMB assessment values of 0.0177 and 0.0058 respectively.

6 Conclusion

The global pandemic COVID-19 has created a catastrophic state for humanity and has abruptly disrupted the healthcare and food sectors. It has not only interrupted routine immunization programs but has also increased health inequality among people throughout the world. Due to this, many people have struggled to survive. In order to diminish the spread of coronavirus, lockdowns, social distancing, mass quarantine and restriction of unnecessary transport and travel have been taken as relief measures throughout the whole world. The COVID-19 pandemic has not only deteriorated the status of human beings' health, causing the loss of millions of lives, but has also disrupted basic operations involving public transport and human interaction. The severe impact of the COVID-19 pandemic has also been observed on the global CSC market. The pandemic has disrupted the global CSC

structure of perishable and other temperature-sensitive products. Its severe impacts have been observed on pharmaceutical and food product cold supply chains. Analysis reveals a massive amount of food waste, unavailability of pharmaceutical products, interrupted immunization programs and loss of demand for some chilled and frozen products. This has resulted in a substantial global economic loss.

This study has analyzed and discoursed the disruption due to the COVID-19 outbreak on CSCs of perishable products under the umbrella of seven broader assessment criteria; the food and pharmaceuticals industries in India have been considered. The severity rates of assessment criteria were formed using the SWARA method. The key findings of the SWARA analysis demonstrate that the COVID-19 outbreak has primarily affected the *structure of the CSC*. At the same time, the *impact of governmental response* is the least affected assessment criteria due to the pandemic outbreak. Therefore, the COVID-19 pandemic has drastically affected all the layers of CSC. On the one hand, it has disrupted the CSC structure due to broken interlinkages among the CSC partners such as suppliers, retailers, distributors and consumers. On the other hand, it has devastated all the financial and economic activities meaning that CSC industries have either slowed down or shut down their production activities. The results also show that the *business and financial aspect of CSC* is the second most affected criteria due to the COVID-19 pandemic. The order of the remaining assessment criteria of CSC disruption due to COVID-19 is consumer behavior and purchasing habits > current cold chain market strategies and trends > impact on quality and security of product > societal impact.

To obtain the preference order for the strategies, three subordinate methods of MOORA (ratio analysis method in integration with full multiplicative form and reference point approach) have been used. The severity weights obtained through the SWARA method are used to develop the relative importance matrix for the proposed strategies. Following this, the preference order for individual triplet methods was calculated. The final (aggregate) preference order of the proposed strategies was determined using the improved Borda rule of rank aggregation. Based on the assessment value obtained from the improved Borda rule (IMB AV), the preference ranking was provided for the strategies. The strategy which forms the highest IMB assessment value is given first priority of preference, while that with the least assessment value can be preferred last.

Our key findings demonstrate that among all the proposed strategies, the ‘development of safe and healthier work scenario for partners of the cold chain’ and ‘successful monitoring and implementation of COVID-19 protocols’ are the two most important strategies; IMB assessment values are 0.0117 and 0.0058 respectively. Therefore, to mitigate the impact of the COVID-19 outbreak on per-

ishable CSCs, management and policymakers can take up these strategies in descending order of their IMB assessment value. The strategy '*facilitating the ease to access PPE and COVID-19 testing for workers and employees*' forms the third-highest IMB assessment value (-0.0342) and, therefore, has the third priority of preference. The results also demonstrate that the strategy S1, '*shortening and simplifying the long cold chain links*' obtained the least IMB assessment value (-0.1104); therefore, it is last preferred to achieve the objective. The remaining strategies 'integration of all parties in the link', 'development of short to medium term strategies and plans for unprecedented situations like COVID-19', 'providing sufficient training of workers to handle the products in a scenario like COVID-19' and 'planning and understanding the demand and supply uncertainty' had values of -0.0482, -0.0593, -0.0376 and -0.0575 respectively; therefore, the preference order is fifth, seventh, fourth and sixth respectively. In order to mitigate the impact of COVID-19 pandemic outbreak on CSC operations and its performance, the proposed strategies can be adopted in order as $S6 > S4 > S3 > S7 > S2 > S8 > S5 > S1$.

The concluding remark of the research is that COVID-19 has influenced CSC both positively and negatively. On the one hand, while it has caused an enormous amount of food and pharmaceutical (excluding COVID-19 care medicines) waste due to unavailability of transportation and disrupted CSC structure, at the same time, it has created some future opportunities from economic, societal as well as environmental points of view. From the economic point of view, the COVID-19 pandemic created a situation of diminished business and financial upheaval of CSC industries such as seafood and meat exports; a massive amount of global losses resulted. From an environmental point of view, the lockdowns and prohibition of travel due to COVID-19 have had a positive effect. It has created hope for better ecological conditions in the future. The scenario of COVID-19 has mounted pressure on management and decision-makers to revise their CSC strategies and policies and focus on developing a robust chain that can survive in adverse circumstances. A need has arisen to learn and revise their processes and technology so that a CSC can shift itself from one state to another to cope with the effects of disasters such as the COVID-19 pandemic.

The findings of the work explore various theoretical and empirical perspectives associated with the impact analysis of the COVID-19 outbreak on CSCs of perishable products. These findings enable CSC managers and decision-makers to develop potential and robust plans for their operations to respond to situations like COVID-19 and turn them into opportunities for organizational growth and optimistic change. To the best of the author's knowledge, this is the first paper that consolidates various areas of perishable

CSCs affected by the COVID-19 outbreak into one frame, proposing theoretical and empirical analysis. The conceptual model and analysis of this paper can help CSC authorities, practitioners and researchers to improve CSC performance and seize the opportunities arising from events such as the COVID-19 outbreak.

6.1 Theoretical and managerial implications

As the food and pharmaceutical industries require a very highly efficient CSC to deliver a safe and hygienic product to the end consumer, this work has produced outcomes to embrace broad theoretical and practical applications. The research explores the more general criteria to analyze the impacts of the COVID-19 pandemic on CSC disruption. In addition, the work also recommends the best possible strategies with their appropriate preference order; this can be adopted to mitigate the impacts of the COVID-19 outbreak on CSCs. This research facilitates a new evaluation model for impact analysis of the COVID-19 outbreak on CSC, establishing the interlinkages among the criteria and proposed strategies. This will help management and decision-makers to select and successfully adopt relief strategies to repurpose the CSC to a level as it was before the pandemic. The analysis also divulges several insights into the pros and cons of COVID-19 on the CSC, enabling management and decision-makers to develop potential and robust CSCs that may help shift processes and technologies from one state to another in situations like the COVID-19 pandemic. The objective of the research work is to cover not only the managerial perspective of the CC but also its social side. This can help managers to establish socially, economically and environmentally stable CC strategies in situations like the COVID-19 pandemic. Thus, it provides an opportunity for CSC management to re-examine their CSC operations and be responsible for the insurance of food security and a healthier public healthcare system.

6.2 Limitations and future avenues of work

In this research, an attempt has been made to cover all the layers of CSC disruption due to the COVID-19 pandemic outbreak. However, the presented work can make significant contributions to current and future CSCs.

The study has some limitations. Firstly, the research has been conducted in India; opinions regarding criteria and proposed strategies were selected from experts from the Punjab region of India only. In other geographical areas, the findings of the work might differ due to the present COVID-19 situation in that region and experts' perceptions. Secondly, the analysis of received responses was performed by excluding the vagueness factor; this might mean a difference in the recorded results from the actual ones. Thirdly, in this

work, CSCs of food and pharmaceutical products have been selected to analyze the effect of the COVID-19 outbreak using the SWARA and MULTIMOORA approach with improved Borda rule for aggregation of the preference order. In future, interested researchers may extend this analysis to other product-specific CSCs such as dairy products, meat products or seafood products. In addition, work can be validated using the same or other MCDM techniques such as DEMATEL and PROMETHEE (Preference Ranking Organization Method for Enrichment of Evaluations) for severity weight evaluation of the criteria and ranking of the proposed strategies. For the aggregation of ranks obtained from the MULTIMOORA approach, other aggregation tools such as the dominance theory method and rank position method can also be used.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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